

■ Abstract

The Japanese cement industry today produces the best quality portland cement with the lowest energy consumption and highest labor productivity in the world. In addition, since the 1990s, the industry has been demonstrating a new role for the cement industry by using industrial and municipal waste as Alternative Fuel and Raw Materials (AFR). The Japanese cement industry has thus come to pursue two industrial missions: the manufacture of quality cement and contribution to a sustainable society.

The cement industry in Japan started in the 1870s when the Japanese government constructed the country's first cement plant, in Tokyo, which relied on European technology and equipment. For the next 90 years, up until the 1960s, Japan imported new technology and equipment from Europe and the U.S.A. Rotary kilns, tube mills, vertical mills, kiln waste-gas boilers/generators, air-quenching coolers, and blending silos were among those imports. Also, major imports of technology included the addition of gypsum in cement, cement quality standards, and several types of special cement such as high-early-strength, low-heat, blast-furnace-slag, fly-ash, and silica cements.

During that time, in 1959, Onoda Cement Co. Ltd. (now Taiheiyo Cement Co.) developed a new cement manufacturing process called the "New Calcined Lime Burning Process (NCB)." With this process, limestone is separately calcined in specially designed shaft kilns, then mixed with other raw materials and sent to a rotary kiln for clinker formation. This produced the astonishing result of a four-fold expansion in unit volume output from the same kiln. The NCB process is considered the first major "Japan original" cement manufacturing technology.

In the 1960s, the Suspension Preheater (SP) kiln process was introduced from Germany. This process rapidly came to prevail in Japan because of its high energy efficiency, excellent upscalability, and prolonged operation period.

Soon after the introduction of the SP process, Japanese cement manufacturers and plant builders, observing the NCB process, began competing with each other to develop a New Suspension Preheater (NSP) process, assuming that unit volume output would greatly increase if a calciner were installed at the bottom of the preheater. These efforts produced fruit in early 1970s. A couple of companies successfully developed NSP processes of their own. Each type of NSP equally achieved higher energy efficiency, better upscalability, and a longer operation period than the SP process. Consequently, the NSP process made the Japanese cement industry the most energy efficient in the world.

The success of NSP stimulated Japanese engineers to innovative further with cement manufacturing technology. The O-SEPA separator, the OK vertical grinding mill, and the vertical pre-grinding mill are among their inventions since the 1980s.

Japanese cement chemists, too, have made a great contribution to the cement industry's progress and development. In 1968, Japan hosted the 5th International Symposium on the Chemistry of Cement. Through this epoch-making conference, Japanese cement chemists played a major role in elucidating the scientific basis for the formation of clinker minerals and the hydration of cement, applying the very latest modern technology such as Electron Probe Micro Analysis (EPMA). In the 1970s, Dr. Yoshio Ono of Onoda Cement created a microscopic method to estimate clinker quality onsite. This method, called the Ono Method, is now recognized worldwide.

The Japanese cement industry began using AFR as early as the 1960s for the purpose of reducing manufacturing costs. Since the late 20th century, however, the industrial and municipal waste problem has become a center of focus along with growing concerns about the global sustainability of natural resources. The Japanese cement industry realigned its position on the use of AFR from mere reduction of manufacturing costs to the even more positive one of contributing to sustainability through greater use of alternative fuels and more recycling of raw materials. In pursuing this new mission, the industry has been developing innovative processes and equipment in order to make greater use of a wider range of AFR. To date, several processes and kinds of equipment have been successfully developed, such as the Chloride Bypass Process, the Ash Washing Process, the Biochemical Conversion Process for household waste (AK System) and Ecocement. These recycling practices are now widely recognized internationally.

Cement consumption in Japan fully matured in the middle of 1990s; however, the Japanese cement industry and its engineers have great hopes for a future in which the industry is positioned at the core of the sustainable society.

■ Profile

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■ Contents

1	Introduction.....	2
2	The History of Cement/Concrete: The Origin of the Modern Cement Industry	6
3	Cement Manufacturing Technology in Japan in the Meiji and Taisho Periods.....	13
4	From the Early Showa Period and the Pacific War to the Post-War Reconstruction Period (1926-1960)	23
5	The Development of Japanese Cement Manufacturing Technology (1960-) ^{1) 2) 3) 4)}	45
6	Environmental Conservation Technology and Measures against Global Warming.....	65
7	Advances in Cement Chemistry.....	70
8	Trends in Cement Standards and the History of the Cement Types and Blended Cements.....	85
9	Evolving to a Contributing Industry for the Sustainable Resource-Recycling Society	95
10	Summary: Systematization of Cement Manufacturing Technology.....	105
11	Conclusion and Acknowledgements.....	108
	Appended figure: Systematization Diagram of Cement Manufacturing Technology in Japan.....	109
	Appended tables: Cement Manufacturing Technology Historical Resources Confirmed Location.....	110
	Chronology of Cement Manufacturing Technology.....	111

1 | Introduction

The cement industry in Japan today is world-class in all aspects, from the high quality of the cement products to the industry's energy conservation technology, labor productivity and technologies for utilizing industrial waste and byproducts as alternative fuel and raw materials (AFR). Since the 1990s, the Japanese cement industry has added another layer of purpose over and above its existing role as "an industry providing basic construction materials", with the mission to become "a core industry in a resource-recycling (sustainable) society". This systematization survey report on cement technology discusses the development of cement manufacturing technology from its introduction to Japan in the early Meiji Period (1870s) through to the present day, with particular focus on "energy-saving technology", "quality control technology" and "resource recycling technology".

Most cement companies around the world concentrate on "cost-effective production of high-quality cement through the skilled use of cement manufacturing equipment purchased from plant manufacturers". By contrast, Japan's main cement companies have not limited the aim of their technology development to simply "improving operation of cement manufacturing equipment". They have become deeply involved in "technologies related to cement utilization", such as concrete and soil improvement, and even as far as "developing cement manufacturing equipment". This approach to technology development has ultimately led to world-standard cement manufacturing technology. This point is also noted in this paper.

In terms of technological content, the aim has been to provide an initial reference guide for researchers, engineers, technicians and students who learn more about cement manufacturing technology, the types and qualities of cement and the history of its development.

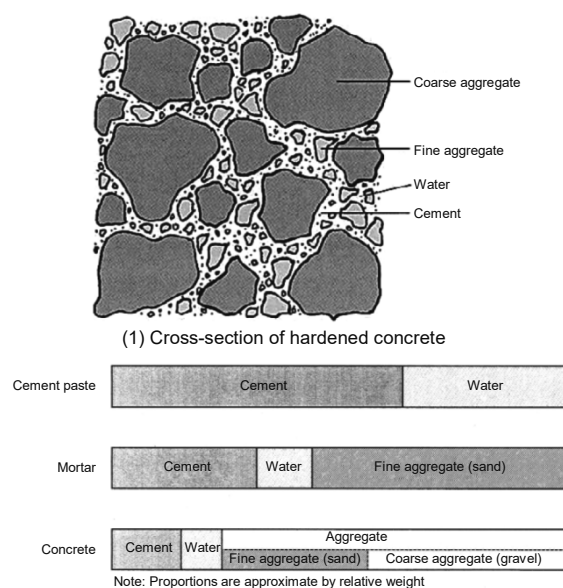
1.1 Cement and Concrete ¹⁾

"Cement" is a fine gray powder that has a characteristic property of hardening when mixed with water (hydraulic-setting). Cement is one of the materials used to make "concrete". Almost all cement produced is used for making concrete. In other words, cement only serves a useful role in the form of concrete.

The main raw materials in "cement" are limestone and clay. To produce 1 ton of cement requires around 1.2 tons of limestone and around 0.3 tons of clay. The materials are dried and ground, then burned in a rotary kiln at 1450-1500°C to produce clinker. The main constituent

mineral contained in clinker is calcium silicate, along with calcium aluminate and calcium aluminoferrite. These minerals have characteristic properties of forming hydrates and hardening when reacted with water (hydraulic-setting). The fine powder product produced by grinding clinker mixed with around 3% gypsum is cement (Portland cement).

"Concrete" is made up of cement, waters, fine aggregate (sand), coarse aggregate (gravel) and admixtures (see Note 1) (Figure 1.1). In terms of the proportion of these constituents within concrete, the highest proportion is taken up by coarse aggregate, followed by fine aggregate, water, cement and admixture. Concrete has become an indispensable construction material used in the construction of buildings, bridges, roads, waterways, tunnels, dams, harbors, airports and various other structures essential to life in society.



(Note) In addition to the above, in many cases admixtures are mixed in to improve the quality or workability of the concrete (see Note 1).

Fig. 1.1 Composition of Concrete ¹⁾

Beside concrete, applications for cement include use as cement paste, mortar and soil stabilizer. Cement paste is a mixture of cement and water, while mortar is a mixture of cement paste and sand (fine aggregate) (Figure 1.1 (2)). Cement paste is used in materials such as grout (see Note 2). Mortar is widely used as an outer wall coating on wooden buildings and as a joint-filling compound for bricks and concrete blocks. Soil stabilizers are used in applications such as improving soft ground; various technologies are being developed for the use of cement as a soil stabilizer.

1.2 The Japanese Cement Industry ¹⁾

The cement industry in Japan began in 1875 with the first domestic production of cement. It has undergone constant technological development, expanding and enlarging as the Japanese economy boomed, to become world-class in cement quality and all aspects of manufacturing technology, as mentioned in the introduction.

In terms of scale of production, as at April 2012 there are 17 companies and 30 plants in the industry, with a clinker production capacity of 54.76 million tons. In terms of scale of enterprise, there are seven large companies with capital stock worth over ¥10 billion and ten medium-sized companies with capital stock worth under ¥10 billion. Eleven of the 17 companies are specialized companies dealing mainly in cement manufacturing, while the remaining six companies are engaged in multiple types of business, such as in the chemicals industry.

1.2.1 Domestic Cement Plants ¹⁾

Figure 1.2 shows a typical cement plant. As mentioned above, Japan has 30 domestic cement plants. Many of these are located in areas rich in limestone, one of the principal raw materials, such as the Kitakyushu area (four plants) and Yamaguchi Prefecture (four plants), or in the Kanto area (six plants), which is Japan's highest area of cement consumption. Typical of process industries, cement plants have an average annual production capacity of around 1.8 million tons, although there are also some larger plants capable of producing over 6 million tons per year. With plants becoming increasingly mechanized and computerized, the average number of full-time employees at a plant is down to around 100 people. The largest cement plant in Japan occupies 680,000m².



Fig. 1.2 Bird's-Eye View of a Cement Plant ²⁾

1.2.2 The Cement Manufacturing Process ¹⁾

Figure 1.3 shows an overview of the cement manufacturing process. The raw materials for cement are limestone and clay (see Table 7.1 for details). The “raw

materials process” involves proportioning, drying, crushing and grinding the raw materials. During the “burning process”, the raw materials are burned at 1450-1500°C. The facilities used for this are the largest and grandest at the plant, with the preheater tower stretching up 80 m in height and the rotary kiln measuring 5-6 m in diameter and 100 m in length (Figure 1.4). The fuel used for burning cement (mostly coal) is fired from the burner into the calcining furnace and the rotary kiln during the “burning process” shown in Figure 1.3. Clinker produced from the rotary kiln is transported into the “finishing process”, where it is mixed with gypsum and ground. The finished cement product is then stored in silos for the “shipping process”. Most of the cement is shipped from cement plants as powder (bulk cement). “Bagged cement” packed in paper sacks accounts for around 3% of shipments. Bulk cement is transported by tanker ships, railroad freight cars and trucks.

1.2.3 Cement Production Volume ^{1) 3)}

The domestic cement production volume reached a peak in 1979 at 87.94 million tons. Although this was followed by a downward trend in keeping with sluggish economic growth, some recovery was seen from 1987. In 1996 there was a late-minute rush in demand before the raising of the consumption tax rate, coupled with high rebuild demand following the Great Hanshin Earthquake. With the Asian export market also firm, production volumes reached all-time record high of 99.27 million tons. This was again followed by a downward trend, with production remaining steady at 70 million tons from 2001. This plateau ended in 2008 with a further downward trend. Production volumes for 2014 were 61.91 million tons, including clinker for export.

1.2.4 Domestic Demand for Cement ^{1) 3) 4)} (see Figure 5.1)

Domestic demand for cement continued to grow consistently throughout the postwar reconstruction and rapid economic growth. With public investment into fundamental infrastructure such as railways, roads, harbors and dams, the production activity of materials industries such as electricity, steel and coal began to increase. Subsequent capital investment focused on manufacturing industries such as petrochemistry, electrical appliances, machinery and automobiles. As a result, the domestic demand for cement kept in step with the pace of industrialization in Japan, which was catching up to the developed countries in the West.

The growing demand for cement came to a halt with the first oil crisis (October 1973). With repeated rises and falls ensuing, a record peak came in 1990, towards the end of the bubble economy. Demand rose to 86.29 million tons that year, followed by a continuing downward trend due to a prolonged recession and dropping more recently to around 40 million tons. In 2014, domestic sales totaled 45.9 million tons.

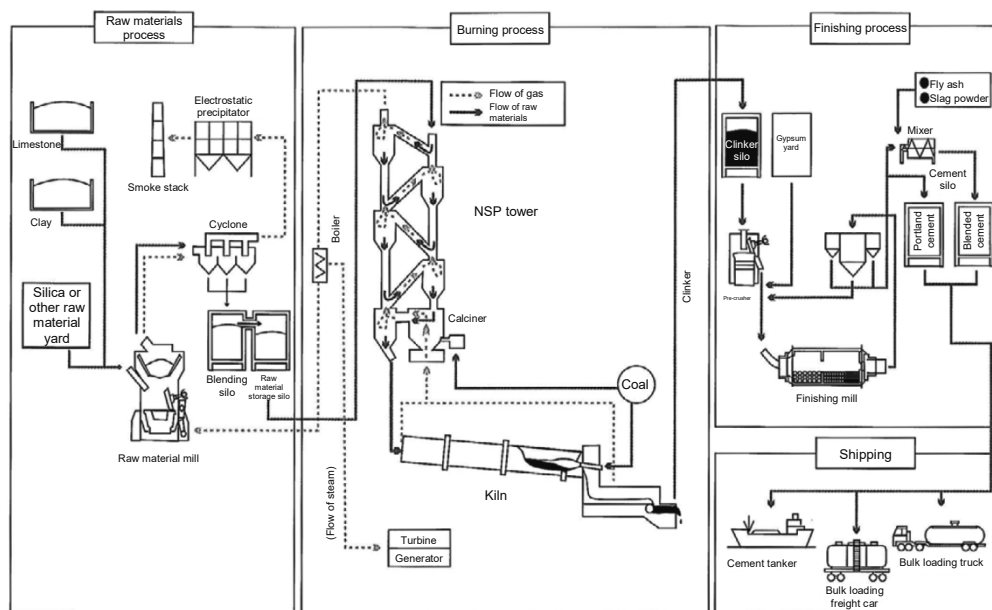


Fig. 1.3 Cement Manufacturing Process ¹⁾



Fig. 1.4 Preheater Tower and Rotary Kiln ²⁾

Examination of domestic cement sales (excluding imports) by demand sector in 2014 reveals that ready-mixed concrete accounted for 72% and precast concrete accounted for 12%, with these two areas together accounting for 84%. Further examination of the final consumption of cement by market sector reveals a near-even split between the public and private sectors of 51.0%:49.0%.

The domestic price of cement is around ¥10,000 per ton (2012, ordinary Portland cement, Tokyo region), which works out at ¥10 per kg, a surprisingly low price for a chemical product, making it a high performer among commodity prices.

1.2.5 Cement Exports and Imports ^{1) 3)}

Japan has continued to hold its position as a major world exporter of cement. The reason for this lies with its cost competitiveness due to its high number of coastal cement plants and its capacity for bulk transportation by ship. Exports have remained steady at around 10 million tons in recent years (since 2010). The 9.11 million tons produced in 2014 was approximately 15% of the domestic production volume. Meanwhile, cement imports into Japan have remained at a level around 600,000 to 900,000 tons. Cement is a completely liberalized commodity and Japan's cement production and distribution costs are internationally competitive.

1.2.6 Overseas Expansion of the Japanese Cement Industry ¹⁾

Following the Second World War, overseas expansion of the Japanese cement industry mainly involved the establishment of transfer stations for the purpose of ensuring reliable export supplies. In the 1990s, overseas expansion began in earnest with the construction of cement plants and other major investments. The main target area for this overseas investment was the booming Pacific Rim. As at 2012, Japan's overseas cement production bases included two plants in Korea (14.76 million ton capacity), seven plants in China (8.87 million tons), six plants in two countries in Southeast Asia (11 million tons), four plants in California and Arizona, USA (4.84 million tons) and one in the Pacific (200,000 tons), making a total of 20 plants in six countries with an annual production capacity of around 40 million tons.

1.3 The Mission to Become a Core Industry in a Resource-Recycling Society ^{1) 4)}

With the growth of the economy, Japan has come to throw away a lot of waste and byproducts. However, difficulties in recent years with locating new landfill sites have raised the question of how to promote recycling and reduce the amount of landfill for society as a whole. In this social climate, the cement industry has gone over and above its existing role as “an industry providing basic construction materials” and taken on the significant role in becoming “a core industry in a resource-recycling society” by utilizing large volumes of waste and byproducts as fuel and sources of raw materials for cement manufacturing, a mission that grows in significance over time.

In detail, the cement industry has developed a broad range of waste and byproduct recycling technologies based on existing cement manufacturing facilities and burning technologies and now reclaims and reuses around 28.5 million tons (in 2012) of more than 20 types of waste and byproducts from other industries. Converted into volume, this is the equivalent of approximately 21 million m³.

While cement production has continued in a downward trend since peaking at 99.3 million tons in 1996, the amount of waste and byproduct used in the manufacturing of 1 ton of cement is actually increasing, thanks to the efforts of the cement industry (1990: 251kg/t-cement → 2012: 481kg/t-cement, see Figure 9.2).

1.4 Scope of Technologies for the Purpose of this Systematization Survey Report on Cement Technology

This report focuses on the technologies indicated in

Figure 1.3. This covers the processes used by most cement manufacturing plants.

The unchanging development goals for cement manufacturing technology have always been energy conservation, improved labor productivity, mass production, sustainable supply and consistent quality. In recent years, another goal has been added, as mentioned above: “technology development that fulfils the mission of a core industry in a resource-recycling society”. In other words, the development of resource-recycling technologies at cement plants is growing in relative importance.

Note 1: Admixtures and Additives

Admixtures and additives are ingredients added to concrete in order to improve its workability or its quality. These are termed according to the mixing ratio. Additives can include blast-furnace slag, coal ash (fly ash) and limestone powder; admixtures can include air-entraining (AE) agents, water-reducing agents, accelerating agents, hardening accelerators, retarders and corrosion inhibitors. Various organic and inorganic chemicals have been developed as concrete admixtures (see 2.4, 8.4).

Note 2: Grout

A general term for cement milk or cement mortar used as filler for gaps between tunnel walls and rocks and for jointing in concrete structures. Also used for increasing the adhesive capacity of steel wires in pre-stressed concrete.

References (all in Japanese)

- 1) Japan Cement Association, *Introduction to Cement & Concrete*, 2013.
- 2) Supplied by Taiheiyo Cement Corporation.
- 3) Japan Cement Association website, September 2015.
- 4) Japan Cement Association, *Cement Handbook*, 2014.

2 | The History of Cement/Concrete: The Origin of the Modern Cement Industry

This chapter discusses: (1) ancient “cement”; (2) the invention of modern “Portland cement” in the United Kingdom during the Industrial Revolution; (3) the origins of the Japanese cement industry in the early Meiji Period (1870s); and (4) the emergence of modern concrete technology.

2.1 The History of Pre-Modern Cement and Concrete^{1) 2) 3) 4)}

With cement broadly defined as “inorganic bonding material”, its origins can be traced back to the Neolithic Period around 9,000 years ago. This is based on the discovery of hydraulic material similar to modern concrete in the floor and walls of a dwelling excavated at Yiftah’El in the Galilee region of Israel. This concrete is reported as being made up of limestone-based cement and crushed limestone aggregate mixed with a small amount of water. In China, hardened substances primarily made up of calcium carbonate and primarily made up of caliche containing silica, presumed to have been hardened by reaction with water, were discovered in the floor of a dwelling site near Xi’an dating back around 5,000 years. While these “cements” are said to be “hydraulic” (see Note 1), it is not known how they were used; the technology was not passed down to future generations and was lost.

Meanwhile, for the construction of the pyramids of Ancient Egypt, believed to be around 2,600 BC, the stones were joined with mixtures of limestone, plaster, sand, ash and mud, which were mixed with water and left to air-harden. This bonding material did not harden in water and is considered to be a different type from the hydraulic bonding materials found at Yiftah’El and Xi’an; however, it fits within the definition of “cement” as an “inorganic bonding material”.

Mortar mixed from slaked lime (Ca(OH)_2) and volcanic ash, from a site in Greece dating back to around 1,000 BC, has been confirmed to have been used as a joint-filling compound.

Thus it appears that humankind, throughout the course of time, came to understand by experience that naturally-occurring gypsum or limestone would harden once heated and combined with water. By around 200 BC in ancient Rome, active efforts were being made to burn natural gypsum and limestone, with plaster of Paris (hemihydrate gypsum, $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$) and quicklime (CaO) being produced using “kilns”. Hemihydrate gypsum hardens as it absorbs water and turns into

dihydrate gypsum. Quicklime reacts with water to form calcium hydroxide (Ca(OH)_2), which reacts with the carbon dioxide in the air to form calcium carbonate (CaCO_3). It hardens through this transformation (carbonization) (air-hardening, see Note 1).

Further forward in Roman times, it was known that a mixture of quicklime and volcanic ash would (1) harden with water and (2) not break down in water (hydraulic setting, pozzolanic reaction, see 8.3.2). This mixture was combined with stone and used liberally on everything from roads, castle walls and watercourses through to houses and temples.

Although these ancient cements can be defined as “cement” in that they are types of “inorganic bonding material”, they are essentially very different from the “cement” we know today. They were produced with the idea that skillful use of mixed materials would produce a strong bonding material, rather than the idea of proportioning, burning and chemically reacting raw materials, distinctive of modern cement. The quality of this “ancient cement” would not be sufficient for the “concrete structures” of today.

Little progress was seen in the history of cement for around 2,000 years, through the Middle Ages to the early 18th century. Consequently, the medieval structures still standing in Europe today are about the same as those from ancient Roman times in terms of materials and construction method, with no fundamental changes discernable.

2.2 The Invention of Modern Cement^{1) 2) 3) 5)}

The Industrial Revolution began in the United Kingdom around the mid-18th century. As part of that wave, there was a succession of research discoveries and inventions that led to the invention of modern cement.

In 1756, John Smeaton (UK) was contracted with the rebuilding of England’s Eddystone Lighthouse (Figure 2.1). The joint-filling compound between the stones at the base of the lighthouse, constantly washed with seawater, had to be far more water-resistant than the conventionally-used mortar made from slaked lime. After researching the burning of various different kinds of limestone, he found that mortar using a slaked limestone with the impurities of clay produces better results than pure slaked limestone mortar in terms of hardening in water and offering superior resistance. (see Note 2). In his published findings, he referred to it as “hydraulic mortar”.

Until then, the idea noted by Marcus Porcius Cato (234-149 BC) of Rome that “to produce good mortar, only high-purity limestone should be used, containing no clay or other impurities” had been taken literally. With his experiment research, Smeaton disproved the “accepted practice”.

While Smeaton wrote that he “did not doubt but to make a cement that would equal the best merchantable Portland Stone in solidity and durability”, he did not file a patent for the material or the name.

In 1796, 40 years after Smeaton, James Parker (UK) burned clay-containing limestone in a limekiln at around 1100°C ³⁾ and ground it to produce a hydraulic cement. Later known as “Roman cement”, this cement was widely used on projects, including the Thames Tunnel. Improvements were made to it in the 1810s by James Frost (UK) and Louis Joseph Vicat (France). Independently, they proved that a ground and blended mixture of limestone and clay produced a similar result to clay-containing limestone (marl). This led to the modern cement manufacturing method.



Fig. 2.1 The Eddystone Lighthouse built by John Smeaton¹⁾

An English mason, Joseph Aspdin, invented a method of producing cement by mixing quicklime made from crushed and burnt limestone with clay in a certain proportion. Water was added to the mixture before finely grinding it, drying it and re-burning it in a shaft kiln (see Figure 2.2). In October 1824, Aspdin patented his invention under the title of “An Improvement in the Mode of Producing an Artificial Stone” and named the product “Portland cement” (see Note 3). Thus, Aspdin became known as the “inventor of modern cement”, although Smeaton, Vicat and other forerunners made significant achievements (see 7.4).

Aspdin’s patent lacked two important points in terms of the modern definition of Portland cement: there is no range given for the ratios of limestone and clay and there is no description given of burning the mixed raw materials until semi-molten. Consequently, objections were later submitted on the naming of Aspdin as the

inventor of Portland cement. See 7.4.1 for more details on this.

The initial burning temperature for Portland cement according to the Aspdin patent is assumed to be around 1200°C ³⁾. The quicklime and clay would have reacted together to produce small amounts of belite ($2\text{CaO}\cdot\text{SiO}_2$ solid solution), interstitial material and other cement minerals, as well as large amounts of quicklime. It would have been little different in quality from Roman cement. However, Aspdin’s invention triggered rapid research progress on Portland cement.



Fig. 2.2 A Shaft Kiln built by Aspdin¹⁾

Isaac Charles Johnson (1811-1912), a technician at Roman cement manufacturer, JB White (UK), was granted permission from his company to start manufacturing the new Portland cement developed by Aspdin. In 1884, based on independent experiments and research, he found that the basic conditions for producing a uniform product are: (1) the ratio of limestone and clay to produce high quality cement; (2) burning the raw materials until semi-molten; and (3) the homogeneity achieved by the proper mixing of raw materials. These findings established the basic principles for modern Portland cement manufacturing.

Johnson’s conditions for manufacturing Portland cement made it possible to achieve significant improvements in quality by “burning the mix of limestone and clay at high temperatures of 1250°C or above until semi-molten”. This led to the adding of alite ($3\text{CaO}\cdot\text{SiO}_2$ solid solution) to the Aspdin-era cement minerals of belite and interstitial material³⁾. (Note: Alite, belite and interstitial material are discussed in more detail in Chapter 7.)

Portland cement was thus developed in the United Kingdom, with four manufacturing plants starting operation in 1850. The superiority of the product was demonstrated at the Great Exposition in 1851 in London, after which it came to be produced at an industrial scale in countries all around the world in place of Roman cement. Portland cement started being manufactured in the United Kingdom in 1825, in France in 1848, in

Germany in 1850, in the United States in 1871 and in Japan in 1875.

2.3 The Origins of the Japanese Cement Industry (late 19th century) ^{1) 2) 3) 6) 7) 8) 9) 10) 11) 12)}

2.3.1 The Beginning of Government-Managed Cement Plants

Japan imported Portland cement and put it to use in construction work in 1861. It is first believed to have been used to join the bricks in the construction of the Nagasaki Iron Works, built by the Japanese shogunate under the guidance of Dutch naval officer Henrik Harges. After that, Japan used small volumes of imported cement in projects such as the Yokosuka Iron Works, started in 1866 by the shogunate and taken over by the Meiji Government (completed 1872, renamed Yokosuka Shipyards), the Nojimazaki Lighthouse (completed 1896) and the Jōgashima Lighthouse (completed 1870). The price of imported cement at the time was ¥50-60 per ton (¥8.50 per 180kg barrel; ¥7.50 per 135kg barrel). Based on the price of rice at the time compared to today, imported cement at the time is estimated to have cost around ¥500,000 per ton in today's currency ¹¹⁾. (The price of ordinary Portland cement in 2013 was around ¥10,000 per ton.)

In 1871, during the construction of the No. 2 Dock at Yokosuka Shipyards, the Ministry of Industry's head of shipbuilding Michiyoshi Hiraoka (Figure 2.3), who was overseeing the construction of the dock, noted that cement was by far the most expensive material used in harbor construction and other construction work. Sensing a pressing need for domestic production, he proposed to the Vice-Minister of Industry, Prince Hirobumi Itō, to start a government-run cement manufacturing enterprise.



Fig. 2.3 Michiyoshi Hiraoka ¹⁾

In February 1872, a fire broke out in Ginza, burning through the entire Kyōbashi district and destroying the Ministry of Industry's buildings in Tsukiji, the Tsukiji Honganji Temple and a number of hotels in Tsukiji. The government decided to rebuild the Ginza district with brick in order to protect it from fire. Plans for the construction of the brick Ginza district were undertaken by overseas contractor Thomas James Waters (UK), overseen by the Department of Construction under the Ministry of the Finance's Bureau of Civil Engineering.

Intending Japan to supply its own bricks and cement, Waters oversaw the construction of a Cement Works on the site of the Sendai Estate in Kiyosumi in the suburban Tokyo district of Fukagawa (Figure 2.4). Construction began in July 1872, with cement production commencing by the end of 1873. The manufacturing method is not known in detail, but based on the fact that Saburō Utsunomiya “succeeded in modifying it to a wet method”, as shall be mentioned later, it is presumed to have been a dry or semi-dry process (see Figure 3.2 for details on dry and semi-dry processes). In any case, the facilities were less than perfect and the quality of the manufactured cement was inferior to its imported counterpart.

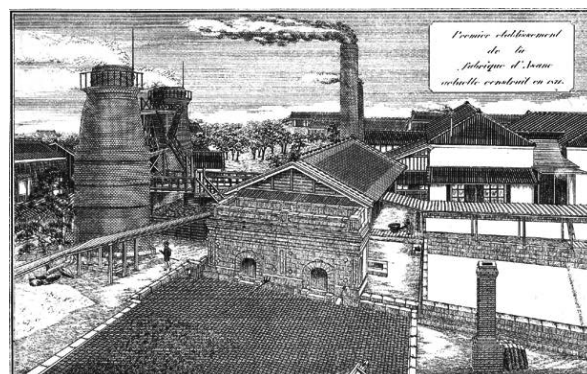


Fig. 2.4 Government-Managed Cement Works (Fukagawa, Tokyo) ⁷⁾

Meanwhile, the Ministry of Industry also embarked on research on cement manufacturing, having received the proposal by Michiyoshi Hiraoka, mentioned previously. Hiraoka invited Saburō Utsunomiya (Figure 2.5, 1834-1902), who had spent time in the West studying modern industry from May 1872 to September 1873, to join his team at a chemicals laboratory in Akasaka, Tokyo to conduct research on cement manufacturing.



Fig. 2.5 Saburō Utsunomiya ¹⁾

The Cement Works in Fukagawa came under the jurisdiction of the Home Ministry in November 1873 and was then transferred to the Ministry of Industry's Bureau of Manufacturing in January the following year. For the first time, the cement manufacturing operations of the Ministry of the Treasury and the Ministry of Industry were merged under the Ministry of Industry, under the oversight of Saburō Utsunomiya.

Utsunomiya had conducted repeated experiments at the Fukagawa plant, but had not obtained a satisfactory quality of cement. He then decided to fundamentally alter the method of manufacture to incorporate the new “wet process” (see Figure 2.6) used by the British and the French. He completely demolished the facilities at the government-managed plant at Fukagawa and brought in new facilities. The plant was completed in 1875 and on May 19, a small quantity of cement was produced – the first Japanese cement that could rival the quality of overseas products. The day has later been celebrated as “Cement Commemoration Day”, with cement technology conventions and other events being held.

(Note) While Saburō Utsunomiya is recorded as having successfully manufactured Portland cement using a dry-process shaft kiln on May 19, 1875, according to Takashi Ueno’s *Supplement to the History of Cement Technology*¹²⁾, it was reported that cement had been manufactured and sold under the oversight of Thomas Waters using a dry-process shaft kiln that had started operating in 1873. A detailed discussion of the historical sources regarding this is provided in Ueno’s work, pp. 5-7.

Having succeeded in manufacturing cement, Utsunomiya traveled back to the United States and the United Kingdom in 1875 and 1876 for further study. On his return to Japan, he immediately set about improving and augmenting his plant facilities, resulting in steady increases in production volumes from the late 1870s onwards. Government-initiated economic and industrial modernization was advancing rapidly at this time and a flurry of construction meant a growing demand for cement for railroads, harbors, military facilities, government buildings, universities and factories.

The production facilities at the government-managed Fukagawa plant under Utsunomiya were as follows.

Two cement kilns (shaft kilns, 14.5m high, 1.2m upper diameter, 3.6m central diameter), one drying area, one powder area, two settling basins and one agitating basin.

Figure 2.6 shows the wet process method employed by Utsunomiya using these facilities.

Slaked lime and local Fukagawa river mud were mixed at a fixed ratio in a basin called an agitating basin, where water was added. After being agitated and coarse particles and other debris had been removed, the mix was then transferred to the settling basin to settle. Once settled, the upper water was removed, leaving a thick slurry to be taken out and dried. The agglomerated mix of slaked lime

and clay was then loaded with coal into a brick shaft kiln called a bottle kiln and burned to produce clinker. The clinker was taken from the shaft kiln, ground and weathered (see Note 4) for around three months in a weathering storehouse to produce the finished cement product. However, while this method did not require the raw materials to be ground, it did require large amounts of water; processing was also labor-intensive and took a long time, as the settling and drying processes had to be included. To begin with, there was no crushing or grinding machinery able to crush and grind the hard limestone and it is thought that a method of hydrating pre-burnt limestone was used to extract the necessary fine lime component.

2.3.2 Mastering of the Technology by Japanese without Relying on Overseas Contractors

Many Japanese industries in the Meiji Period started out by inviting engineers, known as overseas contractors, to provide guidance and instruction on everything from building facilities to operating technology. However, it is worth noting that the cement industry did not use overseas contractors, but started out by mastering Western technology through diligence and hard work. Thomas Waters, who had been contracted for the construction of Ginza’s brick precinct and oversaw the construction of the first Cement Works in Fukagawa to provide the necessary cement, was an architectural engineer and had no experience with cement manufacturing. Consequently, the cement produced in the first plant built under his oversight was poor in quality. It was Saburō Utsunomiya, having personally studied in the West, who put his experience and creative originality to work to completely rebuild the Fukagawa plant and finally produce marketable cement.

For a more detailed account on Michiyoshi Hiraoka and Saburō Utsunomiya, the founders of the Japanese cement industry, as well as Junpachi Kasai and Sōichirō Asano (see following sections), who built cement manufacturing into an industry, refer to Sutezō Sugishita’s *Japanese Cement* (Poplar, 1962)¹³⁾.

2.3.3 Development as a Private Industry

Japan’s first privately-managed cement plant was constructed in 1881, in what is now the city of Sanyo-Onoda in Yamaguchi Prefecture. Operations commenced in 1883. This was the founding of what later became the Onoda Cement Company.

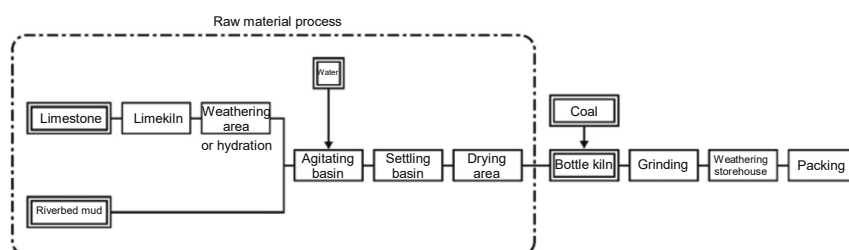


Fig. 2.6 Shaft Kiln / Wet Process Cement Manufacturing Process⁷⁾

At the center of this promotion of enterprise was Junpachi Kasai (Figure 2.7, 1835-1919), a former feudal retainer of the Chōshū Domain. Kasai is said to have seen cement being used in the construction of storehouses in his home area in Yamaguchi in 1875 and developed a keen interest in how a powder mixed with water could harden and firmly bind to stone. He is said to have later learned about cement manufacturing technology at the sole government-managed plant by speaking with Michiyoshi Hiraoka when Hiraoka returned to Yamaguchi in 1879 and started thinking about establishing a cement business “to aid the Chōshū Domain retainers who had lost their income when the feudal system was abolished”.



Fig. 2.7 Junpachi Kasai ¹⁴⁾

The following year, Kasai and his friend Sahee Arakawa decided to travel to Tokyo with local Yamaguchi marble and mud and to start a cement business with guidance from Saburō Utsunomiya at the Fukagawa Works Sub-Bureau (formerly the Cement Works). The reasons Kasai chose the Onoda site were that it was near to sources of the main fuel and raw materials of coal, limestone and mud and that it faced the sea for ease of product transportation, as well as the fact that the area was newly-reclaimed land and the rent was cheap. Figure 2.8 shows the bottle kiln at the Onoda Cement plant constructed in 1883 (still standing, designated as an Important Cultural Property). Figure 2.9 shows a panoramic view of the same plant, taken around 1890.



Fig. 2.8 Shaft Kiln (Bottle Kiln) Still Standing at the Taiheiyo Cement Corporation Onoda Plant ⁷⁾

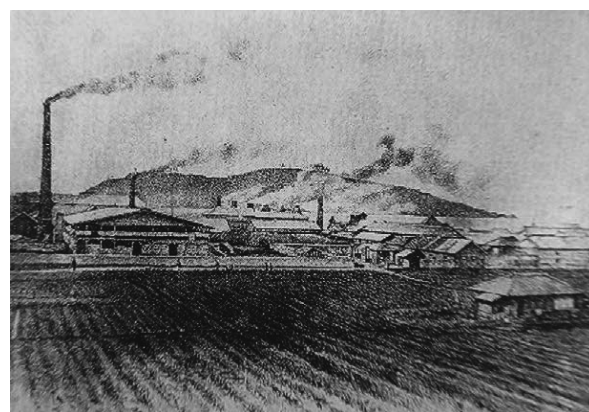


Fig. 2.9 The Onoda Cement Plant (around 1890) ⁷⁾

In 1884, the government-managed Cement Works in Fukagawa was sold off to Sōichirō Asano (Figure 2.10, 1848-1931), an industrialist and merchant who had supplied the factory with coal, and was further developed to become Asano Cement.



Fig. 2.10 Sōichirō Asano ⁹⁾

With the creation of these two companies, the Japanese cement industry developed into the privately-managed industry it is today. Onoda Cement and Asano Cement (which changed its name to Nihon Cement after the Second World War) merged with a third company, Chichibu Cement, in the 1990s to form the present-day Taiheiyo Cement, which remains a core enterprise in the cement industry today.

Although private cement production had begun under the circumstances as outlined, government financial difficulties and a general lack of awareness about cement meant that demand did not grow as expected. Initial production volumes were reportedly around 25 tons per month (1,400 barrels → see note below) for the Fukagawa and Onoda plants combined. However, the Great Nōbi Earthquake of 1891 demonstrated the earthquake resistance of concrete structures, while Japan's victory in the First Sino-Japanese War (1894-1895) and the Russo-Japanese War (1904-1905) saw an increase in demand for cement and a significant increase in production volumes. By 1897, the number of cement companies has grown to 15, while a new rotary

kiln (Figure 3.5) was imported from the United States in 1903 to replace the conventional shaft kiln for burning the raw materials, bringing about a dramatic rise in product quality and production volumes. The advances in Japanese cement manufacturing technology from the late 1880s onwards are discussed in more detail in Chapter 3.

(Note) Meiji-era cement transportation was done in barrels (see 4.12.1). One barrel weighed 400lb, approximately 181kg, when the Onoda and Asano plants were being established (1883). Figure 2.11 shows (1) a cement barrel and (2) the filling of barrels on site.

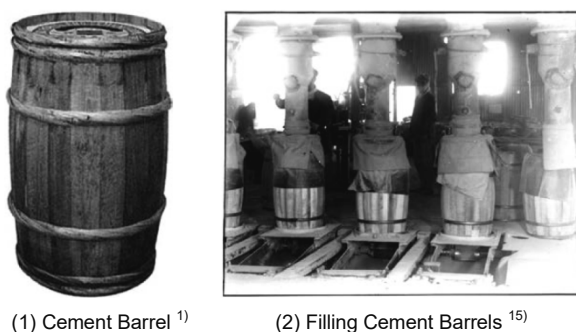


Fig. 2.11 Meiji-Era Cement Barrel for Transportation

2.4 The Emergence of Concrete Technology ¹⁾

While concrete technology lies beyond the scope of this survey report, cement is used as a constituent material in almost all concrete. In other words, cement only serves a useful role in the form of concrete. Consequently, the development of concrete technology beyond the invention of modern cement is briefly discussed here.

Portland cement, invented by Aspdin and improved by Johnson, is superior in quality to Roman cement and has expanded in application from a jointing material (mortar) between stones to being used in structures made entirely from concrete. However, with concrete on its own being found to be weak (brittle) in the tensile direction (lacking tensile strength), research began in France in the 1850s to compensate for this weakness.

In 1867, gardener Joseph Monier (France) successfully created a thin yet strong flowerpot by inserting wire mesh into mortar. The wire compensated for the weakness of the mortar, thus creating reinforced concrete, which would have a major impact on later structures. Monier later put this to use in pipes, water tanks and concrete slabs, going as far as to construct a 15.6m long, 4.2m wide reinforced concrete bridge in 1875.

This prompted the use of reinforced concrete in buildings, bridges, tunnels, dams and other structures in Europe until around 1900, ushering in the “reinforced

concrete era”.

To further increase the tensile strength of concrete, P. H. Jackson (USA) began researching pre-stressed concrete in 1886. This involved inserting steel into the concrete and tensioning it at both ends, thus creating concrete that was strong yet elastic. This technique was later improved upon by researchers from many different countries, with Eugene Freycinet (France) theorizing on the relationship between the concrete and the reinforcing material and applying it to many concrete products and structures, thus laying the groundwork in concrete technology.

Reinforced concrete technology is thought to have been introduced to Japan around 1895. The oldest civil engineering structure built using this method is a bridge (Figure 2.12, 7.3m long) over the Lake Biwa Canal in Kyoto, built in 1903, and it is still standing. The oldest building structure is believed to be a pump house at Sasebo Heavy Industries in Nagasaki, built in 1904.



Fig. 2.12 Japan's Oldest Remaining Concrete Bridge over the Lake Biwa Canal ¹⁾

Pre-stressed concrete was introduced to Japan in 1939 and used for railroad sleepers around 1949 and for a platform at Tokyo Station in 1951.

The invention of reinforced concrete and pre-stressed concrete, combined with improved cement quality, could be called the driving force behind making later concrete structures “taller, longer, wider, deeper, stronger and lighter”.

Concrete admixtures have also contributed to improving the workability and performance of concrete in recent years. Admixtures were introduced to Japan in the late 1940s following the invention and practical implementation of air-entraining (AE) agents in the United States in the 1930s. These began to be used to improve workability (handling prior to hardening), bleeding (water rising to the surface after pouring) and frost resistance. Later, with construction using concrete pumps becoming more widespread, successive AE water-reducing agents with both air-entraining and

water-reducing effects emerged up until the 1990s, along with fluidizing agents and improved high-performance AE water-reducing agents. These have enabled the recent production of an ultra-high-strength concrete with a compressive strength of over 100 N/mm², thus further expanding the possibilities for concrete high-rise buildings.

Other admixtures have also emerged to give concrete a range of different characteristics, including expansion agents, underwater-hardening concrete and other specialty admixtures. These have become an indispensable material for the future development of concrete technology. (See Notes 2, 3 and 4 of Chapter 8.)

Note 1: Air-Hardening and Water-Hardening

Water-hardening or hydraulic refers to the property of hardening when reacted with water, while air-hardening refers to the property of hardening when reacted with air (mainly carbon dioxide gas).

Note 2: Clay-Containing Limestone

While most of the limestone found in Japan is hard with high purity of calcium carbonate (CaCO₃), in Europe and the United States, there are other types of limestone, such as soft limestone (chalk) and marl, which contains quite a high clay fraction. Marl is sometimes also called cement rock, as it can be heated to produce a water-hardening material. Roman cement was manufactured using large amounts of this marl. It can still be used today as a raw material for cement by adjusting a few ingredients.

Chalk is easy to crush and was a particularly useful raw material to prepare in early cement manufacture, when proper crushing machinery had not yet been developed.

Note 3: The Origin of the Name of Portland Cement

Aspdin named this cement Portland cement because the color and hardness of the hardened cement resembled the Portland stone quarried from the Isle of Portland and widely used as a building material in the United Kingdom at the time.

Note 4: Weathering

Weathering refers to the process of spreading cement out on a floor and allowing it to absorb the carbon dioxide in the air in order to carbonize and inactivate the free lime (see Note 4, p. 23) in the cement powder.

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3 | Cement Manufacturing Technology in Japan in the Meiji and Taisho Periods

The previous chapter discussed the efforts by Hiraoka, Utsunomiya and others that enabled the Japanese to manufacture their own cement and the consequent establishment of cement as an industry through the efforts of Kasai, Asano and others. In the late 1880s and early 1890s, the demand for cement grew as other industries began to flourish. Cement companies were established around the country, forming the foundations of Japan's cement industry.

This chapter discusses the development of cement manufacturing technology from the late 1880s to the late 1920s. There were three major innovative technologies in cement manufacturing during this time, all of which involved bringing in technology or equipment from the West.

- (1) Transition from shaft kilns to rotary kilns in the burning process. The main kilns used in the Meiji Period were shaft kilns (bottle kilns); the use of rotary kilns spread rapidly in the Taisho Period.
- (2) The addition of gypsum as a cement setting and hardening regulator in the finishing process. In the Meiji Period, setting was regulated by weathering; the addition of gypsum spread rapidly in the Taisho Period.
- (3) Cement standards were established (Japan's first industrial standards).

3.1 Cement Production in the Meiji and Taisho Periods^{1) 2) 3)}

Cement production in Japan began in the early Meiji Period, with production volumes later increasing as Japan grew in its national capabilities. Figure 3.1 shows the domestic cement production volumes and export/import quantities during this time.

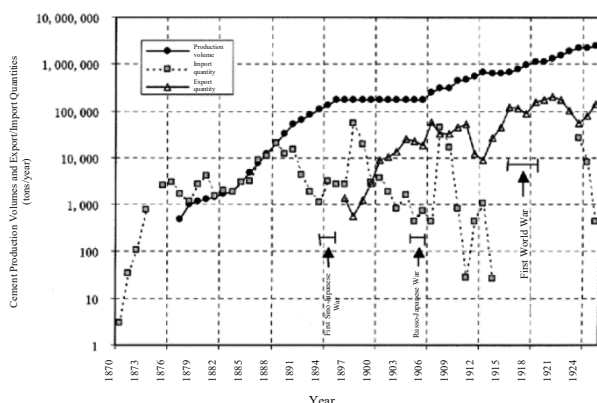


Fig. 3.1 Transitions in Domestic Cement Production Volumes and Export/Import Quantities during the Meiji and Taisho Periods¹⁾ (logarithmic vertical axis)

As illustrated above, imports far exceeded domestic production up until around 1881; cement from the government-managed Fukagawa cement plant could only partially meet the domestic demand. Later, although domestic production grew to around 20,000 tons by around 1888, imports were about the same, covering only around half of the domestic demand.

However, from 1889 onwards, an increase in the number of Japanese cement companies saw production volumes rise to around 100,000 tons by 1893, five times higher in five years compared to 1888; by the end of the Meiji Period, production volumes had soared to around 600,000 tons, 30 times higher in 23 years compared to 1888. As a result, import quantities dropped by several thousand tons to as little as 1% of domestic production volumes. However, this was also a time in which having too many cement companies meant the increased supply outweighed the demand. The First Sino-Japanese War saw some export trends emerging in order to develop and retain new markets, but this only accounted for around 10% of domestic production.

The overcrowding of companies resulted in an industry with unstable trade conditions for individual companies and ever-changing company fortunes. As many as 51 cement companies were founded in the Meiji and Taisho Periods, but only 18 of them survived until the end of the Taisho Period.

The reason for the whirlwind rise and fall of these cement companies is due to the following factors:

- (1) The raw materials could be procured easily in Japan, with deposits of limestone, the principal raw material in cement, everywhere throughout the country and domestically-produced coal for fuel.
- (2) Cement manufacturing facilities at the time were relatively simple and could be constructed easily.
- (3) Since the properties of cement meant it could not be stored long-term, dumping was prevalent at times of downturn or overproduction, making it susceptible to extreme price drops.

As a result, there were many cases of companies going bankrupt several years after constructing a plant.

3.2 Manufacturing Technology in the Shaft Kiln Era (late Meiji Period to around 1920)^{1) 2) 4) 5) 6)}

Cement manufacturing began in Japan at government-managed cement plants and throughout almost the entire Meiji Period it was manufactured using shaft kilns. This section discusses shaft kiln cement manufacturing technology up until rotary kilns were imported from overseas at the end of the Meiji Period.

3.2.1 Shaft Kiln Raw Materials Processing: From Wet Process to Dry Process with the Development of Crushing and Grinding Machinery

Since the chemical reaction through cement burning is a solid-phase reaction, the following points are very important:

- (1) The mix proportion between the limestone and clay has to be properly controlled to keep the chemical composition of the cement as constant as possible (chemical composition).
- (2) The raw powder has to be as fine as possible (fineness).
- (3) The limestone and clay particles have to be distributed as evenly as possible (homogeneity).

With the early cement industry in the latter half of the Meiji Period not yet having developed proper crushing machinery or other mechanical devices, industry pioneers came up with various ways of improving factors (1)-(3) above, even by the slightest amount.

Saburō Utsunomiya took over the Japan's first government-managed cement plant, constructed in 1873, and completely rebuilt the existing facilities. Using a manufacturing method known as the wet process, shown in Figure 2.6, Utsunomiya successfully manufactured Japan's first Portland cement of reliable quality in 1875 (see 2.3.1). The main reason for using the wet process at that time was that no crushing or grinding machinery had been developed that could prepare the limestone properly. Accordingly, the lime material was granulated with much effort by calcining the limestone to produce quicklime and then hydrating the quicklime to produce slaked lime.

As the early Meiji cement plants started by copying the government-managed cement plant in Fukagawa, Tokyo, they all adopted the wet process. However, since the wet process was not very economical or productive, they eventually shifted to using the dry process. The dry process was first used by Onoda Cement in 1888, having imported a set of machinery from Germany, and gradually spread to other companies. Using a shaft kiln as shown at the top of Figure 3.2, the dry process involves drying the clay and feeding it together with the limestone

through three machines in sequence – a primary crusher, a secondary crusher and a mill (see Note 1) – to produce a powder, adding water and mixing it in a blending machine, and then transporting the blended material into a cutter and cutting it into brick-sized pieces, which are burned in the shaft kiln after drying. Using a rotary kiln as discussed in 3.3, the dry process requires no shaping of the raw materials, which are burned in the kiln directly after grinding and mixing, as shown at the bottom of Figure 3.2.

As is evident when comparing the dry process in Figure 3.2 and the wet process in Figure 2.6, the dry process includes the process of grinding the raw materials. As mentioned previously, in the shaft kiln era, the wet process was the alternative used as there was not yet any machinery that could crush and grind the hard limestone. The development of grinding machinery made it possible to transition from the wet process to the dry process.

There were three types of dry process: the common “pure dry process” using limestone, the “semi-dry process” using slaked lime instead of limestone and the “calcined lime burning process” using quicklime powder instead of limestone.

The calcined lime burning process was a method of separately calcining (decarbonizing) the limestone in a limekiln (shaft kiln) before mixing it with the clay. This process was patented by Asano Cement in the late Meiji Period and used with the company's rotary kilns, not with shaft kilns. The calcined lime burning process is significant because it was the pioneering technology behind the NSP kiln, a Japanese technology that flourished in the 1980s. See 4.2.5 and 5.2 for a more detailed account of this.

New innovations in the dry process era included a tube mill (Figure 3.3, also called a ball mill, see Note 2) introduced by Asano Cement in 1899 and an automatically coupled scale adopted by Onoda Cement the same year for mixing raw materials. Later, improvements were made in the fineness and homogeneity of the raw mix with the adoption of different kinds of powder sifting machines.

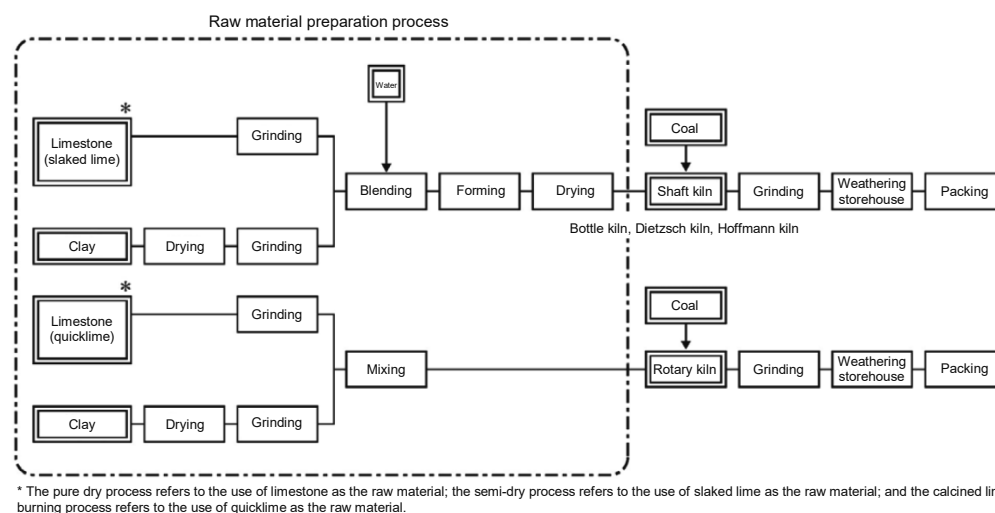


Fig. 3.2 Dry-Process (Shaft Kiln/Rotary Kiln) Cement Manufacturing ²⁾

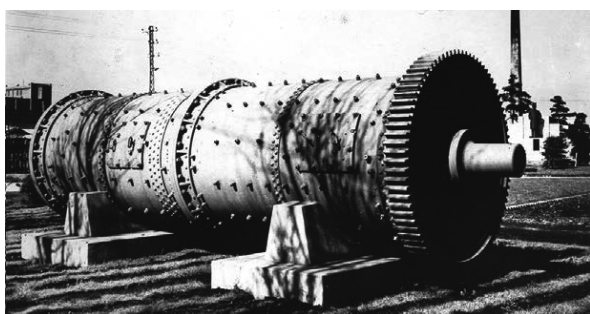


Fig. 3.3 Japan's First Tube Mill ⁷⁾

3.2.2 The Shaft Kiln (Bottle Kiln) Burning Process (1) The Shaft Kiln Burning Method

The main kiln used for cement manufacturing in the Meiji Period was the bottle kiln, such as the one shown in Figure 2.8, which has been preserved at the Taiheiyo Cement Onoda Plant. Built of brick and named for the resemblance to a liquor bottle, many of these were 15-20m in height. With the upper section comprising the smokestack and the lower section comprising the so-called burning chamber, sticks of dead pine or other kindling were placed on the fire grate with coal placed on top as fuel, around two bricks deep, followed by raw material blocks, five bricks deep. This was laid in alternating layers, and then the fire was lit in the fire grate. After around five days of burning, the fuel would burn out and the burnt clinker could be removed from the grate at the bottom. The clinker was sorted into "good quality" and partially-burnt "poor quality", with the good quality product crushed to produce cement. Firing in this kiln was a discontinuous (batch-wise) cycle, with the fire being lit and burning out every cycle. Production capacity often seems to have been 22-30 tons/cycle (130-180

barrels/cycle/kiln).

(Note) Records at the time are given in barrels, but the net weight of the barrels varied with time (see appended chronological table). Calculations here are based on 380lb per barrel (172kg).

(2) The Number of Cement Kilns by Type in the Meiji Period

While bottle kilns (shaft kilns) were the main type of kiln used for cement firing in Japan in the Meiji Period, as mentioned previously, rotary kilns were introduced to Japan from the West in the late Meiji Period and rapidly spread in use to become the main kiln used from the Taisho Period onwards. Dietzsch kilns (shaft kilns) and Hoffmann kilns were also used at some plants during the Meiji Period.

Table 3.1 shows a summary of the cement kilns constructed in Japan from the late Meiji Period to the early Taisho Period at 17 plants operated by 12 cement companies with known histories.

As the table shows, the number of bottle kilns rose to 158 at 17 plants during the Taisho Period, accounting for around 80% of all types of kiln. The cement industry expanded rapidly as a result of the 1904-1905 Russo-Japanese War, with increasing demand for cement; however, it was difficult to make shaft kilns larger due to their shape. Companies responded by increasing the number of kilns, with one company, Aichi Cement, installing as many as 49 kilns at its Higashi-Atsuta plant. As shown in the table, the main kilns were bottle kilns, with far fewer Dietzsch kilns and Hoffmann kilns.

Table 3.1 Number of Meiji-Era Cement Kilns Constructed (12 companies, 17 plants, as at 1913) ²⁾

Factory/plant name		Bottle kilns	Dietzsch kilns	Hoffmann kilns	Rotary kilns
Govt. Fukagawa Works Sub-Bureau		(2-8)*	—	—	—
Asano Cement	Fukagawa Plant	14	—	—	4
	Moji Plant	8	—	—	—
Onoda Cement	Onoda Plant	12	16	1	1
	Dalian Plant	—	—	—	2
Mikawa Cement	Futatsuzaka Plant	1	—	—	—
	Tahara Plant	9	—	—	—
Chuo Cement	Kawaguchi Plant	4	2	—	—
	Kurosaki Plant	17	—	—	—
Aichi Cement	Shirotori Plant	4	—	—	—
	Higashi-Atsuta Plant	49	—	—	—
Hokkaido Cement	Hokkaido Plant	—	—	3	2
Sakura Cement	Osaka Plant	20	—	—	—
(former) Nihon Cement	Yatsushiro Plant	—	—	—	2
Tosa Cement	Tosa Plant	unknown	—	—	3
Toa Cement	Amagasaki Plant	20	—	—	—
Iwaki Cement	Yotsukura Plant	—	—	—	2
Total		158	18	4	21

* After the government-managed Fukagawa Works Sub-Bureau increased from its initial two kilns to eight kilns, it was taken over by Asano Cement, thus overlapping with the 14 kilns shown for that plant.

3.2.3 Shaft Kiln Era Finishing Process: Finishing by Weathering

Once burning was complete in a bottle kiln, the fire grate underneath was removed and the clinker taken out. Since bottle kiln burning was not uniform, the clinker had to be taken out from the kiln and sorted. A steam-driven fret mill (Figure 3.4, see Note 3) was used to grind the clinker. This could produce around 250kg (one barrel) of product per hour initially, which could be increased to 500kg per hour with proficiency. The ground cement was sifted through a rotating hexagonal sieve, after which the fine powder was transported to the cement weathering storehouse, while the remaining sieve residue was returned to the fret mill and ground again with new clinker.

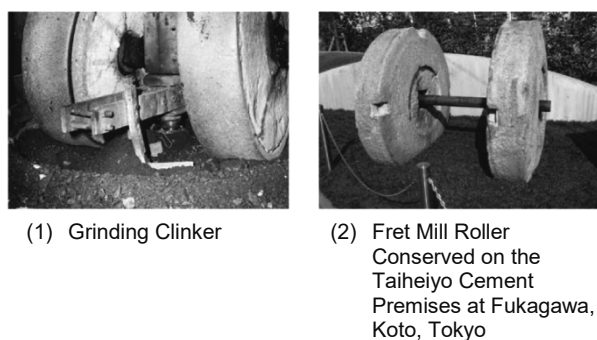


Fig. 3.4 Fret Mill ⁷⁾

Since the fine powder thus obtained had to be properly weathered before it could be used, meticulous attention was paid to the weathering. The weathering method involved setting up a weathering area, spreading out the cement at a depth of 0.1-1m and then occasionally turning it to promote weathering. It was usually weathered for around four weeks or longer, up to six months or more in longer cases.

Cement powder had to be weathered like this for the following reasons.

- (1) The shaft kiln process often produced free lime (see Note 4). There were concerns that the cement would crack when hardened if used as is.
- (2) Adjusting the setting time (see Note 5) within a suitable range when water is added.

Issue (2) above, as mentioned previously, was finally solved in the 1890s with the addition of gypsum. Weathering cement was the usual solution to the issue (1) until the late Taisho Period, when the amount of free lime in the cement was reduced by the widespread use of rotary kilns.

After weathering, the product had a stable lime content and was packed into barrels in the weathering storehouse (Figure 2.11). Packing was also initially done manually.

Tube mills (Figure 3.3) began to be used in the late Meiji Period (1900s) for grinding clinker, with use of steel balls, thus improving grinding efficiency and cement quality.

3.3 The Arrival of the Rotary Kiln Era: Innovative Technologies for Mass-Producing High-Quality Cement ^{2) 4) 5) 6)}

Of the four processes used for manufacturing cement (raw preparation, burning, finishing and shipping), the burning process was the most significant in terms of cost and product quality. In particular, the type of kiln had a direct impact on the quality and manufacturing cost of the cement. Accordingly, this has been constantly improved upon since the dawn of the modern cement manufacturing industry.

Cement burning is basically a solid-phase reaction, although in fact a partial liquid phase occurs at high temperature, allowing the $\text{CaO} / \text{SiO}_2$ reaction. In the solid phase, mass transfer is more difficult to achieve than in the liquid or gas phase, making it less susceptible to chemical reactions. With the shaft kiln, the raw materials are formed into brick shapes, meaning there is almost no mass transfer from external physical force during burning, making it difficult to have any chemical reaction between solid particles. By contrast, with the rotary kiln, developed in the United States in the late 19th century, the raw materials are loaded into the kiln in powder form and blended together by rotational force. This is a far more logical method in terms of achieving a solid-phase reaction.

The use of rotary kilns for cement manufacturing is superior to that of shaft kilns in many ways, including kiln operation capability, fuel efficiency and quality uniformity. Later developments in rotary kiln burning technology made it possible to mass-produce inexpensive yet high-quality cement, thus ushering in the “concrete civilization” of the 20th century.

With the introduction of rotary kilns enabling the mass production of high-quality cement, the accompanying developments in technologies and facilities for the raw materials and finishing processes must not be overlooked. The introduction of tube mills and other such technologies as separators was particularly important.

3.3.1 The Introduction of Rotary Kilns ^{2) 4) 5) 6) 7) 8)}

While rotary kilns were already being used for calcining ore since 1881, it was in 1885 that Frederick Ransome of the United Kingdom patented the use of the rotary kiln for cement burning. After trialing an experimental rotary kiln, he carried out an industrial trial at a plant in Grays, Essex, England, with an experimental kiln 18in (46cm) in diameter and 15ft (4.6m) in length. He scaled this up to 48in (1.22m) in diameter and 30ft (9.1m) in length, with successful results. However, the kiln never made it to implementation, as cement plants in the United Kingdom at the time were manufacturing using the wet process and he could not find a suitable

means of burning wet-process compounds in a rotary kiln, combined with the fact that there were issues with the clinker fusing to the bricks due to the large amounts of fuel required.

Further devices were contrived using this idea, with industrial success achieved by Atlas Cement around 1890 at a plant in Rondout, New York, United States. Production is reported to have commenced on a kiln 50in (1.27m) in diameter and 50ft (15.2m) in length⁸⁾. The first rotary kiln in Japan was imported from the United States in 1903 by Asano Cement and installed at the Fukagawa plant. It was 6ft (1.83m) in diameter and 60ft (18.29m) in length (Figure 3.5). This model was nearly identical to the large-scale rotary kilns used today, with a brick-lined steel cylinder rotated at an incline of around 3%. The powdered raw materials were fed in from the upper end of the incline, with fuel burned in from the lower end (countercurrent heat exchange).

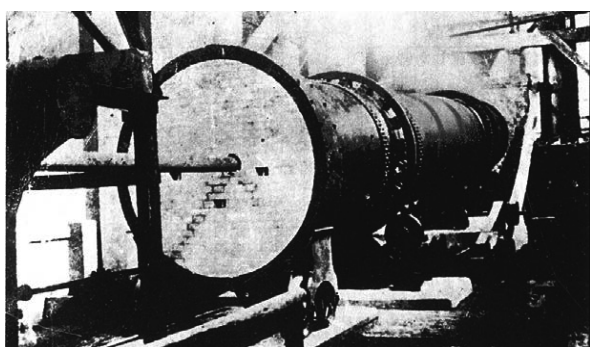


Fig. 3.5 Japan's First Rotary Kiln (1903)²⁾

Other companies in the industry gradually came to recognize that Japan's first rotary kiln was superior to the existing shaft kilns (including Dietzsch kilns and Hoffmann kilns) in burning efficiency, capability and quality uniformity. Rotary kilns started being incorporated into new facilities. It appears that they were also being made progressively larger: a rotary kiln constructed by Onoda Cement a decade later (1913) is recorded as being 2.5m in diameter and 60m in length (Figure 3.6).



Fig. 3.6 An Example of a Rotary Kiln Constructed Ten Years After Fig. 3.5²⁾

Asano Cement was able to spearhead the introduction of rotary kilns thanks to engineer Fuyuzō Sakauchi, who played a pioneering role in cement manufacturing technology in Japan and at Asano Cement during the Meiji Period, with achievements including leading the introduction of "gypsum-adding" technology, as mentioned later, and patenting the calcined lime burning process.

3.3.2 Prevalence of Rotary Kiln

Figure 3.7 shows a summary of the trends in raw materials processing and types of kiln up until 1917 for 8 companies and 14 plants with known histories as cement plants.

Cement manufacturing in Japan started out with the wet process using bottle kilns, modeled on the government-administered cement plants. From the late 1890s, this gradually transitioned to the dry process using shaft kilns, and then to rotary kilns from around 1907. The rotary kilns of this era were very thermally inefficient and were not definitely more cost-efficient than shaft kilns either. It was not until the introduction of facilities for waste heat utilization (waste heat power generation) in 1920 (see 4.2.2) that the rotary kiln era began in earnest.

By 1924, among the 20 companies (32 plants) that were members of the Japan Portland Cement Association, 29 plants had only rotary kilns, 2 plants had both bottle kilns and rotary kilns and 1 plant (inactive) had only bottle kilns. The bottle kiln era thus came to a close at the end of the Taisho Period (1926). The rotary kiln is discussed in more detail from Chapter 4 onwards.

3.4 Adding Gypsum: The Other Major Invention to be Introduced to Japan alongside "Portland Cement" and "Rotary Kilns"^{2) 5)}

Modern Portland cement contains around 3% gypsum. This regulates the setting time of the cement to within a time range that makes it easier to use during construction. The Portland cement invented by Aspdin (1824) only comprised ground clinker, which meant it set very quickly. The use of weathering to regulate the setting time originated in the United Kingdom in the mid-19th century, while a patent granted in 1870 in the United States for a "Mode of Hardening Artificial Stone and Other Articles, or Combination of Materials, by the Introduction of Carbonic-Acid Gas". Weathering in weathering areas was practiced at plants in Japan from the Meiji Period to the late Taisho Period, as mentioned in 3.2.3.

More detail on the European and American cement industry's "invention" of the mixing of gypsum to achieve cement setting consistency is given in 7.5.1.

Year	M6	M11	M16	M21	M26	M31	M36	M41	T1	T6	Reference
(1873)	(1878)	(1883)	(1888)	(1893)	(1898)	(1903)	(1908)	(1912)	(1917)		
Company											
(Govt. managed) Fukagawa Works Sub-Bureau	M8	(Wet process) bottle kiln	Sold to Sōichirō Asano (became Asano Cement)								M5 Cement manufacturing facilities installed
Asano Cement			(Wet process) bottle kiln								M39 Bottle kiln abolished
Fukagawa Plant			M17			M36	(Dry process) rotary kiln				
Moji Plant				M26	(Dry process) bottle kiln			M41	Rotary kiln		M43 Bottle kiln abolished
Onoda Cement		M16	(Wet process) bottle kiln	(Dry process) bottle kiln							T2 Bottle kiln abolished
Onoda Plant			M22	Hoffmann kiln (M22-23)	(Dry process) Dietzsch kiln						T11 Dietzsch kiln abolished
Dalian Plant					M32			T2	Rotary kiln		T2 Rotary kiln installed
Mikawa Cement			M16	(Wet process) bottle kiln	M22 Plant abolished			M42	(Dry process) rotary kiln		
Futatsuzaka Plant											
Tahara Plant			M22	(Wet process) bottle kiln			(Dry process) bottle kiln				T13 Rotary kiln installed / bottle kiln abolished
Osaka Kawaguchi Cement Works			M17	(Wet process) bottle kiln				M44	Plant abolished		
(Chuo Cement) Kawaguchi Plant					M29	(Dry process) Dietzsch kiln					
Kurosaki Plant				M26	(Wet process) bottle kiln		(Dry process) bottle kiln		Rotary kiln		T9 Rotary kiln installed / bottle kiln abolished
Aichi Cement			M20	(Wet process) bottle kiln		M32	Plant abolished				
Shirotori Plant					M30	(Dry process) bottle kiln			Rotary kiln		T9 Rotary kiln installed / bottle kiln abolished
Higashi-Atsuta Plant											
Hokkaido Cement				M25	(Dry process) Hoffmann kiln						T6 Hoffmann kiln abolished
(Asano Cement) Hokkaido Plant							M42	(Dry process) rotary kiln			
Sakura Cement							M41	(Dry process) bottle kiln			T8 Plant abolished
Osaka Plant								T3	Rotary kiln		
Tokuura Plant									T6	Rotary kiln	

M: Meiji Period; T: Taisho Period

Fig. 3.7 Trends in Raw Material Processing and the Types of Kiln in the Meiji and Taisho Periods ²⁾

This technology was first introduced to Japan by Asano Cement engineer Fuyuzō Sakauchi, who started using it at the company's Fukagawa plant when he returned from studying in Germany in 1888. However, it was initially criticized by some consumers in Japan as "adulterated". This criticism was not without cause, as the method of using gypsum to regulate setting was by no means perfect at that time. Later, studies on the composition of cement revealed that setting occurs more quickly with a higher alumina content and lower silicic acid content. Advances were made in increasing the silicic acid content and reducing the alumina content, thereby establishing the method of using gypsum to regulate setting and making setting more consistent.

These product improvements meant the abolition of the weathering method, previously used to prevent rapid setting, early in the Taisho Period (1910s). The abolition of weathering meant it was possible to manufacture cement that set more consistently without sacrificing the strength of the cement. The addition of gypsum to cement was a major invention in cement manufacturing technology, alongside the invention of the rotary kiln. Chapter 7 discusses the cement retardation action of gypsum in more detail.

3.5 Power Source: From Steam Engines to Electric Power ^{2) 4) 5) 7)}

The early industry machinery of the Meiji Period was powered by steam engines, with plants lit by lamplight. In 1899, Onoda Cement installed a 40kw DC generator at its Onoda plant for partial electric lighting. Electric power was first used to power the plant in 1911. The plant went

fully electric in 1913 with the installation of waste heat power generation facilities ⁴⁾.

Asano Cement is also reported to have started using electric power around the same time ⁷⁾. Thus, in the Japanese cement industry, the Meiji Period can be viewed as the age of steam-power, and the Taisho Period onwards as the age of electric power.

3.6 Cement Manufacturing Quality Control and Cement Quality Standards ^{2) 6)}

Since the beginning of Portland cement production in Japan in May 1875, the quality of Japanese cement has improved significantly throughout the Meiji and Taisho Periods to the present day in the 21st century.

However, in the early years up until 1887, cement companies were starting completely from scratch, and they ran their business and manufacturing operations on an ongoing trial-and-error basis.

Production control started with the keeping of necessary records for material balancing, such as the raw materials, fuel and products needed to keep the plant operating. Later, as technology advanced, other management items necessary for operation and management were added, such as the operating hours of main facilities.

The quality control was initially quite removed from scientific controls. Tests began to be carried out on the strength of cement, then chemical analyses were added as well as physical tests, such as for fineness. The late 1890s and beyond saw the foundations laid for quality control, which by the late Taisho Period (1920s) had been developed to cover much of what it does today.

3.6.1 Quality Control Up Until the Late 1880s and Early 1890s

In the early era of cement, there was little awareness of quality control. Up until around 1887 at least, test result reports can be said to have been nonexistent.

From 1887 onwards, scientific controls gradually began to be implemented, with measurements taken of raw material and cement fineness, cement chemical analysis, mortar tension (strength) and hardening (setting). However, companies were unable to conduct their own chemical analyses, which had to be requested of the Ministry of Agriculture and Commerce or other organizations. While companies were conducting their own tests and qualitative evaluations, such as whether hardening was rapid or gradual, the sand used for mortar tests was not standardized, as it was chosen by each company individually.

3.6.2 Towards Uniform Quality Testing Methods

Around the middle of the Meiji Period (1890s), concrete construction was becoming quite popular, but no national standards had been established for cement. Accordingly, government civil engineers drew from their knowledge of events in countries in which they had studied and emulated or revised cement standards from those countries, or else came up with their own testing methods, leading to a diversity of methods. This was very complicated, both from a technological perspective and an operational perspective, and was a major obstacle to cement company operation.

Under these circumstances, members of the cement industry consulted together regarding uniform testing methods. On July 15, 1893, eight prominent cement companies jointly signed and submitted a “Petition to Unify Cement Testing Methods” to Shōjirō Gotō, then Minister of Agriculture and Commerce. Although this proposal was not implemented, the industrial initiatives it triggered had ongoing effects.

Around 1896, following consultation with members of the cement industry and reference to the standards in Germany and other countries, a draft standard was drawn up entitled “Appended Designation of Portland Cement Testing Methods of the Empire of Japan”, on which the “Portland Cement Testing Methods of the Empire of Japan”, proposed in July 1898 at a meeting of industry members, was based.

The “Appended Designation of Portland Cement Testing Methods of the Empire of Japan” firstly stipulated the definition and composition of Portland cement, with Articles 1-4 covering the test items of “setting”, “setting capacity”, “strength testing” and “degree of powder”. “Setting capacity” refers to expansion of cement paste after hardening, while “degree of powder” refers to the fineness of the cement powder. The appended designation stipulated factors such as the net weight of the barrels and the attaching of trademarks. Similar test items were defined in the “Portland Cement Testing Methods of the Empire of Japan”.

Although this draft plan created by nine prominent cement companies was never implemented, manufacturers proceed with their day-to-day production and quality control based on this industry proposal. The testing system is thought to have gradually developed to completion from around 1897. At length, the government also came to recognize the importance of quality standards. Testing method research carried out by a team of six engineers from industrial testing stations and cement companies resulted in the promulgation of the “Japan Portland Cement Testing Methods” by Ministry of Agriculture and Commerce Notice No. 35 on February 10, 1905.

This was neither a law nor a regulation; it was simply a government purchase criterion that specified the quality and testing methods for cement for government orders. However, it was a standard set by government authority and it gradually spread across to other consumers. Similar in content to the “Portland Cement Testing Methods of the Empire of Japan” mentioned above, it comprised Article 1 “Degree of Powder”, Article 2 “Setting”, Article 3 “Expansion Cracking”, Article 4 “Strength” and Article 5 “Limitations on Magnesia and Sulfuric Acid”. This formed the basis of the present-day quality standards.

These testing methods were established around the same time as the United Kingdom (1905) and the United States (1906) and triggered significant developments in the Japanese cement industry, which had started later than its counterparts in the West. Product quality rapidly improved as manufacturing facilities improved, giving the Japanese cement industry a completely new look. As cement quality improved, the cement standards became successively more detailed, with relative weight and other items added and revisions made to standard values for fineness and strength.

The cement standards underwent later detailed revisions and additions based on advances in technology and needs of consumers, eventually taking shape to become the JIS standards of the present day. Chapter 8 discusses the history of cement standards in more detail.

3.6.3 Formation of Cement Technology Organizations

In the first decade of the Japanese cement industry coming into being, there was an overall low level of scientific knowledge in the industry. There were very few issues with the manufacturing or application of cement that demanded scientific or technical research or clarification. Cement manufacturers were carrying out their own research, however, and the Japan Portland Cement Industry Society was formed by ten companies in the industry as early as 1900. The aim of forming the Society was to set aside economic issues and to carry out research in all academic and technical aspects of the manufacturing and application of cement in order to steer the development of cement and concrete in the right direction.

The first issues to deal with were selecting a standard sand for cement testing and establishing the national cement standards. Their efforts were rewarded with the promulgation of the “Portland Cement Testing Methods” by a Ministry of Agriculture and Commerce notice in 1905. Several years later, the Japan Portland Cement Association was formed, which had strong business ties with the Society. Although this organization was initially founded as a friendly society for industry members, its main involvement later shifted to inspecting cement testing equipment, distributing the standard sand for testing and promoting the utilization of cement. The two organizations continued until the age of wartime control, making a significant contribution to the technological development of the cement industry.

During the war, both organizations were assimilated into the Cement Control Association and were relaunched right after the war in 1946 as the “Japan Cement Technology Association”. This merged with the “Cement Association” in 1966 to become what the “Japan Cement Association” of today, with an associated “Research and Development Laboratory”.

The main undertakings of the Laboratory today are as follows.

1. Research and Technical Support
Holding cement technology conventions and lectures, administering research incentives and awards for papers, publishing collected papers on cement and concrete, collaborative testing of cement, etc.
2. Preparing Cement Standards
Preparing Cement Association standard testing methods, managing and selling standard materials and standard sand
3. Commissioned Testing
Commissioned testing of cement and concrete

3.7 Cement Kiln Operational Performance in the Meiji and Taisho Periods ^{1) 2)}

Sections 3.1 to 3.6 above discussed the history of cement manufacturing technology in the Meiji and Taisho Periods. This period that dates back more than a century and very few historical records survive that relate to cement manufacturing during this time. Many of the details of the technology are unknown. However, since Onoda Cement’s (now Taiheiyo Cement) Onoda plant has remained on the same site at the same location since it was established in 1881, quite a number of Meiji- and Taisho-era technical documents have survived. With the help of company retiree Dr. Tomikazu Dainobu, Taiheiyo Cement began collating these records in 2004 and published a summary of the findings in the April, July and October 2008 and January 2009 issues of the

Taiheiyo Cement company bulletin *CEM’s*.

Although these are only records of one plant owned by one company, they are considered to be very valuable resources that reveal how the cement industry operated in the Meiji and Taisho Periods. The main details are outlined below.

(Note) Cement production at the Taiheiyo Cement Onoda plant ended in 1985. Since then, it has been used by associated companies for producing concrete admixtures and additives and static crushing materials.

3.7.1 Bottle Kiln Operational Performance

Table 3.2 shows production performance between 1885 and 1894 in chronological order, including the transition from wet process to dry process and scale-ups. “Number of kiln outputs” represents the number of kiln operations during that period, with the output from the kilns categorized into good-quality “refined product” and inferior “under-burnt/over-burnt product”. The fuel ratio is given as the quantity of coal required to burn one ton of cement in kg units. Product weight was recorded by the number of barrels at the time; this has been converted at 172kg per barrel and represented in tons (the same applies below to rotary kilns).

As shown in Table 3.2, in a period of less than ten years between 1886 and 1894, refined product volume by around 13 times from around 626 tons to 8,415 tons. The refined product volume per kiln also more than tripled from around 10 tons to around 34 tons. While a dramatic increase in refined product volume was observed in 1890 in particular, this is believed to be due to the fact that the number of bottle kilns increased from four to six that year, as shown by the number of kilns in the table, the fact that cement manufacturing shifted from the wet process to the dry process and the fact that some bottle kilns were made to accommodate the growing demand for cement for the construction of railroads, harbors, cotton mills and other domestic facilities.

Although the inferior product rate varied a little year by year, this steadily dropped from 25-30% in 1885 to around 11% by 1893. Considering this reduction in inferior product rate together with the increase in refined product volume per kiln indicates that cement manufacturing technology dramatically improved during this time.

Fuel ratio trends for bottle kilns showed a wide range of variation between years, from 240kg to 519kg, with some years having some records missing. This is thought to be due to the bottle kiln burning method, namely, a discontinuous or batch-type burning method, where operation has to stop at the end of each burning, thus leading to significant variations in heat loss and output clinker quality.

Table 3.2 Bottle Kiln Production Performance ²⁾

Year	Time	No. of kilns	No. of kiln outputs	Refined production volume (a) (t)	Under-burnt / over-burnt volume (b) (t)	Total (c = a + b) (t)	Inferior product rate (b/c) (%)	Refined product per kiln (t/operation)	Fuel consumption (kg/t)	Raw material production method
1885	2 nd half	4	Wet 39	366	130	496	26.2	9.4	404	Wet process
1886	1 st half	4	Wet 37	352	135	487	27.8	9.5	519	
	2 nd half	4	Wet 26	274	97	371	26.1	10.5	464	
1887	1 st half	4	Wet 38	539	96	635	15.1	14.2	284	
	2 nd half	4	Wet 50	760	142	902	15.8	15.2	266	
1888	1 st half	4	Wet 60	941	271	1212	22.3	15.7	240	
	2 nd half	4	Wet 56	870	259	1129	23.0	15.5	270	
1889	1 st half	4	Wet 47	743	248	991	25.0	15.8	364	
	2 nd half	4	Wet 51	838	227	1065	21.3	16.4	350	Both wet and dry process
1890	1 st half	4	Wet 61	1161	233	1394	16.7	16.3	372	
	2 nd half	6	Wet 34	649	134	783	17.1	19.1	(523)	
		6	Dry 63	1750	292	2042	14.3	27.8	(427)	
1891	1 st half	6	Wet 2	32	9	41	21.9	16.0	-	
		6	Dry 88	2632	497	3129	15.9	29.9	397	
	2 nd half	6	Dry 74	2144	415	2559	16.2	29.0	395	
1892	1 st half	6	Dry 88	2776	452	3228	14.0	31.5	386	
	2 nd half	6	Dry 99	3195	391	3586	10.9	32.3	No record	Dry process
1893	1 st half	7	Dry 102	9426	434	9860	11.2	33.6	No record	
	2 nd half	7	Dry 103	3553	452	4005	11.3	34.5	No record	
1894	1 st half	7	Dry 109	3856	705	4561	15.5	35.4	No record	
	2 nd half	7	Dry 142	4559	860	5419	15.9	32.1	No record	

Notes) 1. The wet process was used until the first half of 1890; both wet and dry processes were used between the second half of 1890 and the first half of 1891; the dry process was used from the first half of 1891.

2. Entries in () under fuel consumption are not full-year averages due to fewer records being available.

3.7.2 Rotary Kiln Operational Performance

Rotary kilns are characterized in that they can continuously produce consistent clinker because it is possible to continuously feed in raw material and fuel and reduce or increase this input depending on the burning conditions. There is no need for shaping the raw materials or screening the clinker, thus simplifying the manufacturing process and enabling mass production as a result. Despite the drawback with the structure of the kiln in generating a lot of radiant heat and being less thermally efficient than shaft kilns due to the raw material shifting to the bottom of the kiln while the hot gas rises to the top, waste heat power generation that efficiently utilizes the heat energy of the waste gas has been implemented since the start of the Taisho Period. Chapter 4 discusses the utilization of waste heat in rotary kilns in more detail.

(1) Rotary Kiln Operating Rate, etc.

The Onoda plant abolished shaft kilns in 1913, entering an age of rotary kilns only. Table 3.3 shows the operating performance of the No. 1 rotary kiln (diameter 3m, length 50m) from that time until 1924. The table shows kiln output, operating rate (ratio of rotary kiln operating time per calendar time), coating (*anzatz*)-clearing wait time (see Note 6), coating-clearing wait time rate and fuel ratio in chronological order.

Table 3.3 Rotary Kiln Production Performance ²⁾

Year	Kiln output		Operating rate*	Coating-clearing wait time		Fuel ratio
	t	t/day	(%)	Hours/ year	Wait time rate** (%)	(kg/t)
1913						
1914	38131	129	81.3		No record	302
1915	53082	177	82.4			262
1916	56459	179	86.1			283
1917	57845	188	85.6	473	6.4	289
1918	53148	176	82.9	308	4.3	297
1919	55842	180	86.0	407	5.5	281
1920	53947	174	85.2	208	2.8	285
1921	60266	191	87.1	356	4.7	291
1922	58698	185	88.7	220	2.9	292
1923	64159	195	89.7	221	2.7	262
1924	60266	184	87.5		No record	282

* Ratio of operating time per calendar time. Same as working ratio.

** Ratio of coating-clearing wait time per rotary kiln operating time.

The wait time rate under the “coating-clearing wait time” column is the ratio between the number of hours the kiln was temporarily stopped to manually clear the excessive coating clinging to the inside of the kiln (once per shift) and the number of operating hours of the kiln. Although the operating rate rose from 81% when the kiln was first installed to around 88-89% by 1924, it was stopped more than three days per month. This was due to many factors, including bricks dropping out of the inner wall of the kiln, breakdowns in machinery around the kiln and shortages of raw materials. Specific to the operation of the rotary kiln was the regular extinguishing of the fire for around 20 minutes per eight-hour shift (around one hour per day) from 1917 to 1921 to manually scrape out

the coating clinging to the interior of the kiln. The wait time rate for the “coating-clearing wait time” was still around 3% (40 minutes per day) even in 1922. Rotary kilns rotated at the same fixed rate, but more proficient control of the amounts of raw material and fuel input had eliminated the need for coating-clearing by around 1926.

Thus, although cement burning in the Taisho Period (1912-1926) was more consistent than it had been in the past, kilns still required repeated short breaks for clearing coating or repairing mechanical breakdowns.

Rotary kiln operation (burning) logs also record the pressure used for blowing in the coal fuel from 1924 onwards. Since there are no records of temperature, it is presumed that suitable temperature-measuring instruments had not yet been developed and that the inputs of raw material and fuel were controlled by observing the burning conditions within the kiln and the clinker by eye.

(2) Rotary Kiln Output Trends

Since rotary kiln operation was consistent, there was no need to sort the output after burning into superior and inferior products. The “kiln output” on its own was synonymous with the “refined production volume” of the bottle kilns.

As shown in Table 3.3, the annual burning output rose to 38,000 tons in 1914, right after the rotary kiln started operating, equivalent to around 130 tons per day. This is around 3.7 times higher than the 35t/day achieved by bottle kilns. Burning outputs later gradually increased due to increased operating proficiency, reaching around 190t/day by 1923. At around 60,000 tons per year, this dramatic increase was more than 1.5 times the annual kiln output achieved in 1914.

The initial rotary kiln fuel ratio (kilograms of coal per tons of cement) was slightly over 300kg/t-cement at the start of rotary kiln operation in 1914, but remained consistently below 300kg/t-cement after that. Compared to the 240-519kg/t-cement achieved by bottle kilns, regardless of the lower thermal efficiency of the rotary kiln compared to the shaft kiln due to its type, the fuel ratio was actually lower and varied very little, meaning much more consistent operation compared to bottle kilns.

Note 1: Mill

A stone mill comprising a circular (diameter around 1.2m, thickness 0.2-0.4m) runner stone with a raw material inlet at the center and a bed stone with radial grooves; the rotating of the runner stone would shear and grind the raw material, pushing the powder out through the grooves to the edge.

Note 2: Ball Mill and Tube Mill

A ball mill is a general term for a rotating cylindrical crusher, in which the material to be crushed is inserted into the cylinder together with balls as a crushing medium and is crushed by the rotation of the cylinder. Ball mills in which the cylinder is longer than the diameter are called tube mills. Since most ball mills currently used at cement plants are tube mills, the terms ball mill and tube mill are used interchangeably in this report. Chapter 4.5.1 and Figure 4.12 provide more detail on the invention of the tube mill, its introduction to Japan and the structure of the mill.

Note 3: Fret Mill (Fig. 3.4)

Also called an edge runner. Two stone rollers around 1.2m in diameter rotate on a freely rotating stone table (later steel), crushing by compression and shear.

Note 4: Free Lime

Refers to unreacted lime (CaO) in clinker. An important part of the burning process is to cause the lime content of the raw material to react with the clay content as much as possible to produce hydraulic cement minerals. Clinker with very little free lime is termed “properly burnt clinker”. Excessive free lime can cause cracking in concrete.

Note 5: Setting and Hardening

The process from when water is added to cement until when the cement hardens is called “setting”, while the process from when it hardens and becomes stronger is called “hardening”.

Note 6: Coating (*Anzatz* in German)

This term refers to the fused raw material that has adhered to the bricks on the inner wall of the kiln. At an appropriate thickness, coating improves heat exchange by preventing raw materials from sliding and also protects the surface of the bricks; however, when too much adheres, it can prevent the flow of raw material within the kiln, thereby reducing the capacity of the kiln and lowering the production efficiency.

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4 | From the Early Showa Period and the Pacific War to the Post-War Reconstruction Period (1926-1960)

The previous chapter discussed cement manufacturing technology in Japan from its origins with the bottle kiln through to 1926. During this time, the following significant advances were made.

- (1) Mass production of cement was made possible through rotary kiln
- (2) Setting and hardening were made more consistent by adding gypsum
- (3) Quality improved with the establishment of quality testing methods and quality standards.

Production volumes, which in 1882 had totaled around 3,000 tons per year between Sōichirō Asano's Fukagawa plant in Tokyo and Junpachi Kasai's Onoda Cement plant in Yamaguchi, increased to 600,000 tons by around 1912 and 3 million tons by 1926, with plants being built all around the country.

This chapter discusses the trends in domestic Japanese cement manufacturing technology from the late 1920s through the Pacific War to 1960 and the end of the postwar reconstruction period. The following four points can be identified as significant to the development of manufacturing technology during this time.

- (1) Advances in the technological development of rotary kiln exhaust heat (waste heat) recovery and utilization methods. Several types of rotary kilns emerged with different systems.
- (2) Advances in improving technology for preceding and following processes, as achieving mass production using rotary kilns required sufficiently capable raw materials and finishing processes. Dust collectors were also fitted due to pollution issues as plants expanded in scale.
- (3) Diversification of the types of cement as the applications for concrete grew.
- (4) Although most cement manufacturing technologies were still being introduced from the West until this time, a "new calcined lime process", using calcined quicklime instead of limestone was a forerunner for later technological developments that were uniquely Japanese.

(Note) In 1909, Onoda Cement constructed its Dalian Plant and commenced operation in what was then the Kwantung Leased Territory (now northeastern China). Although Japanese cement companies later expanded into Taiwan, the Korean Peninsula and Manchuria (now northeastern China) between the 1910s and the Second World War, building new plants in various areas, the facilities and technologies adopted there are not covered in this report, which focuses on the idea of "in Japan first".

growth in production volumes, as the figure shows, cement company fortunes were tempestuous from the Meiji and Taisho Periods through to the Second World War. The economic recession that began in 1920 after the First World War, the Showa financial crisis of 1927 and the worldwide Great Depression that began in 1929 had an ongoing impact; this coupled with unregulated competition to increase production and dumping sales meant hardship for smaller manufacturers, with many of them either being taken over by larger companies or closing down altogether.

With the outbreak of the Second Sino-Japanese War in 1937, the Japanese economy shifted into a wartime regime. Like other industries, the cement industry was subjected to national control, with restrictions placed on all aspects, including production, sales, prices and allocation of materials. As Japan entered the Pacific War, business operators entered a time of severe difficulty. The war meant a forced decline in domestic cement operations, with severe restrictions imposed, including (1) reduced allocation of raw materials and decreased production, (2) curtailment of business operations (compulsory mergers) and (3) enforced relocation of plants to Japanese-occupied territories in the south by military order.

Japan's defeat in the war struck a devastating blow to the cement industry. Numerous overseas plant assets (many of them new facilities) were lost in a single stroke. Although plants on home soil suffered relatively little direct damage from bombs or other attacks, the machinery and facilities were run down from overuse during the war and production volumes dropped dramatically. Monthly production at the end of the war fell to 30,000 tons (from a prewar average of 300,000 tons), with annual production volume for 1945 eventually dropping to around 1 million tons, including the time before the war ended and afterwards.

However, once the controls on coal fuel were lifted in September 1949, production conditions rapidly improved and monthly production rose to 300,000 tons once more. In 1950, the controls on cement price and distribution were lifted and free selling was reinstated. In 1951, annual production reached 6.5 million tons and surpassed the prewar peak.

With the controls lifted, the Japanese cement industry made astounding progress. First of all, the domestic and international demand for cement grew rapidly. Rebuilding waterways, roads, harbors and other infrastructure that had been damaged in the war required large amounts of cement first and foremost, as did the construction of railroads and dams to facilitate economic recovery and the reconstruction of homes and factories. This "reconstruction demand" was also further spurred on by the favorable domestic economy that resulted from the Korean War that started in 1950.

4.1 The Cement Industry from 1926 to 1960 ^{1) 2)}

Figure 4.1 shows the transitions in cement production volumes during this period. Production rose from around 3 million tons in 1926 to around 6 million tons by 1937. However, although the cement industry had favorable

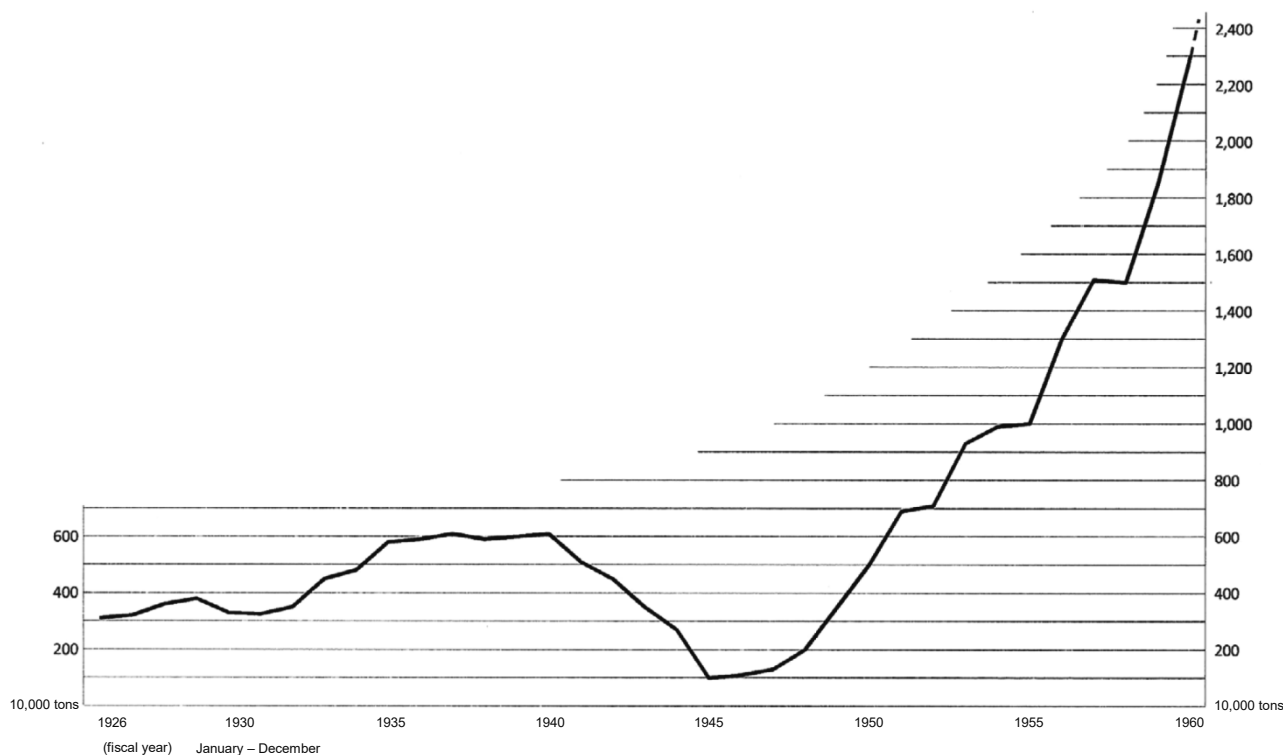


Fig. 4.1 Transitions in Cement Production Volumes 1926-1960 ¹⁾

From 1951, annual production volumes increased in an unprecedented steep curve. Domestic demand increased at an average of around 17% from 1951, more than double the prewar growth rate of around 8%.

The first factor cited for this surge in demand is the soaring reconstruction demand. However, the growth from 1956 onwards, a decade after the war, indicates the presence of another underlying factor with more aggressive demand: expanding the Japanese economy, along with public investment into roads, harbors, dams and other industrial facilities to support this.

Meanwhile, cement exports resumed in 1947 and steadily increased each year to reach 2.2 million tons in 1956, making Japan the world's largest exporter of cement. The cement industry was well able to manage this sudden growth in demand by increasing production. Great success was achieved after the war with efforts to reinstate management systems, rebuild facilities and actively expand.

4.2 Development of Cement Burning Technology (from the late 1920s to the 1950s) ^{1) 2)}

In 1903, Asano Cement installed Japan's first rotary kiln (diameter 1.8m, length 18.3m), imported from the United States, as discussed in 3.3 above.

After that, rotary kilns spread in popularity among companies until they completely superseded the conventional shaft kilns by the late 1920s, as also discussed in 3.3 above. Thus, the emergence of rotary kilns brought about a major transformation in the history of cement manufacturing technology. This enabled cement plants to transition into "mass-production facilities" with rotary kilns at the core.

In 1920, Onoda Cement installed the first private power generation facilities at its Onoda plant, utilizing waste heat from rotary kiln exhaust gas. Japan was facing a shortage of electric power at the time and this method of waste heat power generation (see 4.2.2) did not go unnoticed. Waste heat power generation became more widespread until eventually most rotary kilns were fitted with waste heat boilers.

Many rotary kilns used the dry process (the method of loading dry, powdered raw materials into the kiln). However, with the use of "high-early strength cement" (details in Chapter 8) becoming more common in Europe from around the late 1920s, Asano Cement attempted to manufacture it in 1929 by loading raw material slurry into a rotary kiln. The company established a wet process

plant in Nishitama, Tokyo. In 1932, Onoda Cement installed the first “slurry filter” on wet process kilns at its new Fujiwara plant in Mie, making waste heat power generation possible with the wet process. This filter method later became a common choice for the wet process.

In 1934, Mikawa Cement (later merged with Onoda Cement) established Japan’s first “Lepol kiln” at its Tahara plant. The innovation of the Lepol kiln was the use of a preheater for exhaust gas heat recovery for the first time in history. A preheater is a device that transfers the heat from the kiln exhaust gas to the raw materials by conduction, thus decarbonizing or “calcining” the limestone.

Table 4.1 shows the types of kilns used from the late 1920s to the present day. This section discusses the “dry process”, “wet process” and “semi-dry process” in terms of the trends and developments in each from the late 1920s to the 1950s and the different issues with each of the processes. The Japanese cement industry overcame these issues and went on to successfully develop the NSP method at the peak of modern cement manufacturing technology today, discussed in Chapter 5.

Table 4.1 Categorization of Cement Kilns by Type (late 1920s-) (source: author)

Dry process kiln	
* Short kiln	
	Waste heat boiler attached (DB)
	New calcined lime burning process (NCB)
	Suspension preheater attached (SP, NSP)
* Long kiln	
* Shaft kiln (S)	
Wet process kiln	
* Short kiln	
	Filter attached (WF)
	Filter attached, boiler attached (WFB)
* Long kiln	
	Semi-dry process kiln
* Lepol kiln (L)	
Note: Parentheses show the abbreviations used in the Japanese cement industry for each type.	

(Note) The “shaft kiln” in the table is not the Meiji-era shaft kiln (bottle kiln), but a shaft-type kiln built by some cement companies for a short time after the end of the war using licensed technology from Germany. Although cheaper to build and more thermally efficient than other types of kilns, they stopped being used after about a decade due to issues with operability and cement quality. They have not been mentioned in detail in this chapter due to being overseas technology and having had very little impact on other manufacturing technologies. Also, although there have been some

cases of “dry process long kilns” in the United States, they were not used in Japan and so have also not been mentioned in detail. SP and NSP kilns are discussed in detail in Chapter 5.

4.2.1 Improving Thermal Efficiency and Reducing Fuel Consumption of Rotary Kilns

The introduction of rotary kilns was an epoch-making event in the history of cement manufacturing technology in the sense that it improved cement quality and made mass production possible. However, despite these major advantages, there were several drawbacks with rotary kilns, the most significant being their poor thermal efficiency. There two factors allowing heat to escape: “heat retained in exhaust gas” and “heat retained in the clinker”.

(1) Heat Retained in Exhaust Gas

In a rotary kiln, the chemical reaction between the raw materials is caused by countercurrent heat exchange between the raw materials traveling to the bottom of the cylinder and the burnt gas traveling to the top. Most of the heat transfer between the burnt gas and the raw materials is due to radiative heat transfer from the combustion flame, with conductive heat transfer playing a very small role. While the gas temperature drops toward the gas exit of the kiln, the radiative heat transfer rate between the gas and the material drops proportional to the fourth power of the absolute temperature. This consequently makes the heat exchange rate low and the thermal loss high.

(2) Heat Retained in the Clinker

The hot clinker burnt in a rotary kiln is cooled by the air on coming out of the kiln. The cooling air is drawn into the kiln as secondary air (see Note 1). There is a low rate of radiative heat transfer between the hot clinker and the air being drawn into the kiln; sometimes the clinker comes out of the kiln still very hot. Consequently, this thermal loss is also very high.

Fuel costs account for a high proportion of the manufacturing costs of cement. Therefore, improving the thermal efficiency of rotary kilns and reducing the amount of heat required are very important factors for reducing costs. This section 4.2 discusses the measures taken to recover heat retained in the kiln exhaust gas, while the following section 4.3 discusses the measures taken to recover heat retained in the clinker.

4.2.2 Power Generation from Exhaust Gas Heat in Dry Process Rotary Kilns (Dry Process Kiln with Waste Heat Boiler Attached / DB) ²⁾ ³⁾

Dry process rotary kilns (short kilns) with waste heat boilers attached (DB) were the main kilns used from the

late 1920s to the postwar reconstruction period. Since many dry process kilns were 70-80m long, the exhaust gas was around 800-900°C, around 50% of the amount of heat being blown into the kiln. To efficiently utilize this exhaust gas heat, a method was developed of mounting a boiler at the kiln end (gas exit) to generate electricity. American boiler manufacturers and other companies marketed this technology in the 1910s. Despite the First World War delaying its introduction to Japan, the first boiler was installed at Onoda Cement's Onoda plant in 1920 and it was subsequently widely adopted by plants all over the country.

Using this method allowed 60-70% of the exhaust gas heat to be recovered, making it possible to generate 120-150kWh of electricity per ton of clinker, enough to provide around 90% of the electricity needed for one kiln system, from the raw materials process to the finishing process. Accordingly, plants began shifting away from steam-powered machinery to electric-powered machinery. Despite power shortages during the Pacific War and the time that followed, cement production lacked only for coal; the benefit of waste heat power generation was the capability to continue producing steadily due to being almost self-sufficient for electricity.

However, from the late 1950s at the end of the postwar reconstruction period, ideas began to change regarding rotary kiln heat recovery. Rather than indirectly utilizing waste heat for power generation, it was more cost-effective to lower the exhaust gas temperature as much as possible to increase thermal efficiency. Boilers attached directly to rotary kilns were an impediment to long-term operation, because the high-temperature dust particles in the exhaust gas caused a lot of wear on the boiler pipes. The best option was to ensure long-term rotary kiln operation by discontinuing the use of waste

heat boilers and either purchasing power from external electricity companies or supplying it with efficient generators. Consequently, dry process kilns with attached boilers were gradually phased out with the transition to suspension preheater (SP) kilns from the 1970s onwards. The next chapter (Chapter 5) discusses suspension preheater kiln waste heat recovery in the section on cement manufacturing technology during Japan's postwar economic growth period. Figure 4.2 shows a schematic diagram of a dry process kiln with attached boiler, while Table 4.2 provides an example heat balance.

4.2.3 Wet Process: The Slurry Filter System and the Long Kiln System^{2) 3) 4) 5) 6)}

In 1929, Asano Cement adopted a wet process for manufacturing high-early strength cement at its Nishitama plant in Tokyo. With the technology level at the time, it was easier to mix and grind raw materials in the wet process than in the dry process; the wet process also produced a far better quality product. However, the dry process required less heat for burning, while the wet process consumed 15% more fuel. The wet process also offered little power generation using waste heat boilers and lower clinker burning volume per rotary kiln unit capacity. The wet process kiln was selected for manufacturing high-early strength cement, on the assumption that it could be sold as "high-performance cement" for a higher price than ordinary cement.

"Wet process kilns with attached slurry filters" and "wet process long kilns" attempted to leverage the wet process advantage of "burning good-quality clinker" to surmount the drawbacks of "high fuel consumption" and "poor production capacity".

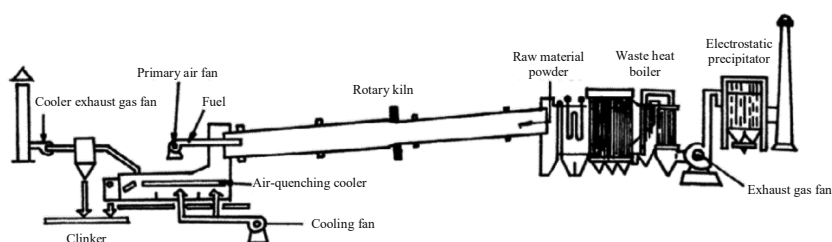


Fig. 4.2 Dry Process Kiln with Attached Boiler³⁾

Table 4.2 Example Heat Balance for a Dry Process Kiln with Attached Boiler³⁾

Kiln size: 3,500φ × 3,200φ × 82,000
Effective capacity (shell capacity): 718m³
Clinker output: 25.5t/d
Specific clinker output: 35.5kg/m³h
Firing heat (low calorific value): 1,517 × 10³kcal/tcl^{*}
Burning efficiency: 29.4%
Boiler heat transfer surface area: 2,063m²
Steam pressure: 23.8kg/cm²
Boiler efficiency: 70%
Turbine efficiency: 20%
Evaporation: 17.5t/h
Power generated: 120kWh/tcl^{*}

Heat balance (low calorific value)		× 10 ³ kcal/tcl [*]	%
Input heat Q ₁	Heat from fuel combustion Q ₂	1517	99.5
	Sensible heat from fuel Q ₃	4	0.3
	Sensible heat from raw materials Q ₄	3	0.2
	Sensible heat from primary air Q ₅	—	—
	Total	1524	100.0
Output heat Q ₂	Heat used for burning clinker Q ₆	449	29.5
	(Sensible heat from clinker entering the cooler) Q ₇	(289)	(19.0)
	Heat escaping in the clinker Q ₈	19	1.2
	Heat escaping in the cooler exhaust Q ₉	26	1.7
	Raw material moisture evaporation heat Q ₁₀	0	0
	Heat escaping in the kiln exhaust gas Q ₁₁	739	48.5
	Dust, emissions, other Q ₁₂	291	19.1
	Total	1524	100.0
Burning efficiency $\frac{Q_6 - c}{Q_2} \times 100$		—	29.4

(1) Wet Process Kiln with Attached Slurry Filter (WFB)

In the wet process, evaporating moisture content consumes around 2,100kJ (500kcal) of heat per 1kg of clinker. To reduce this, a method was devised that used a filter to filter out the moisture content of raw material slurry. Although wet process filters had long been used in mining, they were first adopted by the cement industry in the United States in 1925.

Onoda Cement installed Japan's first wet process rotary kiln with attached slurry filter and waste heat boiler (WFB) at its Fujiwara plant in Mie in 1932, achieving success with the wet process comparable to the dry process in terms of heat used and waste heat power generation. After that, many wet process kilns were installed with filters attached. Records indicate that when Asano Cement changed the existing wet process kiln at its Nishitama plant to one with a filter attached in 1933, the filter reduced the moisture content of the raw materials by up to 20%, thereby reducing fuel costs by 15%, increasing production by 20% and generating 20% more electricity.

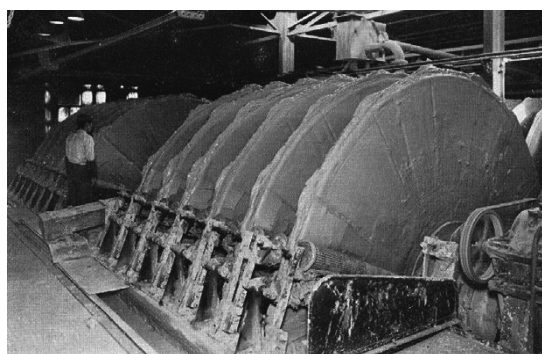


Fig. 4.3 Slurry Filter on a Wet Process Kiln with Attached Boiler ⁷⁾

(2) Wet Process Long Kiln (W)

The simplest method of reducing exhaust gas temperature and increasing thermal efficiency is to make the rotary kiln longer. Many of the kilns in postwar Japan were so-called short kilns, 60-80m in length. Following the installation of a long kiln (135m) by Tokuyama Soda at its Tokuyama plant in 1954, long kilns began to be built in increasing numbers. When a long kiln is used, the raw material slurry is poured directly into the kiln. By the early 1960s, the heat usage had improved to 5,440kJ (1,300kcal) per 1kg of clinker, while exhaust gas temperature had dropped to 160°C. There were also no issues with boilers, since there was no waste heat power generation. The use of slurry simplified the raw materials process and also meant the raw material fed into the kiln was highly consistent. Further, kiln operation without the troublesome boiler made long-term operation possible, making this kiln far more competitive than other types of kiln and earning it the name of "economical long kiln".

Figure 4.4 shows a schematic diagram of a wet process long kiln, while Table 4.3 provides an example heat balance. Figure 4.5 shows a photograph of this type of kiln.

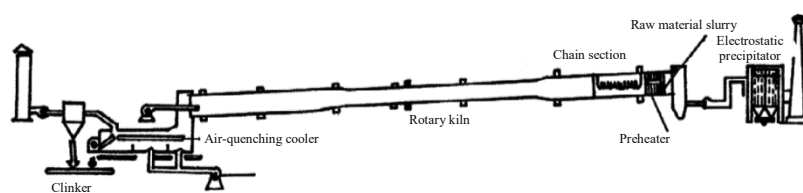


Fig. 4.4 Wet Process Long Kiln ³⁾

Table 4.3 Example Heat Balance for a Wet Process Long Kiln ³⁾

Kiln size: 3,750φ × 3,450φ 3,750φ × 170,000
 Effective capacity (shell capacity): 1730m³
 Clinker output: 30.0t/h
 Specific clinker output: 17.4kg/m³h
 Firing heat (low calorific value): 1,269 × 10³kcal/tcl¹
 Burning efficiency: 33.4%
 Preheater: Smith type
 Chain heat transfer surface area: 1,660m²

Heat balance (low calorific value)		x 10 ³ kcal/tcl ¹	%
Input heat Q _i	Heat from fuel combustion Q _h	1269	98.3
	Sensible heat from fuel Q _h	2	0.2
	Sensible heat from raw materials Q _r	15	1.2
	Sensible heat from primary air Q _a	4	0.3
	Total	1290	100.0
Output heat Q _o	Heat used for firing clinker Q _c	440	34.1
	(Sensible heat from clinker entering the cooler) Q _c	(291)	(22.5)
	Heat escaping in the clinker Q _h	13	1.0
	Heat escaping in the cooler exhaust Q _h	46	3.6
	Raw material moisture evaporation heat Q _h	524	40.6
	Heat escaping in the kiln exhaust gas Q _h	146	11.3
	Dust, emissions, other Q _h	121	9.4
	Total	1290	100.0
Burning efficiency $\frac{Q_{h-c}}{Q_a} \times 100$		—	33.4



Fig. 4.5 Photograph of a Wet Process Long Kiln (Kiln Length 170m) ⁷⁾

4.2.4 Semi-Dry Process: Lepol Kiln (L) ^{2) 3)}

The innovation of the Lepol kiln was the use of a preheater for exhaust gas heat recovery for the first time in history. A preheater is a device that transfers the heat from the kiln exhaust gas to the raw materials by conduction, thus decarbonizing or calcining the limestone. The name comes from the names of the inventor Georg Lellep (Germany) and the plant manufacturer Polysius (Germany).

Lepol kilns (Figure 4.6) have a movable grate (indicated as “preheater” in Figure 4.6) fitted at the end of the kiln (the rotary kiln exhaust gas outlet = raw materials intake). Moisture content of around 14% is added to the raw materials, which are then made into pellets using a pelletizer and spread on the floor of the grate to a thickness of around 20cm. Exhaust gas is drawn through the grate from above and heat exchange takes place as the

gas passes through the layer of raw material. The raw materials fed into the kiln are preheated to over 900°C, while the exhaust gas drops to around 200°C, thereby reducing fuel consumption. The rotary kiln can also be made shorter, to around 10-13 times the diameter. The first Lepol kiln to be erected in Japan was at the Mikawa Cement Tahara plant in 1934. After the war, Lepol kilns became quite widespread throughout Japan, with Iwaki Cement (now Sumitomo Osaka Cement) using Lepol kilns almost exclusively in its new plant in Hamamatsu, Shizuoka, as well as at its plants in Yotsukura (Fukushima), Tochigi and Nanao (Ishikawa). The reason for this was the low heat usage, as low as 4,200kJ/t-cl (1,000kcal/t-cl). However, Lepol kilns had the following drawbacks.

- (1) The raw material (clay) had to have very good granular properties, which placed limitations on the site location and raw material preparation.
- (2) Since the preheater grates operated at high temperatures of 900-1000°C, the larger they were, the more susceptible they were to mechanical breakdown, making it difficult to scale up the size of the kiln (maximum capacity of around 1,200t/d).

Due to reason (2) above, Lepol kilns were phased out of the Japanese cement industry from the 1980s onwards with the rise of large-scale SP and NSP kilns capable of producing over 3,000t/d.

Figure 4.6 shows a schematic diagram of a Lepol kiln, while Table 4.4 provides an example heat balance.

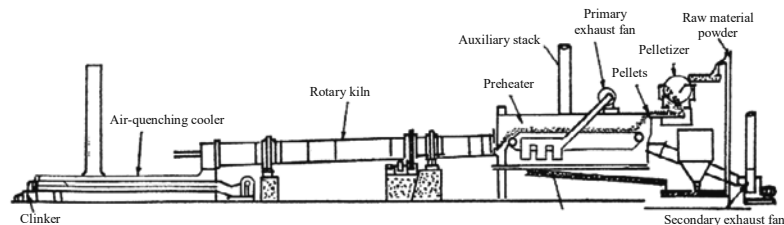


Fig. 4.6 Lepol Kiln ³⁾

Table 4.4 Example Heat Balance for a Lepol Kiln ³⁾

Kiln size: 3,900φ × 70,350
 Effective capacity (shell capacity): 837m³
 Clinker output: 50.2t/h
 Specific clinker output: 60.2kg/m³h
 Firing heat (low calorific value): 884.5 × 10³kcal/tcl¹
 Burning efficiency: 48.1%
 Grate size: 3,804 × 29,252

Heat balance (low calorific value)		× 10 ³ kcal/tcl ¹	%
Input heat Q ₁	Heat from fuel combustion Q ₁	875.6	99.0
	Sensible heat from fuel Q ₂	3.6	0.4
	Sensible heat from raw materials Q ₃	15.3	0.6
	Sensible heat from air bursts Q ₄	—	—
	Total	884.5	100.0
Output heat Q ₂	Heat used for burning clinker Q ₅ (Sensible heat from clinker entering the cooler) Q ₆	426.3 (393.1)	0.6 (38.8)
	Heat escaping in the clinker Q ₇	8.5	0.6
	Heat escaping in the cooler exhaust Q ₈	120.4	13.8
	Raw material moisture evaporation heat Q ₉	134.1	15.2
	Heat escaping in the kiln exhaust gas Q ₁₀	76.3	8.7
	Dust, emissions, other Q ₁₁	126.2	13.6
	Total	884.5	100.0
	Burning efficiency $\frac{Q_{5+6}}{Q_1} \times 100$	—	48.1

4.2.5 New Calcined Lime Burning Process (NCB): The First Domestically-Developed Manufacturing Technology ^{4) 5) 8)}

All of the cement manufacturing methods discussed thus far have involved the “raw limestone burning process” of crushing the limestone in its natural state, mixing it with clay and then feeding it into the kiln. By contrast, the “calcined lime burning process” involves calcining the limestone in advance in a limekiln to produce quicklime, which is then mixed with clay and burned in the kiln. In the conventional cement burning process, around 50% of the heat is used in decarbonizing the limestone. Converting the limestone to quicklime using a more thermally efficient shaft kiln reduces the overall heat usage. Quicklime is also far softer than limestone, thereby reducing the amount of power used for grinding.

Asano Cement patented the calcined lime burning process in 1907 and implemented it at its Moji plant. Records indicate that the process increased the production output without needing to increase the capacity of the rotary kiln and accordingly spread throughout the company’s other plants as well ⁴⁾. However, there were some issues recorded: (1) proportioning of raw materials tended to disperse; (2) calcining the limestone was labor-intensive; and (3) it required coke. Reports indicate that Asano Cement consequently adopted the ordinary limestone burning processes at all of its new plants built from the late 1920s on and abandoned the calcined lime burning process around the late 1940s.

In 1956, the president of Onoda Cement, Toyoroku Andō (with an engineering background) noted the advantages of the calcined lime process, namely, its superior thermal efficiency and increased output, and commissioned his technology team to try to surmount the problems with the process and see it through to practical implementation. In addition to the issues (1), (2) and (3) mentioned above, there was also the issue of (4) the limekilns of the day were too small to be used for mass production of cement.

The technology team searched the literature to successively develop a test plant, a miniature plant and then a small-scale plant and was able to solve the issues, except for the use of coke, as outlined below.

- (1) The team successfully developed the technology for large-scale limekiln (shaft kiln, 350t/d) to support mass production of quicklime.
 - * Successfully achieved “consistent burning in every corner of the shaft kiln”, difficult to achieve in conventional shaft kilns.
 - * From the quality perspective, “uniform calcination” was made possible.
 - * “Automation” introduced to the limekiln operation; processes developed to enable efficient operation by a small workforce.
- (2) The team used an air-blending method (see 4.8) to mix the quicklime powder with the clay powder (Japan’s first “continuous blending”), ensuring

product quality matching that of any other type of kiln.

(Note) In the ordinary kiln process, the limestone and the clay were ground together. In the new calcined lime process, the quicklime and the clay were ground separately and then blended in the proper proportions. It was essential to have equipment that could blend quicklime powder and clay powder as homogeneously as possible.

Natural coke and anthracite were examined in regards to the cited issue of fuel; however, since no steady supply of these could be expected, implementation went ahead using coke as fuel. Figure 4.7 shows a photograph of limekilns used in the new calcined lime process.



Fig. 4.7 Limekilns for the New Calcined Lime Process ⁷⁾

When Onoda Cement converted its existing dry process kilns with attached boilers (DB) to the new calcined lime burning process (NCB), it turned out that the production approximately quadrupled with the same kiln. From 1959 to 1961, Onoda Cement converted a total of ten rotary kilns at its plants in Fujiwara, Tsukumi, Onoda and Ofunato to the NCB process and approximately doubled its cement production in three short years, from 2.7 million tons in 1959 to 5.15 million tons in 1962 (Figure 4.8). This was the result of converting to the NCB process. The company’s shares also rose accordingly, leaping up 3%-points in 1960.

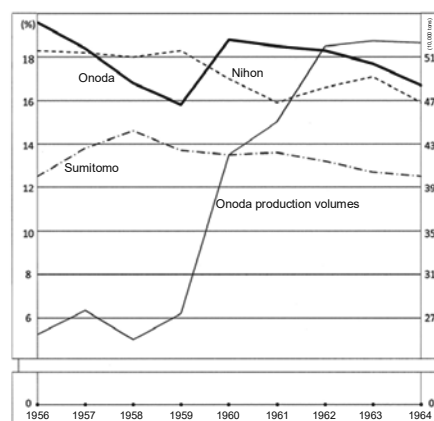


Fig. 4.8 Onoda Cement Production Volumes and Shares Before and After Implementing the New Calcined Lime Burning Process ⁵⁾

However, with trade liberalization in 1961 and the “energy revolution” providing cheap and easy access to fuel oil, companies quickly shifted from coal to fuel oil to fuel their rotary kilns (see 4.9). With this upheaval in the fuel situation, the NCB process using coke-fueled shaft kilns was at a disadvantage to other types of kilns from a fuel cost perspective due to the rising price of coke. Instead of expensive coke, efforts were made to develop technology using oil-fueled limekilns or using pellets made from cheap oil coke (see Note 2) to fuel the limekilns, with limited success. Ultimately, the emergence of the innovative technology of SP and NSP kilns meant the abolition of NCB kilns and other types of kilns by the late 1970s.

The calcined lime process, patented by Asano Cement and developed by Onoda Cement, was the first native Japanese manufacturing technology in the history of the Japanese cement industry, the industry having relied on introduced technology since the Meiji Period (1870s). This is of noteworthy importance, as it paved the way for the various other “native Japanese” cement manufacturing technologies that began to blossom in the 1980s, the NSP kiln in particular. Strong leadership demonstrated by Onoda Cement Co. president Andō has been attributed to somehow making it possible to overcome many financial and technical difficulties faced in the technological development process. This technological development meant that mechanical, electrical and chemical engineers could now be involved at the machinery/equipment design stage rather than just being machinery/equipment users, leading on to further developments in “native Japanese” cement manufacturing technology.

In 1976, Onoda Cement made its engineering department into a separate entity, Onoda Engineering (now Taiheiyo Engineering), with the aim of taking its technology developed since the NCB process marketing it in Japan and overseas. Later, other companies also established similar subsidiary companies.

4.3 Clinker Residual (Sensible) Heat Recovery: Using Air Quenching Coolers^{2) 3)}

Clinker coolers serve two main roles: “heat recovery” from 1200-1300°C red-hot clinker at the kiln outlet and “rapid cooling” of the red-hot clinker. Both functions have a significant impact: “heat recovery” on the amount of fuel used and “rapid cooling” on the quality of the cement.

One reason for the poor thermal efficiency of rotary kilns is the heat loss from the clinker leaving the kiln at a high temperature, as discussed in 4.2.1. Various attempts

were made to effectively recover this residual clinker heat and improve the thermal efficiency of rotary kilns. The planetary cooler and air quenching cooler (AQC) were developed in the United States and introduced to Japan in late 1920s, and both of these coolers made a significant improvements in terms of the amount of heat recovered from the clinker. These coolers were intended to make maximum use of conductive heat transfer between the clinker and the air.

Below is a summary of the development of clinker residual heat recovery technology, or clinker coolers.

4.3.1 The Era of Rotary Kilns and Standalone Coolers

Early rotary kilns did not have coolers for recovering and utilizing the waste heat from clinker cooling, but only had nearby devices for cooling the high temperature clinker coming out of the kiln.

4.3.2 The Era of Rotary Cylinder Coolers (Under-Coolers) Connected in Series

In this cooling system, the high temperature clinker dropped out of the rotary kiln into a rotating, cylindrical cooler fitted underneath the kiln. Air from a blower cooled the clinker through countercurrent heat exchange and was drawn into the kiln as secondary air. Recovering the residual heat in the clinker as secondary air improved thermal efficiency. However, the single cylinder was not sufficient for heat exchange and the clinker was still hot at 300°C after cooling.

Rotary kilns built from around 1916 through to 1926 used this type of cooler, but by the 1960s it had been abandoned. Figure 4.9 shows a typical under-cooler.

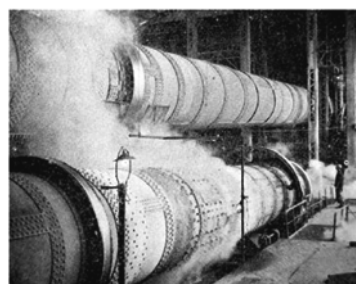


Fig. 4.9 Under-Cooler Fitted Under a Rotary Kiln (Top)²⁾

4.3.3 Multi-Cylinder Coolers (Planetary Coolers)⁹⁾

This cooling system used 10-15 cooling cylinders (1m-2.5mφ, 5mL) attached in a planetary manner around the kiln outlet. The cooler rotated with the kiln; the clinker came into contact with the cool air in the cooling cylinders, with countercurrent heat exchange taking place. Figure 4.10 shows a representative model planetary

cooler: the Unax cooler by FL Smith (Danish plant manufacturer). The photograph shows the Unax cooler attached to a large-scale SP kiln (6m diameter, 100m length, 4,700t/d) built in 1972. A total of ten cylindrical coolers are attached in a planetary manner.

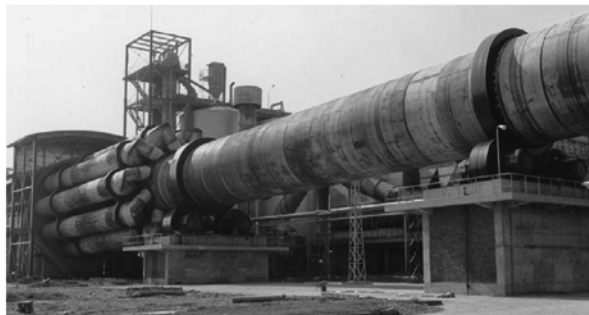


Fig. 4.10 Unax Cooler (Chichibu Cement Kumagaya Plant)
10)

The first of this type of cooler in Japan was a remodeling by Asano Cement of a kiln at its Tokyo plant into a Unax cooler kiln in 1927. Since this type achieved better cooling results than the under-cooler type, most new kilns built from then on (until the 1940s) used planetary coolers. Besides the Unax cooler, other types of planetary cooler included the Corpex type and the Yogyosha type. All of these types of coolers were designed to increase thermal efficiency by increasing the contact area between the clinker and the air. This was achieved by methods such as fitting chains or lifters inside the cooler. These coolers offered the following advantages:

- (1) High thermal efficiency could be achieved.
- (2) The mechanisms were simpler and operation was easier than the air quenching cooler (AQC) system discussed in the following section.
- (3) Since all of the cooled air was utilized as secondary air for kiln burning, there was no need for exhaust gas fans or dust collectors for coolers.

- (4) Low power consumption.

However, the following drawbacks were also identified:

- (1) Having a number of heavy cylinders were attached to the hot part of the main kiln made it prone to thermal and mechanical strain, causing breakdowns.
- (2) Since all of the air was reused as secondary air, the system was susceptible to shortages of air for adequate cooling. If this happened, the clinker tended to cool more gradually, which was not ideal for cement quality. (Section (2) of 7.1.2 Clinker Minerals discusses the relationship between clinker cooling rate and cement quality.)

- (3) The output clinker temperature was 150-200°C, higher than the AQC system.

At the present time, almost all of these coolers have been phased out. The reason for this is that the NSP kilns, which gained prevalence in the 1980s, were designed with further improved thermal efficiency by utilizing the remaining gas as combustion air in the calcining furnace after using it as secondary air in the kiln (see Chapter 5 for details).

4.3.4 Air Quenching Coolers (AQC)s ⁹⁾

This cooling system uses the idea of “crossflow heat transfer”, enabling more efficient heat transfer between the red-hot clinker coming out of the rotary kiln and the cool air (atmosphere). The distinguishing characteristics of this type of cooler are as follows.

- (1) The clinker is cooled by air blown through a grate that moves the clinker. Clinker of around 1300°C drops into the cooler from the rotary kiln and is rapidly cooled as it comes into direct contact with the air at atmospheric temperature. This results in high temperature secondary air, as well as high-quality, rapidly-cooled clinker. The temperature of the clinker coming out of the cooler drops to around 100°C.
- (2) There is more air for cooling than needed for secondary air. There have been various clever uses of the surplus heated air to help reduce the overall heat used for cement production, such as for drying raw materials (in the dry process). The newest type of kiln, the NSP kiln discussed in Chapter 5, has the capacity to utilize this surplus heated air as secondary air for the calcining furnace, thus helping to further improve the thermal efficiency of the NSP kiln.

Air quenching coolers (AQC) were first used in the United States prior to the Second World War. Usage spread throughout the West after the war. While an FL Smith AQC at a Tokuyama Cement plant built in 1928 is regarded as the first use in Japan, usage did not become widespread until 1951, after the Pacific War, when Nihon Cement (formerly Asano Cement, now Taiheiyo Cement) installed a Fuller-type AQC at its Nishitama plant. After that, AQC)s were used in new facilities, while also gradually replacing the existing planetary coolers in existing facilities. By the late 1980s, almost all cement kilns in Japan used AQC)s ¹¹⁾.

There were several different types of AQC)s, named after the respective plant manufacturers that developed them, including the Fuller type (USA), the Allis-Chalmers type (USA) and the FL Smith type, as well as the Japanese Kawaju type (Kawasaki Heavy Industries) and KY type (jointly developed by Yogyosha and Kisha Seizo).

4.3.5 Fuller Type Coolers ^{12) 13)}

The Fuller type was the most suitable AQC for large-scale production. From the 1970s onwards, when SP and NSP kilns were the predominant kilns being built, all kilns were being fitted with this type of cooler. Some kilns built were capable of handling outputs of 8,000-9,000t/day. Figure 4.11 shows a schematic diagram of a Fuller type air quenching cooler.

Ongoing improvements have been made to Fuller type coolers, although the basic design concept has not changed significantly. One drawback with Fuller type coolers is the phenomenon of red-hot clinker flowing down on the floor of the grate, known as the “red river” phenomenon. To prevent this, a number of structural ideas have been developed since the 1990s to ensure long-term, continuous operation and improve heat recovery efficiency by reducing the amount of breakdowns due to grate burnout.

One such idea that has even gained popularity in Japan is the “air beam” type clinker cooler, which has a mechanism fitted to supply cooling air to the grate plate units using a dedicated fan ¹²⁾. The “air beam” system is used from where the clinker drops down to the secondary air recovery area. This has improved the heat recovery efficiency of the conventional system on a couple of percentage points.

There are several different types of air beam systems; by the year 2000, these had been adopted for use on around 32% of kilns. The system is expected to continue to spread in use as existing coolers are updated.

4.4 Trends in Thermal Efficiency Improvement from the Late 1920s to 1960

Table 4.5 shows the changes in overall amount of heat consumption by types of manufacturing process during

this period, focusing on the two main areas of heat recovery, namely “rotary kiln exhaust gas heat utilization” and “cooler exhaust gas heat utilization”, as well as other efforts to reduce the amount of heat used.

4.5 Grinding and Separating (Classifying): Capacity Increase in the Raw Materials Process and Finishing Process

Section 4.2 above discussed how mass production capability was achieved for kilns and coolers, that is, for the burning process. However, in order for the central process of burning to be capable of mass production, the preceding and following raw materials process and finishing process also need to increase in capacity accordingly. The following sections outline the technological developments in crushing, grinding and separating equipment used in the raw materials process and finishing process from the late 1920s to 1960. These sections also provide a detailed discussion on the raw materials process, including raw materials preparation, and the finishing process.

4.5.1 Crushing and Grinding ¹⁵⁾

The operation of crushing is very straightforward. The use of quern-stones for crushing has been depicted in frescoes from Ancient Egypt and Ancient Greece. However, even with the industrial crushing or grinding machines in the modern era of advanced technology, very little of the input energy actually contributes to grinding (breaking down solid matter). With over 95% of the energy supplied is lost, mainly in the form of heat these machines can be termed “energy wasting machines”. On the opposite hand, the “grinding process” can also be termed as an area in which there is a lot of scope for energy conservation.

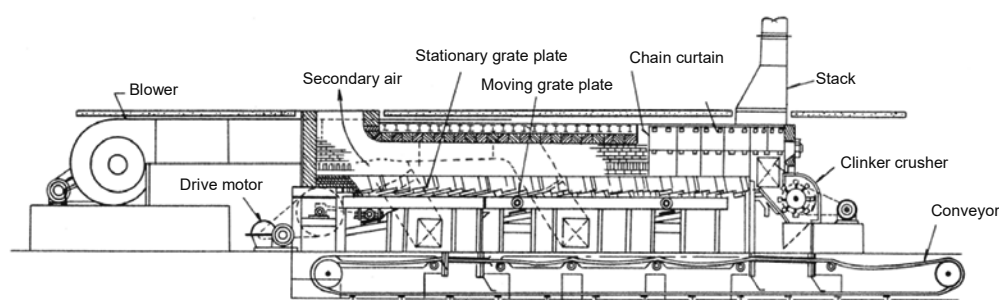


Fig. 4.11 Fuller Type Air Quenching Cooler ¹⁴⁾

Table 4.5 Changes in Heat Consumption by Manufacturing Method ²⁾

(unit 1,000 kcal/t-clinker)									
	Aug-Dec 1940	1951	1952	1953	1954	1955	1956	1957	1958
Dry process	1,891	1,772	1,764	1,738	1,716	1,681	1,652	1,616	1,581
Wet process	2,089	2,041	2,034	1,976	1,941	1,874	1,676	1,819	1,823
	—	—	—	—	—	—	—	1,442	1,400
Lepol	1,300	1,381	1,349	1,377	1,424	1,305	1,080	1,095	1,012
Shaft	—	—	—	—	—	1,327	1,106	1,107	957
Average	1,934	1,839	1,829	1,777	1,748	1,710	1,624	1,547	1,487

(Notes) 1. According to Cement Association survey.

2. For 1955 and 1956, the figures for wet process short kilns included those for long kilns as well.

3. Figures given in () are in fuel oil units, l/t.

Crushing machinery used in the cement industry includes tube (ball) mills and vertical mills (roller mills). Vertical mills are discussed in Chapter 5.

The tube mill was invented in 1892 by Meyer Davidsen (Denmark). The first tube mill used in Japan was imported from Germany by Asano Cement in 1899 and used for grinding raw materials. It was powered by steam (see Figure 3.3), as plants did not shift from steam power to electric power until around 1912 (see 3.5, 4.2.2).

Although it is not known what the first tube mill was like on the inside, the tube mills from the late 1920s onwards were multiple-compartment mills with two to five compartments on the inside, separated by perforated partitions. The first compartments contained larger balls for coarser crushing, while the later compartments contained smaller balls for finer grinding. Many “open circuit” tube mills, mentioned later, had three to five compartments, while many “closed circuit” mills had two compartments.

Figure 4.12 shows (1) the exterior of a tube mill, (2) an interior cross-section and (3) the balls and raw materials.

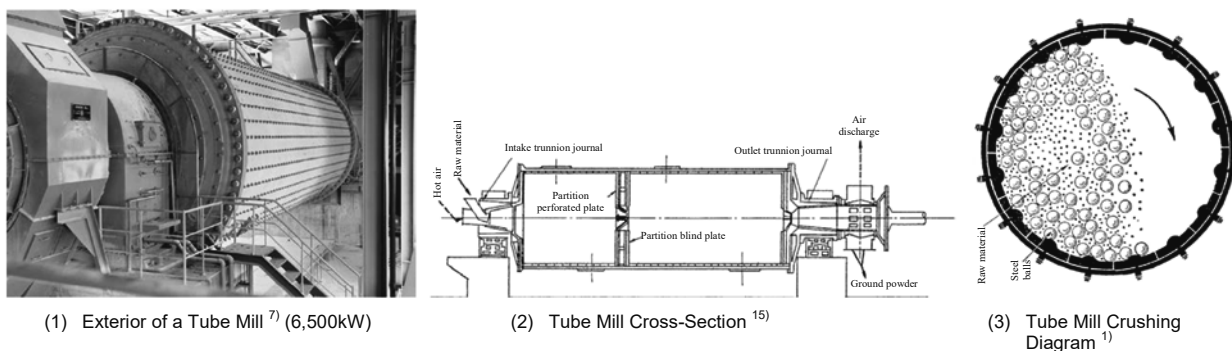


Fig. 4.12 Tube Mill

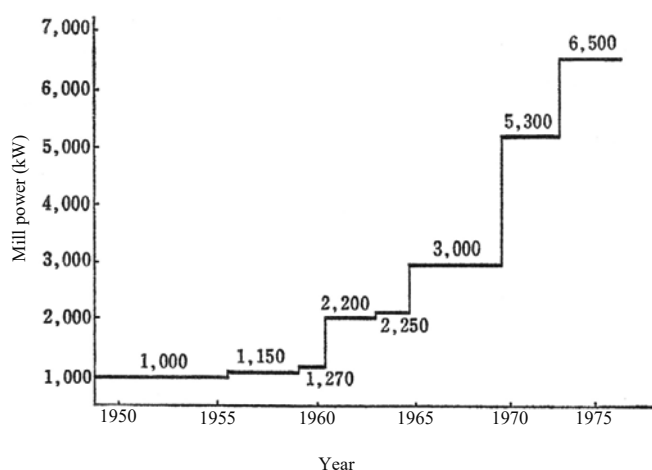


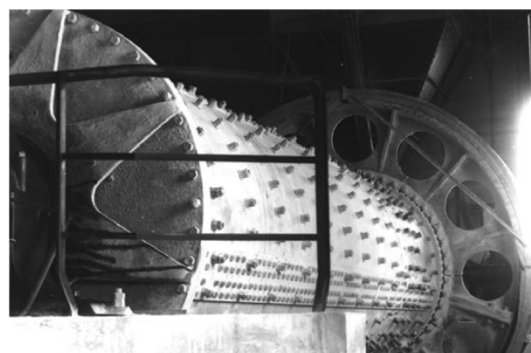
Fig. 4.13 Finishing Mill Power Upscaling Trend ³⁾

The mill in the photograph is a raw materials mill (5.6m diameter, 6,500kW). Finishing mills have essentially the same exterior and interior. The photograph (1) and diagram (2) in Figure 4.12 are from the late 1960s, when mills were being made larger. The mills up until the late 1950s and early 1960s were mostly the same in style, but far smaller in dimension. Figure 4.13 shows the upsizing trend in finishing mills from the mid-1940s onwards after the war, while Figure 4.14 shows photographs of (1) finishing mills installed in 1932 (2.47m diameter, 14m long, 637kW) and (2) a raw materials mill installed in the late 1950s (3m diameter, 10m long, 975kW).

(Note) “Cylpebs” were used as grinding media in the later compartments of tube mills until around the end of the 1960s. Cylpebs were cylindrical pieces of steel 16-25mm in diameter and 16-35mm long. They fell out of use as the use of small, abrasion-resistant balls became more widespread. Since the use of cylpebs had little impact on later technological developments, they are not discussed in detail in this report.



(1) Finishing Mills Installed in 1932 (637kW)



(2) Raw Materials Mill Installed in the Late 1950s (975kW)

Fig. 4.14 Example of Upsizing of Grinding Machinery (Mills) (Compared to Fig. 4.12 (1)) ⁷⁾

4.5.2 Dry Process Grinding (Raw Materials Grinding) ¹⁵⁾

Raw materials grinding methods can be categorized by cement manufacturing method as “wet process grinding” and “dry process grinding”, or by grinding process as “open circuit grinding” and “closed circuit grinding”, as discussed later.

Grinding machinery for dry process grinding include “tube mills” and “vertical mills (roller mills)”. There are two types of tube mills: (1) the “consecutive drying and grinding type” and (2) the “simultaneous drying and grinding type”. Type (1) tube mills have a drier fitted in front of the grinding machinery. All vertical mills used in Japan have been the simultaneous drying and grinding type since they were first imported. Up until the early 1960s, dry process raw material grinding was done on tube mills with driers fitted in front. Chapter 5 discusses “simultaneous drying and grinding mills (air-swept mills)” and “vertical mills”.

4.5.3 Wet Process Grinding (Raw Materials Grinding)

By around 1975, the SP and NSP dry process methods were being used for all cement manufacturing in Japan. Before that, some companies were still using wet process kilns with “wet process grinding”. The raw materials were fed into the tube mill together with water and the resulting slurry, which had around 35% moisture content, was transported by pump.

Wet process grinding has the advantages of good particle dispersion and low power consumption. It also has the benefit of the raw materials being more easily homogenized in later processes. Due to these advantages, the use of Japan’s first wet process kiln in 1929 made it possible for Asano Cement to produce a very high-quality high-early strength cement (see 4.2.3).

However, the rate of wear on the grinding media was far greater compared to the dry process. Even with wet process grinding, it was better in the following processes for the slurry to have as little moisture content as possible. In some cases, calcium lignosulfonate or other chemicals

were used as plasticizers to reduce the water content as much as possible while still being able to be transported by pump.

4.5.4 Finish Grinding ^{3) 10)}

In the Meiji Period (1868-1912), finish grinding was done using a fret mill (Figure. 3.4). Although tube mills were first used by Asano Cement for raw materials grinding in 1899, as mentioned previously, it is not clearly known when tube mills were first used for finish grinding. However, from the circumstances outlined below, it can be assumed that tube mills were adopted for finish grinding soon after they were adopted for raw materials and that they gradually grew more widespread in use throughout the Taisho Period (1912-1926).

Chichibu Cement completed its Chichibu plant and commenced operation in 1925. The finishing mill installed at the new plant was a 7.32m long, 680kW, two-compartment tube mill manufactured by Allis-Chalmers (USA), with a grinding capacity of 7.6t/d. Records indicate that when the company later expanded its facilities in 1927, the expansion included a 13m long, three-compartment FL Smith mill with a grinding capacity of 12.6t/d. It is therefore presumed that tube mills were being used for all finish grinding by the late 1920s.

The finish grinding process at the time appears to have been mostly open circuit. It was not until the late 1950s that closed circuit grinding was widely adopted into the finishing process.

4.6 Separating / Open Circuit Grinding and Closed Circuit Grinding ¹²⁾

“Separating” is the process of using certain characteristic delineating values to separate solid particles that are on a continuous scale of characteristic change. In the cement industry, the delineating value is “particle size”. The device used for separating is called a “separator (classifier)” and is discussed in 4.7 below.

For dry process grinding, “dry process separating” is carried out, using air as the separating medium. For wet process grinding, there has often been no separating process, partly because no coating forms on the surface of the balls inside the mill as they are constantly being bathed in slurry, and partly because there are no suitable wet process separators.

There are two grinding processes: “open circuit grinding”, which involves only the grinding machinery, and “closed circuit grinding”, which involves a combination of grinding machinery and a separator (Figure 4.15).

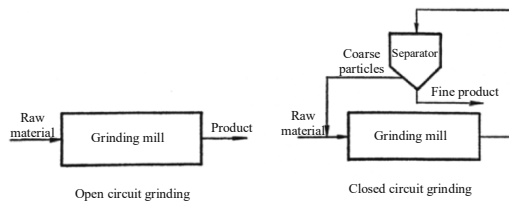


Fig. 4.15 Open Circuit Grinding and Closed Circuit Grinding ³⁾

Open circuit grinding is the simplest method. The raw materials are fed into one side of the mill and the finished product comes out the other side. Consequently, although the facilities are economical, it is difficult to adjust the particle size of the product. By contrast, closed circuit grinding separates the particles after grinding and the coarser particles are sent back to the mill again. While this has advantages, such as allowing a greater degree of freedom in adjusting particle size and increasing grinding capacity and efficiency by preventing over-grinding, the facilities require a greater outlay and more space.

4.7 Separators (Air Separators, Classifiers) ¹⁶⁾

In closed circuit dry process grinding, grinding efficiency and product quality rely heavily on the separating capability of the separator.

The separator is a machine that separates solid particles into different particle groups based on the fact that the balance relationship between the external forces acting on the particles, such as gravity and centrifugal force, and the fluid resistance on the particles as they move through liquid differs according to the size and density of the particles.

Separators used in cement plants are categorized as “air separators” because they use air as the separating medium. Until the invention of the “eddy current separator” in 1979, the following three types of separators were used for the raw materials process and the finishing process. Each of these separators primarily used centrifugal force for separating.

- (1) Gayco air separators
- (2) Sturtevant air separators (single-axle, dual-axle)
- (3) Cyclone air separators

Chapter 5.5.4 discusses eddy current separators.

4.7.1 Gayco and Sturtevant Air Separators

Gayco air separators were first used in Japan in the 1910s, while Sturtevant air separators spread rapidly in use from around 1955. The Gayco separator and single-axle Sturtevant separator were almost exactly the same in their basic structure and operation, with the only difference being the method of feeding in the raw materials. The Gayco separator had a hollow vertical shaft to which the main blades, auxiliary blades and distributor were attached; the raw materials dropped through the shaft to the distributor. In the Sturtevant separator, the raw materials were fed to the distributor through a fixed chute on the outer rim of the central vertical axis, which was not hollow. The single-axle Sturtevant separator was an improved version of the Gayco in terms of separating capability and maintenance.

Figure 4.16 shows a Gayco separator, while Figure 4.17 shows a Sturtevant separator.

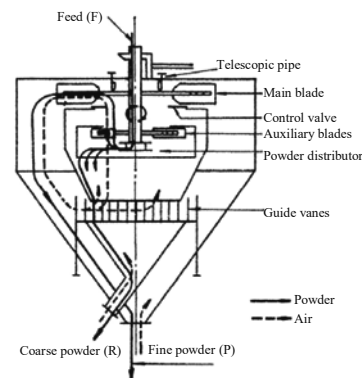


Fig. 4.16 Gayco Separator ¹⁶⁾

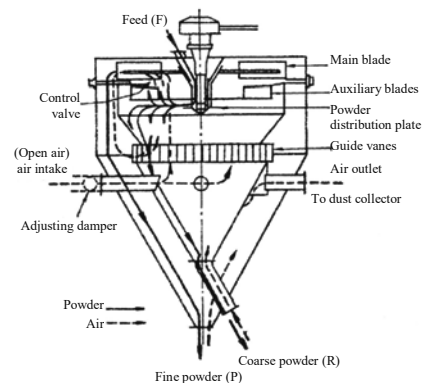


Fig. 4.17 Sturtevant Separator ¹⁶⁾

With the Gayco and single-axle Sturtevant separator, the fineness of the powder could only be adjusted during operation by increasing or decreasing the opening area on the control valve. As a result, if it became impossible to adjust the fineness of the powder by adjusting the control valve, due, for example, to significant variations in raw material grindability, operations would have to stop and measures be taken, such as changing the number of

auxiliary blades. To achieve the necessary powder fineness and separating efficiency, this would sometimes have to be repeated ten or more times, which required considerable time and labor. Increasing the rotation of the main axle to increase the centrifugal force of the auxiliary blades and make the powder finer would actually act to the contrary by increasing the air flow of the main blade attached to the main axle exponentially and thereby increasing the updraft through the guide vanes, thus reducing the effect of increasing the rotation of the main axle.

The dual-axle separator that emerged in 1972 rectified the above flaw with the single-axle separator, allowing the powder fineness to be adjusted by altering the rotation of the auxiliary blades without stopping operation. These were developed in competition to the cyclone separators discussed below, but were not widely used and a detailed discussion is omitted here.

4.7.2 Cyclone Air Separators

Cyclone separators have six to eight cyclones mounted around a central cylinder. Fans are mounted separately and are connected by ducts. The basic separating mechanism is not very different from that of the Gayco and Sturtevant separators.

However, cyclone separators have the fan for circulating air and the electric motor for dispersing powder completely mechanically separate. This makes adjustment during operation much easier and also makes the machines suitable for upscaling. As a result, most new separators built from the late 1960s onwards were cyclone separators, both for the raw materials process and the finishing process.

Figure 4.18 shows a cyclone separator.

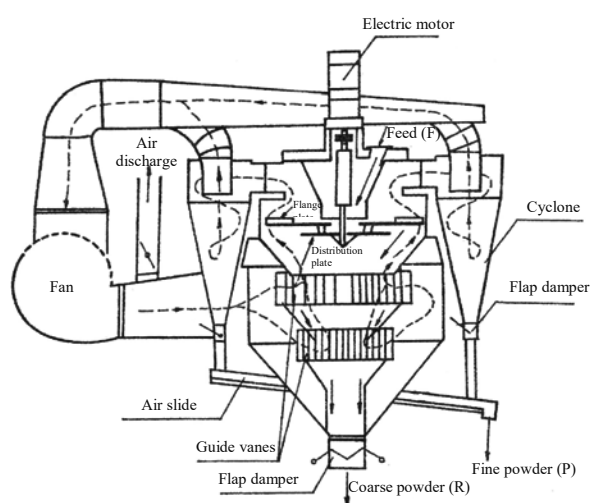


Fig. 4.18 Cyclone Separator ¹⁶⁾

The raw material is fed into the upper chute and is distributed into the circulating ascending air current by the centrifugal force of the distribution plate. The coarse particles are affected more strongly by gravity and centrifugal force and either drop down directly or lose momentum on reaching the side wall and drop down to the internal baffles. The circulating airflow through the guide vanes at the upper and lower levels acts again to lift any fine particles mingled in with the coarse particles back up with the circulating ascending air current, while the coarse particles drop down as coarse powder.

When the fine powder is distributed into the air current, it is lifted up by the ascending air current and subjected to the separating action of the flange plate. Any coarse particles mingled in with the fine particles are affected by the centrifugal force of the flange plate, sending them to the side wall, where they lose momentum and drop down. With the coarse particles separated out, the fine particles are lifted again to the exhaust duct, where cyclones arranged in the direction of the airflow circulation separate them out of the airflow and collect them as fine powder. With the fine particles separated out by the cyclones, the circulating air is directed by the air collection ducts on the upper part of the cyclone through a fan into the central casing and is circulated back through the separator.

Cyclone separators were developed by German plant manufacturer Wedag in 1962. Records indicate that they were first introduced to Japan at the Chichibu Cement (now Taiheiyo Cement) No. 2 plant in 1966.

4.8 Raw Material Mixing and Storing Facilities: The Emergence of Air Blending Silos Led to Prevalence of the Dry Process ^{3) 17)}

Due to significant variation in raw material composition, milled raw material powder (fines) cannot be sent to the kiln as is, even if the feed into the mill is constant. There needs to be blending machinery for the raw material feedstock for the kiln to ensure as little variation as possible.

Using the wet process, a homogenized raw mix can be achieved relatively simply with a slurry tank and slurry basin. By contrast, it is very difficult to achieve a homogenized raw mix with the dry process. For example, even if the milled powder is distributed into small tanks, called mixing tanks, and poured out from three or four tanks at the same time, it is difficult to keep composition consistency within the permissible range.

Consequently, many cement companies used the wet process (see 4.2.3) until the emergence of the “air blending” method, as the wet process was better for large-scale mixing of raw materials.

In 1934, Polysius (Germany) developed “air blending”

machinery, making it possible to achieve homogeneous mixing of dry process raw materials to the same level or better than the wet process. After that, companies transitioned to the dry process, as it used less heat and the process was easy to upscale.

Air blending methods include batch blending and continuous blending. The batch method involves mixing using multiple blending tanks in alternation. When the target composition range is achieved, the powder drops into a storage silo. Powder mixtures that do not qualify are rectified using separately-prepared powder adjustments before dropping into the storage silo. In such cases, the corrective calculations are relatively simple and can be calculated manually.

Meanwhile, continuous blending involves collecting and analyzing the milled powder at regular intervals and calculating the corrective adjustments based on deviation from target values, then resetting the constant feed weigher (CFW) to align with the target values. The continuous method has demonstrated its true capabilities from 1965 onwards, with the development of computer-controlled continuous analysis equipment for raw materials. After that, all blending silos have used the continuous method.

Figure 4.19 shows the basic configuration of an air blending system. The basic structure of an air blending silo is as follows.

- (1) High-pressure air enters the silo through the “diffuser” attached to the base of the silo.
- (2) The powder inside the silo is blown upwards and mixed (aerated).

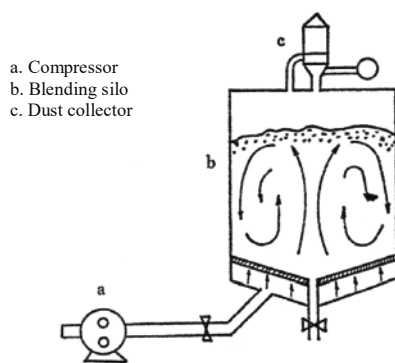


Fig. 4.19 Basic Configuration of an Air Blending System ¹⁷⁾

Several types of blending systems have been devised, with variations in diffuser layout and method of aeration. The first system (batch type) used in Japan was by Aso Cement in 1957, while the first use of a continuous system was by Onoda Cement in 1959.

A typical Fuller (USA) continuous air blending system (Fuller Quadrant Blending) is shown below (Figure 4.20).

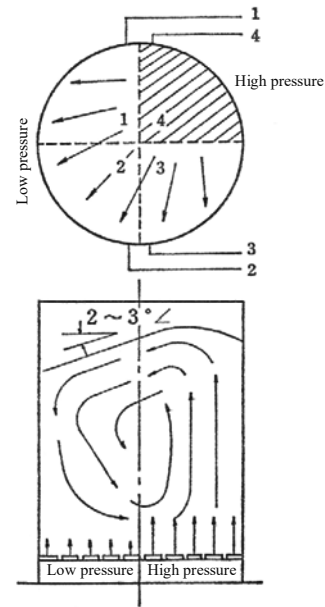


Fig. 4.20 Fuller Air Blending Silo ¹⁷⁾

The base of this silo has a slight incline towards the outlet. The entire base is fitted with aeration units (diffusers). The piping for the aeration units divides the base of the silo into quarters, with each section having its own air supply. This system is used for “cycling”. In other words, once low-pressure air has been sent into the aeration units in one section of the silo to promote aeration, high-pressure air is sent in, while low-pressure air is sent into the other three sections. After a certain amount of time has passed, the high-pressure air changes to the next section, allowing all four sections to be supplied with high-pressure air in turn. In the section being supplied with high-pressure air, the aerated powder lifts up as it increases in capacity and goes above the level of the other three sections being supplied with low-pressure air. The powder in the high-pressure air section then starts to flow into the low-pressure air sections. Due to this cycling action, the powder is repeatedly agitated as it changes height level and shifts in position from left to right and top to bottom. The transition usually takes 10 to 20 minutes; within 40 minutes to 2 hours, the powder has been completely mixed. A device is used to supply the high-pressure air as periodic pulsation rather than at a constant rate.

Air blending silos are another epoch-making technological development in the history of cement manufacturing technology. This equipment has made it possible to achieve “homogeneity of kiln feedstock” with the dry process that is equal to or better than that of the wet process. The wet process lost its dominance in producing “superior homogeneity of raw materials and high quality of cement”. From 1965 onwards, all new kilns built used the dry process, which was better for thermal efficiency and for upscaling. Now, no wet

process kilns are used to manufacture Portland cement in Japan.

4.9 Trends in Fuel: Coal → Fuel Oil → Coal^{2) 4) 5)}

The cement industry is a “fuel-intensive industry”. For around 90 years, the fuel used to manufacture cement in Japan was almost always coal, from the shaft kilns of the 1870s right through to the 1960s. Given the scarcity of Japan’s natural resources, the cement industry has been a rare and valuable industry in that it has been capable of supplying all of its own raw materials and fuel domestically. When coal is used in regular combustion furnaces, there is an issue with disposing of the ash; however, since the coal ash from cement kilns is used as a raw material in cement, there is no problem disposing of the ash, making coal a very convenient fuel source.

With several coal miner strikes in 1951-1952 making coal harder to obtain, the cement industry took an interest in using fuel oil for burning. At the end of 1951, Ube Industries started using fuel oil for burning, with other companies gradually following suit in switching from coal to fuel oil. However, with the deteriorating balance of international payments leading to restrictions on oil consumption in 1955 and the Suez Crisis in 1956, there were growing concerns over the stability of the fuel oil supply. Since fuel oil was also a little more expensive than coal, the fuel oil trend abated for a while. Later, as the demand grew for mass production of cement, the demand for fuel also increased, while trade liberalization caused the cost of oil to drop. As a result, the transition to fuel oil quickened in pace from 1960 onwards.

The 1973 oil crisis threatened the stability of the oil supply and saw the price of fuel oil rise significantly. The 1979 oil crisis in the wake of the Iranian Revolution threatened the oil supply once more and saw prices rise again. The movement back to coal fuel spread rapidly throughout the cement industry. Since the previous coal facilities had already been scrapped and the domestic coal industry had all but disappeared, coal burning resumed using imported coal at new coal facilities that were designed to be safer and more efficient. It is reported that by the end of 1980, less than two short years after the second oil crisis, 72% of the entire industry had transitioned to using coal.

Imported coal has remained the main fuel source for cement burning from that time to the present. Meanwhile, active efforts have been made from the 1980s onwards to use waste products as fuel, including used tires, waste oil, waste plastic, waste wood and even city garbage. Chapter 9 discusses this in more detail.

4.10 The Beginnings of Diversification of the Types of Cement²⁾

Japan’s first Portland cement was produced at the government-managed cement plant in Fukagawa, Tokyo in 1873. This marks the beginning of “ordinary Portland cement” in Japan.

The rest of the Meiji Period through to the 1910s was devoted to making improvements to this Portland cement and to the methods used to manufacture it. Accordingly, there was no product diversification during this time. Product diversification eventually began with the aim of further enhancing the characteristics and functions of “ordinary” cement. Most diversification went in one of the following two directions.

- (1) Achieving the aim through the preparation of the Portland cement, such as by adjusting the chemical composition.
- (2) Achieving the aim by adding other mixtures to the Portland cement (blended cement).

Chapter 8 discusses these diversified types of cement in more detail. This section discusses the course of diversification and differentiation from its origins in the 1910s.

Onoda Cement manufactured Japan’s first “blended cement” in 1900, for building the dock at the Sasebo Naval Station. To make this blended cement chemically resistant, it was blended with volcanic ash at a 3:1 ratio (ratio by weight). This was the original blended cement, aiming to produce the same effect as the slag cement and silica cement that were to emerge later. (Chapter 8 discusses blended cement and the quality improvements made to it.)

In 1913, Yawata Iron Works manufactured “slag cement” blended with blast furnace slag. This was an attempt to effectively utilize the slag produced from blast furnaces in the manufacturing of pig iron. It was also an attempt to improve ordinary Portland cement, as Onoda Cement had done with volcanic ash blended cement.

Onoda Cement began manufacturing “white Portland cement” in 1916, catching the attention of the architectural world. Production of this white cement has continued to the present day, with gradual improvements in quality. Not only is it used for sculptures and cement coatings, it is also completely suitable to be used in structural concrete.

With the applications for concrete increasing and its fields of use expanding in scope from the late 1920s onwards, there was growing demand from customers for cement that could meet different needs. Meanwhile, the cement industry brought out several kinds of new manufacturing facilities in succession, as mentioned previously, and made advancements in chemical research related to cement (details in Chapter 7). The industry grew in its capacity to meet various customer demands and the types of cement began to diversify as a result. In 1929, Asano Cement started manufacturing “high-early

strength Portland cement” and marketed it under the name of “high-performance cement” or “Asano Velo Cement”. Other companies followed suit and began manufacturing similar cement, naming their products as “refined” or “high-performance” cement. All of these were improved products characterized by the early development of high strength.

In 1934, Asano Cement successfully manufactured low-heat and moderate-heat Portland cement and starting marketing these under the name of “Asano Mascon Cement”. With some innovation in the chemical composition of the cement, the product had a low hydration heat rate (see 7.3) and was used for constructing dams and other such projects.

Chapter 8 discusses the diversification of Portland cements in more detail, including the “white cement”, “high-early strength cement” and “moderate-heat cement” mentioned above.

The manufacturing of various different “blended cements” gained traction from the late 1920s onwards. Asano Cement returned to manufacturing blast furnace slag cement, mentioned above, in affiliation with Tsurumi Iron Works (now DC). Around 1935-1937, a number of companies started manufacturing silica cement and marketing it under different names, such as silica cement or silicate cement. As all of these had added chemical resistance, like blast furnace slag cement, they were mainly used for constructing levees.

The Pacific War was a major obstacle to diversification. It became impossible to manufacture high-early strength cement, moderate-heat cement and other high-performance cements due to shortages of good quality coal and other materials needed for manufacturing. Meanwhile, production of blast furnace slag cement and silica cement increased, as these required fewer resources. For a while, production of these cements accounted for one third of all cement production. Cement usage had to be rationalized; low-strength, non-structural cements were also being produced, such as all-purpose cement and plastering cement.

After the war, cement restrictions were lifted in 1950 and freedom of manufacturing and marketing was reinstated, accompanied by a revival of high-early strength cement and moderate-heat cement manufacturing. Since then, advances in cement chemistry and modern manufacturing facilities have enabled the continuing diversification of cement products with different functions. Chapter 8 discusses the modern diversity of cement products in more detail. At the present time, 68% of the cement on the market is “ordinary Portland cement”. Combined with high-early strength, moderate-heat, low-heat and sulfate resistant cement, “all Portland cement” accounts for around 75%, while “blended cement”, including blast furnace slag cement, accounts for around 25% ¹⁸⁾.

4.11 Cement Plant Pollution Issues → Installation of Dust Collectors

With manufacturing machinery at cement plants including crushers, grinding mills, kilns (rotary or shaft) and fans, the inevitable challenge is dealing with dust, particulate matter (see Note 3), noise and other pollution and environmental issues.

4.11.1 Pollution Issues ^{4) 6)}

The first cement company in Japan to incur a serious pollution issue with local residents was Asano Cement’s Fukagawa plant (Tokyo). This is outlined in the following summary of excerpts from *100-Year History of Nihon Cement* ⁴⁾.

Around 1885, residents of Fukagawa voiced their concerns over ash fall from the cement plant. The Superintendent-General of the Metropolitan Police (author’s note: this was Sadakiyo Ōsako until December 1885, then Michitsune Mishima) enlisted Tatsuzō Sone, associate professor at the Imperial College of Engineering and assistant engineer for the Metropolitan Police, to investigate ways to eliminate smoke pollution from the Asano plant. In the end, Saburō Utsunomiya’s (author’s note: see 2.3) assertion that particulate matter is unavoidable and harmless to humans and the persuasive efforts of the authorities on the residents meant no major social issue arose from the Asano plant ash fall at that time. Later, the ash fall was reduced by shaping the raw materials into bricks for feeding into the shaft kiln and the issue appeared to be resolved for the time being.

In 1903, the Fukagawa plant became the first plant in Japan to use a rotary kiln, leading to a major revolution in manufacturing methods. Signs began to appear that the ash fall issue would recur. This was not such an issue when the rotary kiln was first introduced, as at first the ordinary raw limestone burning process was being used. However, as the process transitioned to the calcined lime burning process, the number of rotary kilns in use steadily increased. When production volumes surged, enabled by continuous burning, the amount of ash being dispersed outside of plant sites also increased.

The issue resurfaced around 1907. The Fukagawa Youth Association was formed in the vicinity of the plant, lodging petitions to the authorities and staging protests against the company. The antagonism between the company and the residents grew volatile around 1910-1911. With mediation from the authorities, the company promised the residents in March 1911 that it would close the Fukagawa plant within five years (by the end of 1916). Substitute land was selected in Kawasaki, but although fast progress was made on the construction of the new facility, the outbreak of the First World War made it difficult to obtain materials and caused delays in the delivery of the machinery that had been ordered. With consent from the residents, the timeframe for closing the Fukagawa plant was extended for one more year.

Despite the acceptance of the one-year extension, the closure of the Fukagawa plant was inevitable. However, as luck would have it, news arrived at that exact time that the Cottrell electrostatic precipitator had been a success in the United States. The Cottrell electrostatic precipitation method was a method devised by American chemist Fredrick Gardner Cottrell of applying a principle invented in Germany in 1824 to a plant facility.

In 1916, Asano Cement decided to directly purchase the patent rights and all of the machinery from the United States. The precipitator machinery arrived in 1917 and the installation was completed with some round-the-clock work under the supervision of American engineers. By the end of the year, four rotary kilns were confirmed to have fully functioning dust collectors. The Fukagawa Youth Association and resident representatives met with the company president and other company executives and agreed that the precipitators were extremely effective. They finally withdrew their appeal to close the plant. The Fukagawa plant ash fall issue was resolved amicably.

The above is a summary of a passage on the Fukagawa plant ash fall issue in *100-Year History of Nihon Cement*. This incident was the first introduction of a Cottrell dust collector (see 4.11.3) at a cement plant in Japan. After that, the use of electrostatic precipitators at cement plants spread throughout the country. Records indicate that the first use of a Cottrell device by Onoda Cement was at the Atetsu plant in Okayama in 1933 and the first use by Iwaki Cement (now Sumitomo Osaka Cement) was at the Yotsukura plant in Fukushima in 1927, while Chichibu Cement began using it in 1925.

4.11.2 Establishing and Tightening Environmental Laws and Regulations

Up until around the mid-1960s, cement plant environmental and pollution issues were mainly tangible, such as particulate matter, dust and noise. Policies for this “pollution” involved reducing or suppressing the contaminant, such as through the use of dust collectors and soundproofing. Most plants carried out operations without any major issues with local residents. However, this does not mean that cement plants were emitting zero particulate matter, dust or noise, but rather that the sight of the roofs of neighboring houses white from years of dust buildup was “the usual view”. Local residents resigned themselves to the sight as “unavoidable, because the plant provides jobs”. Japan’s first law on air pollution was the *Act Concerning Regulation of Soot and Smoke Emissions* (or the *Smoke and Soot Regulation Law*), enacted in 1962. Before that, situations such as the one described above were not in violation of the law.

The *Air Pollution Control Act* was created in 1968 and underwent significant amendment in 1970 at the 64th Diet

session, otherwise known as the “Pollution Diet”, along with the creation of the *Noise Regulation Act*. Cement plants had to take strict pollution control measures. Through these laws and later amendments, people began to understand “environmental regulation” in the broadest legal sense, that it covers more than tangible pollution and includes nitrogen oxide emissions, sulfur oxide emissions and heavy metals in the cement. These are discussed in Chapter 6.

Below is a brief discussion of the two main dust collectors used at cement plants.

4.11.3 Electrostatic Precipitators ¹⁹⁾

Typified by the Cottrell precipitator (Figure 4.21) mentioned previously, there are several different models of electrostatic precipitator from different manufacturers, but the fundamental principle is the same.

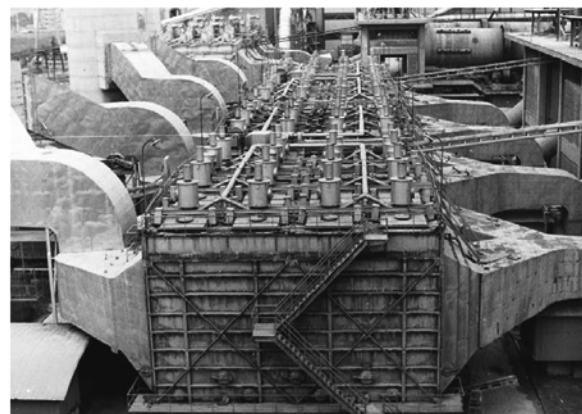


Fig. 4.21 Cottrell Precipitator ⁷⁾

The underlying principle for electrostatic precipitators is to pass exhaust gas through an electrical field that is generated between a discharge electrode and a dust collecting electrode. Negative ions generated by a cathode corona adhere to and electrify particles in the exhaust gas. The electrified particles are separated and collected at the dust collecting electrode through the effect of the electrical field.

The main advantages of electrostatic precipitators include: (1) high dust collection rate (over 90%); (2) low pressure loss (10-20mmAq); (3) low power consumption; (4) ease of maintenance; and (5) ability to handle hot gas. Disadvantages include: (1) high setup costs; (2) large facility footprint; and (3) depending on its composition, exhaust gas can cause corrosion or impede dust collection performance. Given these advantages and disadvantages, these precipitators have mainly been used for processing exhaust gas from kilns and clinker coolers used in the main burning process at cement plants. However, mainly due to disadvantage (3) above, the use of bag filters has become more widespread for processing kiln exhaust gas

since the 2000s.

4.11.4 Bag Filters¹⁹⁾

Besides electrostatic precipitators, bag filters are also widely used for dust collectors at cement plants. The underlying principle for bag filters is the same as for the bag filters used in household vacuum cleaners. Although they can be used at smaller facilities, are suitable for directed dust collection and have high dust collection efficiency, they cannot be used for high-temperature or high-humidity gas due to the fiber bag used. They have mainly been used for collecting dust from crushing and grinding systems and transporting systems.

In the 2000s, large quantities of different kinds of recycled resources began to be used for fuel and raw materials. For the conventional electrostatic (Cottrell) precipitators used in cement kiln exhaust gas processing, this caused operating instability, deterioration and other problems. Meanwhile, advances in burning technology and waste heat utilization lowered the temperature of kiln exhaust gas and made it more stable, while advances in heat-resistant fibers improved the heat resistance of bag filters. Accordingly, bag filters began to be used for kiln exhaust gas dust collectors as well (see 6.1.3).

4.12 Trends in Cement Delivery Format: Barrels → Bags → Bulk → Cement Distribution Revolution^{4) 5) 10)}

In the early days of the cement industry in the late 1800s and early 1900s, all cement was freighted from factories in barrels. Jute sacks began to be used from the 1910s, followed by paper sacks from the mid-1920s. Barrels and jute sacks were no longer used by around 1940.

The Meiji-era barreled cement was mainly delivered to customers by wagon or boat. While trucks and railroads replaced wagons in the 1910s and jute and paper sacks replaced barrels, the delivery method of “transporting packaged cement” changed very little for around 80 years, until the mid-1950s.

In 1936, Ube Industries started transporting cement in bulk, using Japan’s first cement tanker (a special ship with facilities for loading and unloading bulk cement). Transporting in bulk means transporting the cement powder without packing it in bags or other containers. However, there was no major shift to bulk transportation in the overall industry for another 20 years. It was not until around 1954 that companies started rapidly adopting bulk transportation of cement by railcar, truck or ship. At the present time, 97% of all cement transported from cement plants is transported in bulk.

The following sections discuss the trends in cement delivery format and the significant impact of bulk transportation on the overall cement industry.

4.12.1 From Barrels to Jute Sacks

The idea of using barrels as product packaging in the early days of the cement industry was imported from the West along with cement manufacturing technology. Traditional Japanese barrels come in the form of a bucket and lid, such as those still used today for sake, miso and soy sauce. By contrast, the barrels used for cement were “Western style” barrels (the same as those used for whiskey and beer, see Figure 2.10). Consequently, the early barrels were made by bucket makers. They were made from slats of Japanese cedar encircled with bamboo rings and were filled with cement by hand. Records from Onoda Cement indicate that a barrel-making machine was introduced in 1894, a decade after the industry began, and that barrel-filling machinery was being used by around 1897 at the latest. The unit of weight used for cement trading was set as the “pound” at government-administered plants in 1880.

When Onoda Cement and Asano Cement were established (1883), one barrel was 400 pounds (181 kg). In January 1901, the weight of one barrel was standardized across the industry as 380 pounds (172 kg). However, since it was transported by wagon or by foot, it was also sold in half-barrels and quarter-barrels, depending on the needs of the customer. Although the wooden barrels were sealed and could also conveniently be transported by rolling, there were some challenges with them, such as if the wood had not been properly dried, it could shrink and allow the contents to leak out, or if large numbers of barrels were needed, it was difficult to prepare the timber.

In 1898, Onoda Cement trialed Japan’s first transportation of cement in jute sacks (152 pounds; 69 kg). The sacks were not standardized and were mostly reused sugar, fertilizer or flour sacks. Transportation in sacks progressed no further than being a secondary usage until the 1910s. In 1911, the company standardized a “one-third sack” (127 pounds or 58 kg was one-third of a barrel). After that, jute sacks of this size began to be more widely used.

Jute sacks expanded in use in 1914, as the soaring price of timber from the outbreak of the First World War made it difficult to manufacture barrels. In 1921, there were two sizes of jute cement sacks, 127 pounds (58 kg) and 95 pounds (quarter-barrel, 43 kg). The metric system was adopted in 1924, with the cement industry defining the net weight of one jute sack as 50 kg and one barrel as 170 kg.

4.12.2 From Barrels and Jute Sacks to Paper Sacks

Although it was standard practice to retrieve barrels and jute sacks from customers after use, this of course cost time and money. Consequently, cement companies started using “throwaway” paper sacks from around 1926-1927.

The first company in Japan to use paper sacks is thought to have been Chichibu Cement when it began operations in 1925. When the company ordered a paper sack filling machine from the United States for a new plant, the order came with 4,000 paper sacks. These sacks were made from four layers of kraft paper; this type was used until the late 1930s¹⁰⁾. Accordingly, paper sack filling machines (packers) have been used for packaging cement into paper sacks (bagging) since the use of paper sacks was first introduced. The operator loads the cement into the packer and the cement fills the sack automatically. When the bag reaches the designated weight, the cement feed stops automatically and the sack drops onto a transporting conveyor (Figure 4.22).



Fig. 4.22 Paper Sack Filling Machine (Packer)⁷⁾

The net weight of a paper cement sack remained at 50 kg for the first 50 years. This was later changed due to demand from the plastering industry and other users, down to 40 kg in 1971 and down again to 25 kg in 1996.

During the three decades from the adoption of paper sacks in the late 1920s to the widespread adoption of bulk transportation, discussed below, more than 90% of all cement orders from plants were delivered in paper sacks. While paper sacks are still used for transporting cement today, the amount of cement sold in paper sacks is now as little as 3% of all cement.

4.12.3 From Paper Sacks to Bulk Cement: “Distribution Revolution” in the Cement Industry

In the late 1950s, the delivery of cement from cement plants suddenly changed from paper sacks to

transportation in bulk. This transition to bulk transportation in the delivery and distribution of cement was more than just a change in delivery format. It was a major revolution in cement distribution and a significant factor in reforming the structure of the entire cement industry (details in Chapter 5).

The three main reasons cement companies were drawn to bulk transportation are as follows.

- (1) Cement companies working to reduce their transportation costs
- (2) Increasingly widespread use of ready-mixed concrete (see Note 4) at construction sites
- (3) Growth of the concrete products industry

Since reducing transportation costs by transporting cement in bulk was an advantage for the customer as well, customers rapidly adopted bulk transportation and actively began to improve their facilities and take other steps to handle bulk cement.

(1) Bulk Transportation to Reduce Transportation Costs²⁾

As a product, cement has the distinguishing characteristics of (1) being heavy and bulky, (2) not lasting long in storage and (3) having a poor value-to-effort rate. Since most cement plants in Japan are located near sources of raw materials, transporting cement to metropolitan areas where it is needed can be quite costly. As a result, the cost of distribution makes up a large proportion of the sales price of cement. It has been a significant challenge for cement companies to try to reduce transportation costs by devising improved and more rationalized means and methods of transportation.

Before the war, railcar and ship each accounted for 40% of cement transportation, with the remaining 20% carried by truck or other modes of transport. However, with a shortage of ships after the war making ship transportation more expensive, there was a rapid increase in the amount of cement transported by freight car. By 1945, 63% was transported by railroad, 20% by ship and 17% by other means. In 1952-1953, during the Korean War, there was a rapid increase in freight transportation due to a rise in domestic industry, putting pressure on land and sea transport. The economic boom in 1957 led to further difficulties with transportation. Rising rail freight prices led to a surge in sea freight prices, resulting in a very poor transportation situation.

The bulk cement transportation system emerged to break this deadlock. Cement companies streamlined transportation by setting up their own bulk transportation facilities and managing their own cement transportation.

The bulk cement distribution channels were as follows:

- (1) Coastal cement plants

Cement plant → cement tanker → service station (SS) → bulk truck → customer (ready-mixed concrete plant, concrete products plant, dam or other major construction site)

(2) Inland cement plants

Cement plant → bulk truck → customer

Many coastal cement plants were in areas of Hokkaido, Chugoku, Shikoku and Kyushu that were far away from major cities. Cement was initially transported by tanker ship to service stations (SS) in major consumer areas in the Tokyo, Nagoya and Kansai regions. By contrast, many inland cement plants were located near major consumer areas and the cement was often transported directly from the plant to the customer by bulk transportation truck. The distribution for cement powder came to be similar to that of liquid petroleum products. Figure 4.23 shows a bulk transportation truck being loaded with cement.



Fig. 4.23 Cement Being Loaded onto a Bulk Transportation Truck ⁷⁾

The main outcomes achieved by rationalizing cement distribution through bulk transportation are as follows.

(1) Transportation mobility

Bulk transportation allows all handling to be mechanized, taking far less time than loading and unloading packaged product. Loading and unloading can also be done in the rain without any problem. Since the ships, railcars and trucks are all owned or operated by the company, transportation can be very flexible.

(1) Reduced transportation costs

With simpler and faster handling as mentioned above, the handling costs are also cheaper. There is also far less product loss during transportation than with packaged product. A relative drop in the cost of sea transport compared to land transport (railcar, truck) has meant that remote coastal plants can compete fairly with inland plants in suburban areas.

(2) Widespread Use of Ready-Mixed Concrete at Construction Sites ⁴⁾

Regardless of the advantages given in (1) above, the “packaged product” handling and distribution format changed very little in the first 80 years of Japan’s cement industry because of the concrete construction method of “mixing concrete at the construction site”, that is, “mixing cement, gravel, sand and water on site” did not change.

The major change to this situation came with the introduction and popularization of ready-mixed concrete. The concrete was not mixed at the construction site, but measured and combined at the ready-mixed concrete plant and then mixed in the truck (concrete mixer truck) while being transported to the site. Thus began a dramatic change in concrete construction, with the fluid concrete only poured into the formwork at the construction site.

While the use of ready-mixed concrete had spread throughout the United States before the Second World War, the first ready-mixed concrete plant in Japan was built in 1949 at Narihira-bashi, Tokyo, by Tokyo Concrete (a subsidiary of Iwaki Cement, now Sumitomo Osaka Cement) ²⁰⁾. It became more widely used over the next while, mainly in urban areas, until around 1961, when the number of ready-mixed concrete plants rapidly increased. In 1967, there were 1,067 plants in the country; five years later in 1972, there were 2,936. Five years after that in 1977, there were 4,808, increasing nearly five times over in ten years and spreading right throughout the country.

Almost all cement delivered to ready-mixed concrete plants was transported by truck in bulk.

(3) Growth of the Concrete Products Industry

Concrete products produced at plants today are used in every corner of society. While some of this diverse range of concrete products took shape in the West and have been produced in Japan since before the war, the proliferation of concrete products we see today did not come about until after the Pacific War. The range of demand grew during postwar reconstruction, while the economic boom from the late 1950s ushered in an era of expansion in every direction in the concrete products industry, from highways and the bullet train to sewerage development and apartment buildings.

Up until the early 1950s, concrete products plants were small in scale and had cement transported in sacks. From the late 1950s onwards, it was transported by trucks in bulk.

(4) Summary of the Transition to Bulk Transportation

From the postwar reconstruction period to the economic boom, cement transitioned to bulk transportation due to three phenomena occurring almost simultaneously, as mentioned above: (1) a shift to bulk transportation handling and distribution facilities to reduce transportation costs; (2) advances in ready-mixed concrete; and (3) growth of the concrete products industry. In 1951, the amount of cement transported in bulk accounted for 6% of all cement transported. Seven years later in 1958, this figure had risen to 25%. By around 1980, over 90% of all cement was transported in bulk. Today, 97% of all cement transported from cement plants is transported in bulk.

Although it goes without saying that the economic benefit was the greatest incentive for the bulk cement transportation system mentioned above, it must also be remembered that it was undergirded by technological advances in transportation and storage facilities to be able to transport powder in bulk. However, many of these facilities and devices lay beyond the walls of cement plants, shown in Figure 1.3, and many were used in other powder industries as well. Accordingly, detailed descriptions have been left out of this report, which focuses on “cement manufacturing technologies in cement plants”.

As at 2013, around 72% of cement orders are for ready-mixed concrete and around 13% are for concrete products, with the remaining 15% going to other uses¹⁸⁾.

Note 1: Primary and secondary air

The air that is blown into the kiln from the burner together with the fuel is called primary air, while the air that travels into the kiln from other vents than the burner to supplement primary air is called secondary air. In cement burning, secondary air is the air used to cool the hot clinker in the cooler.

Note 2: Oil (Petroleum) Coke

A solid residue of mostly carbon, obtained by pyrolysis of vacuum residual oil or other heavy petroleum oil in a coker.

Note 3: Dust and particulate matter

Defined as follows in the *Air Pollution Control Act*.

Dust: Soot and dust generated by the combustion of fuel or by the use of electricity as a heat source (in other words, soot).
Particulate matter: any substance generated or dispersed as a result of crushing or sorting materials or any other mechanical process, or as a result of the accumulation of such materials.

Note 4: Ready-mixed concrete

Concrete with cement, gravel, sand and water measured and mixed but not yet set. Also called fresh concrete. Plants that manufacture ready-mixed concrete are called “ready-mixed concrete plants”, while the trucks that transport the concrete from the plant to the construction site are called “ready-mixed concrete trucks” or “mixer trucks”.

Note 5: Concrete products

Concrete products are products made of concrete that are cast or produced at a plant and transported to the construction site, rather than being poured into formwork at the site. There are various different kinds of concrete products, including U-channel blocks, blocks for walls, paving blocks, concrete walls for homes and other buildings, sewer pipes, utility poles, river revetments, road and rail bridge girders and tunnel walls.

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5 | The Development of Japanese Cement Manufacturing Technology (1960-)^{1) 2) 3) 4)}

For the two decades from the early 1960s to around 1980s, the Japanese economy maintained its rapid growth, rebounding from the two oil crises that took place during that time. In 1960, cement production volumes were around 22 million tons. By 1979, they had reached an unprecedented peak of around 88 million tons (83 million tons for the domestic market). Although the demand for cement later dropped off as the Japanese economy went into a period of low growth, the Great Hanshin Earthquake of 1995 and exports to Asia prompted a temporary rise in the market. In 1996, production volumes reached just less than 100 million tons (82.4 million tons domestic). However, the downward trend continued after that, with volumes dropping to 61 million tons (45 million tons domestic) by 2014, around 60% of the 1996 figure, despite some demand for rebuilding after the 2011 Tōhoku Earthquake. Figure 5.1 shows the trends in domestic cement demand.

With the cement industry trending from high growth → low growth → shrinking market, the following development trends were observed in cement manufacturing technology.

- (1) Ongoing enlargement of manufacturing facilities during high growth
- (2) Focused efforts on energy-saving technology to reduce costs during low growth
- (3) Focus for technology development shifted to contributing to a resource-recycling society in the face of a shrinking market

The trends in cement-related technology from the 1960s onwards can be broadly categorized as follows.

- (1) Upscaling of cement kilns
As kilns grew in size, the machinery and equipment for the raw materials process, the finishing process and the shipping process also had to grow in size. Since upscaling required significant investment, “priority investment plants” were selected in terms of the size of limestone deposits and access to major cement markets.
- (2) In the process of upscaling, the superiority of the suspension preheater kiln (SP kiln) over dry process kilns with attached boilers, wet process kilns, Lepol kilns and other existing types became apparent.
- (3) Following on from (2) above, development began on the new suspension preheater kiln (NSP) as an improvement to the SP kiln. The NSP method was established as world-leading Japanese cement manufacturing technology.
- (4) Following the two oil crises of the 1970s, the goal was to conserve energy with all machinery and equipment at cement plants. The superiority of NSP kilns and vertical mills became apparent, while Japan technology continued to contribute to major energy savings in grinding machinery with eddy current separators (such as the O-SEPA), vertical mill pre-crushers (such as the CKP) and vertical cement mills (such as the OK mill). Waste heat power generation also became widespread, using up as much heat as possible from kilns and coolers. As a result, the Japanese cement industry ranked top in the world for energy conservation.

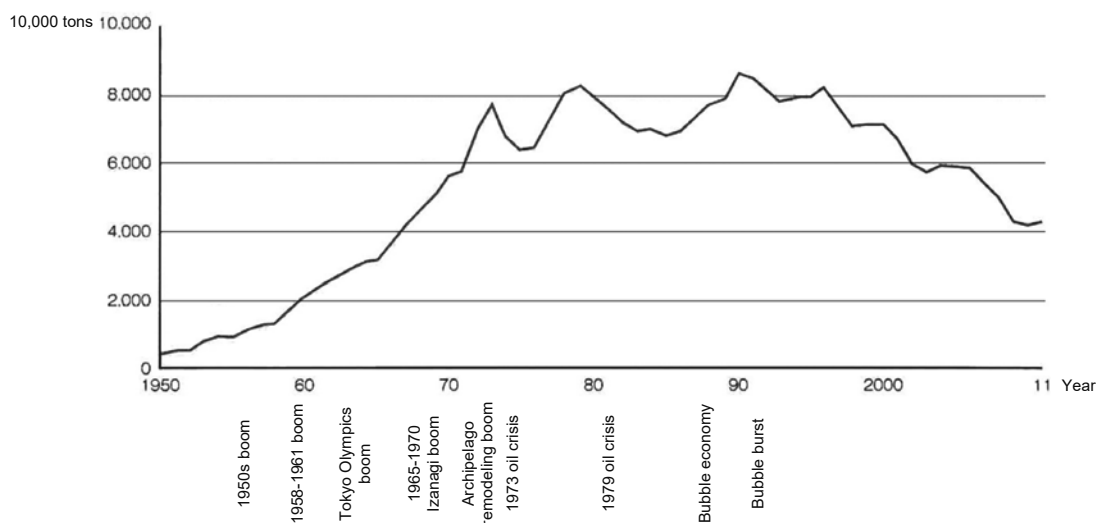


Fig. 5.1 Trends in Domestic Cement Demand (1950-2011)¹⁾

- (5) Throughout the entire course of (1) to (4) above, developments were being made in computerized control of processes. This made processes more stable and improved product quality.
- (6) Environmental regulations were enacted in the 1970s and the cement industry had to comply with strict enforcement. Full use of existing technology and new technological developments made it possible to meet the strict controls.
- (7) Global warming became a topic of attention from the 1990s onwards. Since the cement industry caused carbon dioxide emissions by burning fuel and decarbonizing limestone, efforts were made internationally to research countermeasures.
- (8) From the 1960s onwards, major advances have been made in instrument analyzers, electron microscopes and X-ray analyzers. This has made it possible to know about the minerals and hydrates in cement in much more detail. Based on this knowledge, successive “functional” cements have been developed.
- (9) Amidst efforts towards conservation of energy and resources to preserve the global environment, ideas have come forward about new initiatives for using waste materials in cement manufacturing.
- (10) With the demand for cement dropping since the late 1990s, ventures for disposing of industrial and municipal waste have provided a significant income source. In order to expand their waste recycling operations, developers have gone for technology that can dispose of even more waste in the cement manufacturing process. Successive new ideas have been implemented, including eco-cement, chlorine bypass systems and the AK system (all discussed in detail in Chapter 9).

The above has provided an outline of developments in Japanese cement manufacturing technology over the past half-century since the 1960s. Items (1) to (5) above are discussed in this chapter. Chapter 6 provides a more detailed discussion of (6) and (7); (8) is discussed in Chapters 7 and 8, while Chapter 9 discusses (9) and (10).

5.1 Suspension Preheater Kilns (SP Kilns) ^{1) 5) 6)}

The two decades from the 1960s to the 1980s were a time of constantly-increasing domestic demand for cement, as well as increasingly stricter enforcement of environmental regulations. In this business environment, cement kilns had to: (1) have good thermal efficiency; (2) have greater kiln output; (3) be capable of long-term stable operation; (4) produce high quality clinker; and (5) have a low pollution factor.

SP kilns and the improved NSP kilns, discussed later, proved to be superior to conventional kilns in these

aspects. Daiichi Cement (now DC in Kawasaki, Kanagawa) started operating Japan’s first SP kiln in 1963. From then until the development of the NSP kiln in the mid-1970s, most new kilns built were SP kilns.

Table 5.1 shows the heat consumption, output per capacity and maximum capacity for the different types of kilns in use in 1975.

Table 5.1 Heat Consumption, Output per Capacity and Maximum Capacity by Kiln Type ⁵⁾

Kiln Type		Heat consumption (Hr) kcal/kgcl ¹	Output per Capacity kg/m ³ -h	Maximum Capacity t/D
Dry	Attached boiler (DB)	1,520	38.8	3,300
	Lepol (L)	850	63.0	2,800
	Shaft (S)	890	125.4	260
	New calcined lime burning process (NCB)	450	167.6	2,600
	Suspension preheater (SP)	760	64.4	5,300
	New suspension preheater (NSP)	710	141.0	8,000
Wet	Attached filter and boiler (WFB)	1,520	35.4	740
	Attached filter (WF)	1,390	23.7	860
	Long (W)	1,240	22.9	2,200
	Lepol (WFL)	920	48.7	850

Note 1) The “heat consumption” column shows kilocalories of heat per kilogram of clinker (kgcl¹ = kg-clinker).

“Output per capacity” represents the clinker output per hour per cubic meter of kiln capacity.

Note 2) “Heat consumption” only refers to “burning heat blown into the rotary kiln”.

To compare NCB (new calcined lime burning process) with other methods, the limekiln heat (around 550 kcal/kgcl¹) must be added.

The SP kiln was developed by German plant manufacturer Humboldt in 1950 to (1) achieve heat exchange by suspending powdered raw materials in kiln exhaust gas and to (2) preheat and decarbonize raw materials using residual heat in exhaust gas, thereby (3) gaining greater thermal efficiency than other conventional kiln types. Later, Polysius, Wedag, Krupp (all Germany), FL Smith (Denmark) and other companies announced their own SP kilns, each with different designs but the same basic principle. Figure 5.2 shows a structural diagram of a typical SP kiln and the later improved NSP kiln (details in 5.2).

The SP system was superior to conventional kiln systems in three main aspects: better thermal efficiency, capability for upscaling and capability for long-term continuous operation. These features are discussed below.

5.1.1 SP Kiln Features ^{1) 2) 3) 5) 6)}

(1) Good Thermal Efficiency

The key to good thermal efficiency (see “Heat Consumption” column in Table 5.1) is the “suspension preheater”, an innovative mechanism for exchanging heat between the hot gas and the raw material.

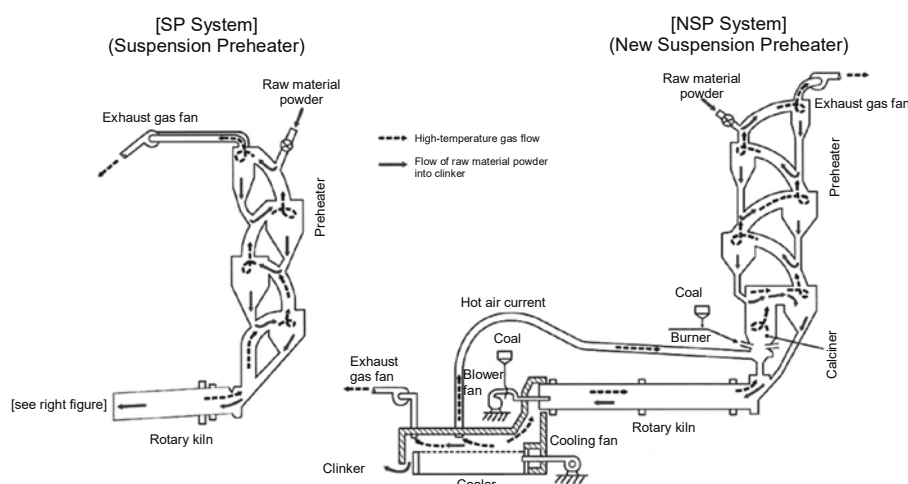


Fig. 5.2 Comparative Structures of SP and NSP Systems ¹⁾

The raw material is dried, proportioned, ground and blended (homogenized). It is then transported to the preheater through the constant feed weigher (CFW) and fed into the hot gas from the top (see Figure 5.2). The powder goes downwards while repeating a cycle of suspension → heating → solid separating at each cyclone (four to five stages). It is decarbonized to around 40% and then enters the rotary kiln.

Meanwhile, the kiln exhaust gas (1050-1100°C) rises, exchanging heat with the raw material at each cyclone. By the time the gas exits the highest cyclone, it has dropped in temperature to 350-370°C. This residual heat is drawn out of the preheater by the exhaust gas fan and then utilized for waste heat power generation and for drying raw materials. Most of SP kilns have four-stage cyclones; however, SP kilns with five stages have been built to improve heat exchange even further.

The overall preheater system is an ingenious mechanism designed for the principles of heat exchange. The raw material is fed in from the highest point at the top and then undergoes thermally efficient co-current heat exchange at each cyclone stage. It goes down through each level by gravity and undergoes counter-current heat exchange as it reaches the higher temperature zone. Around 40% of the CO₂ in the CaCO₃ is decarbonized, while heat consumption improves to 3,150-3,250 kJ/kg-clinker. The system is also compatible with larger kiln sizes and capable of long-term stable operation, as discussed below.

Table 5.2 shows the heat balance of a SP kiln. Although it appears from the table that there is little difference in relative merit between the types, the data have not been compared under identical conditions. It would thus be fair to conclude that “no substantial difference between models has been confirmed”. Table 4.2 provides a definition of burning efficiency.

Table 5.2 SP Kiln Heat Balance (unit: kcal/kg-clinker) ⁶⁾

Item	Type (no. of kilns)	SP Kilns				
		Dopol (21)	Humboldt (14)	Wedag (7)	Smith (1)	Total (43)
Heat input	Heat from fuel combustion	(97.1) 816.7	(97.6) 828.9	(97.1) 785.8	(97.1) 782.0	(97.3) 814.8
	Other	(2.9) 24.3	(2.4) 20.6	(2.9) 23.4	(2.9) 23.1	(2.7) 23.0
	Total heat input	(100.0) 841.0	(100.0) 849.5	(100.0) 809.2	(100.0) 805.1	(100.0) 837.8
	Heat used for burning clinker	(50.6) 425.9	(47.3) 401.1	(52.3) 423.1	(53.7) 432.9	(49.8) 417.5
Heat output	Sensible heat from preheater exhaust gas (including sprayed water evaporation heat)	(20.2) 169.5	(22.2) 188.6	(20.9) 169.1	(21.9) 176.1	(21.0) 175.8
	Heat escaping in the clinker	(2.9) 24.0	(1.9) 16.4	(2.9) 23.2	(4.1) 33.3	(2.6) 21.6
	Sensible heat from cooler exhaust gas	(14.2) 119.4	(13.2) 112.3	(12.6) 102.2	(0) 0	(13.3) 111.5
	Radiant and other heat loss	(11.0) 92.2	(13.4) 114.0	(9.3) 75.1	(19.2) 154.3	(11.7) 98.0
	Other	(1.1) 10.0	(2.0) 17.1	(2.0) 16.5	(1.1) 8.5	(1.6) 13.3
	Total heat output	(100.0) 841.0	(100.0) 849.5	(100.0) 809.2	(100.0) 805.1	(100.0) 837.8
	Burning efficiency (%)	50.8	46.8	51.9	52.9	49.7

(2) Capability for Long-run Operation and Upscaling

As the Japanese economy boomed, there was a rapid increase in demand for cement. This placed high demand on cement plants to expand in size and production capacity. With these economic conditions, most kilns built from the mid-1960s onwards were SP kilns. SP kilns offered increased daily production capacity as well as long-run operation; that is, increasing both (daily production capacity) × (number of days of continuous operation).

The two advantages of SP kilns, upscaling and long-run operation, were due to the preheater, which had no moving parts, boiler pipes or other wearing parts in the high-temperature gas channel. Some additional explanation is given below (see Table 5.1).

Lepol kilns are not markedly inferior to SP kilns in terms of heat consumption. They are also easier to use, considering that they are not affected by cyclone blockage, a drawback with SP kilns discussed later. However, as discussed in 4.2.4, the Lepol preheater has a grate that is continuously moving in the high-temperature gas flow at

900-1,000°C. At larger sizes, this is susceptible to mechanical breakdown and failure, meaning a maximum output of around 2,000t/d. As a result, when large-scale SP and NSP kilns were built in the 1980s and later, capable of producing over 3,000t/d, the Lepol kiln disappeared from the Japanese cement industry.

Kilns with attached boilers (dry process and wet process) were no match for the SP kiln in terms of heat consumption. They also required several scheduled breaks per year for boiler pipe maintenance and boiler inspections and could not operate for more than half a year at a time. The structure of the waste heat boiler also meant that kilns with attached boilers reached their maximum size in the 1960s.

While wet process long kilns were no match for SP kilns in terms of heat consumption, they were adequate in terms of long-run operation. However, the scale of the kilns (diameter and length) was the maximum possible in terms of the mechanical structure and it would have been difficult to make them any larger than the existing kilns at the time. Since long kilns were already large in size, in some cases a SP tower was added to increase production two or more times over. These were called “converted” long kilns.

5.1.2 Issues with SP Kilns

The above advantages enabled SP kilns to dominate existing kiln types within a short time. However, several issues came to the fore. These included cyclone blockage and firebrick lifespan issues, as discussed below.

(1) Cyclone Blockage

The greatest problem with SP kilns is cyclone blockage. With high-temperature raw material flowing through the cyclone, any low-melting compounds (mainly sodium or potassium salts) contained in the raw material or the exhaust gas melt and adhere to the inner wall of the cyclone. As this builds up and peels off, it can cause a blockage in the raw material outlet chute at the lower end of the cyclone. Once the cyclone outlet is blocked, the cyclone immediately fills up with high-temperature raw material due to the several tons of raw materials flowing through it every minute. The kiln is forced to stop while the dust is manually removed from the cyclone. This is a hazardous task in a high-temperature environment. Stopping the kiln also causes significant financial loss. Countermeasures taken include the following:

- (1) Selecting raw materials with low alkali content
- (2) Efforts at stable preheater operation (keeping exhaust gas temperature stable and minimizing variations in raw material amount and composition)

- (3) Periodic (e.g., once per shift) coating removal from the interior of the cyclone (automatic air blowers and manually using high-pressure water)

The reality at most plants is that efforts are made to prevent cyclone blockage using combinations of the methods (1), (2) and (3) above, but blockage still occurs. This issue of cyclone blockage remained largely the same for the NSP kilns that followed.

A major improvement came in 1990 with the invention of the chlorine bypass by Chichibu Cement (now Taiheiyo Cement). A chlorine bypass is a device that draws some of the hot gas out of the system when the concentration of low-melting alkalis in the preheater gets too high. More details are given in 9.2.2. This system significantly reduced the cyclone blockage issue. Originally invented as a means of preventing cyclone blockage, chlorine bypass systems are now an indispensable part of waste treatment at cement plants.

(2) Lifespan of Firebrick Lining

SP kilns were chosen for new facilities built in the 1960s and 1970s for reasons of thermal efficiency, long-term continuous operation and upscaling. However, even these kilns faced an obstacle when upscaling to diameters of 6m and burning outputs of 5,000t/d. This was the issue of the firebrick lining lifespan.

Japan's first SP kiln started operating in 1963. It was 4m in diameter, 62m long and had an output of 1,200t/d. Thereafter, new kilns and converted kilns were scaled successively larger. The largest kiln was built in 1972 with a diameter of 6.2m, 125m in length and with an output of 5,300t/d. The largest kiln was built in 1972 with a diameter of 6.2m, 125m in length and with an output of 5,300t/d.

It became apparent that there were limitations on the long-term operation of the kilns. As the kiln approached 6m in diameter, the lifespan of the firebricks lining the interior of the kiln grew shorter. The two main factors affecting the lifespan of the firebricks are given below.

- (1) The larger the diameter of the kiln, the weaker the arch support for the firebricks lining. This increased the risk of bricks falling during operation.
- (2) The greater the kiln output, the more fuel required to be blown into the kiln. The greater the heat load on the burning area (the hottest section), the lower the life expectancy of the refractory.

Surmounting this obstacle was the main objective for the development of the NSP kiln, discussed in the following section.

5.2 NSP Kilns: World-Leading Japanese Technology ^{1) 2) 3) 5) 6)}

The NSP kiln is a Japanese technology still used throughout the world today. It was developed by several Japanese cement companies, either independently or in collaboration with plant manufacturers. Several different successful systems were developed, but all of them included a separate furnace (calciner) with the preheater, thereby improving the decarbonization rate of the raw material and increasing the output of the rotary kiln. Figure 1.4 shows an exterior photograph of an NSP preheater and kiln. Figure 5.2 shows a comparison of the SP and NSP kiln structures. Figure 5.3 shows a comparison of the burning processes.

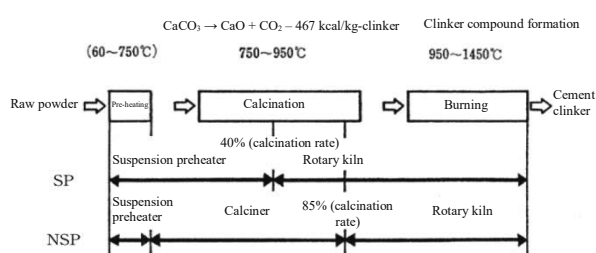


Fig. 5.3 Comparison of SP and NSP Burning Reaction Processes ⁶⁾

As shown in Figure 5.3, SP kiln preheaters have a raw material decarbonization rate of 40%. The remaining 60% calcination and the burning reaction have to be carried out in the rotary kiln with poor thermal efficiency. By contrast, the NSP system has a calciner added to the preheater. The heat needed for decarbonization is supplied separately by the calciner, thereby increasing the decarbonization rate to 85% or higher. Only the little remaining calcination and the exothermic burning reaction are carried out in the rotary kiln. This has made it possible to more than double the output of the same sized rotary kiln (see Table 5.1). Table 5.3 shows an example NSP kiln heat balance.

5.2.1 The NSP Kiln Concept

Table 5.3 NSP Kiln Heat Balance (example SF kiln; clinker output: 8,000t/d) ⁶⁾

Heat Input			Heat Output		
Item	Heat (kcal/kg - clinker)	Rate (%)	Item	Heat (kcal/kg - clinker)	Rate (%)
Heat from fuel combustion	745.0	97.0	Heat used for burning clinker	420.9	54.8
Sensible heat of fuel	3.1	0.4	Heat used for evaporating moisture content of raw materials	4.7	0.6
Sensible heat of raw materials	12.2	1.6	Heat escaping in the preheater exhaust gas	166.5	21.6
Sensible heat of primary air	7.5	1.0	Heat escaping in the cooler exhaust gas	85.0	11.1
			Heat escaping in the clinker	17.9	2.3
			Heat escaping in the dust	7.2	0.9
			Radiant and other heat loss	66.6	8.7
Total	767.8	100.0	Total	767.8	100.0

The cement industry is an energy-intensive industry. Developing energy-conserving technologies is an unchanging goal for the experts in the industry. As soon as the SP kiln was introduced in Japan, Japanese cement manufacturers began to conceive the basic idea of the NSP kiln: adding an auxiliary furnace to the preheater in order to increase the efficiency of limestone decarboxylation, the most heat-consuming part of the cement burning process, thereby increasing the kiln's burning output per capacity as well as its thermal efficiency. In a sense, this was a natural progression. If the idea could be realized, it would definitely increase SP kiln production and save more energy. The "new calcined lime burning process", still used by Onoda Cement at the time, gave credibility to the idea.

It was well known in the cement industry at the time that the burning output per kiln capacity using the improved burning method was so much higher than any other method, including the SP kiln, that it was in a league of its own (see Table 5.1). Japanese cement manufacturers were leading the West with advanced cement manufacturing technology. These experts took hold of the NSP idea because they had the uniquely Japanese new calcined lime burning process right before their eyes.

From around 1965, Mitsubishi Cement teamed up with Mitsubishi Heavy Industries to work on developing NSP kilns. Chichibu Cement did the same with Ishikawajima-Harima Heavy Industries, while Onoda Cement took the proprietary development route (working in collaboration with Kawasaki Heavy Industries at the actual kiln construction stage). The development aims were: (1) to make the SP kiln more thermally efficient; (2) to achieve long-term continuous operation for the SP kiln; (3) to increase SP kiln capacity.

Japan's first (= the world's first) working NSP kiln was completed in December 1971 at the Mitsubishi Cement Higashitani Plant in Fukuoka. Mitsubishi Cement and Mitsubishi Heavy Industries named this NSP kiln the "MFC type".

In July 1972, Chichibu Cement and Ishikawajima-Harima Heavy Industries started operating the “SF type” at the Chichibu No. 1 Plant in Saitama. In December the same year, Onoda Cement began operation of its independently-developed “RSP type” kiln at its Tahara Plant in Aichi. Within one short year from the end of 1971, three NSP systems had commenced operation.

Although other major cement companies, including Nihon Cement and Sumitomo Cement, initially adopted NSP kilns developed by other companies, Sumitomo Cement eventually developed its own “SCS type” NSP kiln and started operating it in 1979 through its subsidiary company Hachinohe Cement (Aomori Prefecture). Nihon Cement teamed up with Kobe Steel to develop the “DD type” NSP kiln and started operating it at its Kamiiso Plant in Hokkaido in 1979.

(Note) MFC: Mitsubishi Fluidized Calcliner System
 SF: Suspension Preheater & Flash Furnace
 RSP: Reinforced Suspension Preheater
 DD: Dual Combustion and Denitration Process
 SCS: Sumitomo Cross Suspension and Spouted Calcliner

Later new models and improvements to NSP kilns were released. Table 5.4 shows the different NSP kilns developed prior to 1982.

Table 5.4 NSP Types (as at 1982) ²⁾

Type	No. of kilns	(Note) Average capacity (t/d)	Developed by
DD	7	3,950	Nihon Cement Kobe Steel
FLS	1	4,001	F.L. Smith
GG	2	3,300	Mitsubishi Heavy Industries
KSV, NKS	8	3,600	Kawasaki Heavy Industries
MFC, NMFC	16	3,532	Mitsubishi Kogyo Cement
RSP	12	3,258	Onoda Cement
SCS	4	3,780	Sumitomo Cement
SF, NSF, CSF	19	3,776	Chichibu Cement Ishikawajima-Harima Heavy Industries
Total	69	3,617	

(Note) Average capacity calculated based on Cement Association notified capacity.

5.2.2 NSP Kiln Features

Although the developers of the different models of NSP kiln each advocated their own distinguishing features, it would be difficult to compare them without identical raw materials, preceding and following processes and other conditions. Technically speaking, there is very little difference between the models. Accordingly, a detailed comparison between the different models of NSP kiln has been omitted from this report.

Ultimately, the NSP kilns that were developed clearly had the following outstanding characteristics ⁴⁾.

1) The kilns were capable of greater output per capacity

and were able to be scaled up in volume. The capital investment and installation area required were also less than for SP kilns of the same size. The largest working kiln had a daily output of 9,000 tons, with an output per capacity of 130-150kg/m³h, compared to the 60-70kg/m³h achieved by the SP kiln.

- 2) Kiln operation was stable. Since the raw material was calcined before being fed into the kiln, the kiln could operate in a stable state. Consequently, it was easy to adopt computerized process control.
- 3) Since the heat load inside the kiln was reduced, the firebrick lining had a longer service life, making longer continuous operation possible.
 Improved refractory SP kilns 800-900g/t-clinker consumption rate: NSP kilns 500-600g/t-clinker
 (Note) Refractory consumption rate: the figure obtained by dividing the weight of the lining refractory by the volume of clinker produced through the kiln by the time the lined refractory was removed.
- 4) Since the temperature inside the calciner does not have to be as high as inside the kiln, lower quality fuel such as low-grade coal could be used.
- 5) NO_x emissions were low, while SO_x absorption was as high as the SP kiln.

As per the above, the NSP kiln not only dramatically increased the production capacity per kiln, but also had a significant impact in aspects of energy conservation, labor saving, automatization and computerized control. It was also epoch-making in terms of environmental measures for its effective low-NO_x (nitrogen oxide) burning. The kiln drew much attention, both in Japan and overseas. The efficacy of the NSP kiln as a low-NO_x countermeasure is discussed in 6.1.1.

The successful technological development of the NSP kiln prompted Japanese cement companies to build up their technological development know-how. Companies successively began to develop new cement-manufacturing-related machinery. Japan came to lead the world in cement manufacturing technology. Currently, all cement manufacturing in Japan is done by SP and NSP kilns. NSP technology has also been actively licensed overseas. In 1974, Ishikawajima-Harima Heavy Industries and Chichibu Cement licensed SF kiln technology to Fuller (USA). This was Japan’s first cement technology export. After that, Onoda Cement licensed RSP technology to Creusot-Loire (France), Allis-Chalmers (USA) and other overseas companies.

5.3 Structural Reform of the Cement Industry achieved through SP/NSP Kilns and Bulk Transportation^{2) 3)}

From the 1970s to the 1980s, the cement industry experienced trending growth in demand, but also some severe conditions, as given below.

- (1) Tight labor market due to the booming economy, with wages rising substantially every year
- (2) Substantially rising energy prices due to the oil crises and oil cartels
- (3) Pressure to invest in pollution control facilities in response to tightening pollution regulations

In order to overcome the severe business conditions caused by these external factors, cement companies embarked on drastic “structural reforms”. This meant consolidating plants and selecting “priority plants”. Up to that point, fixed manufacturing costs such as capital investment and repair costs were distributed across all plants using the same evaluation criteria, despite the differences between “major plants” and “minor plants”. This changed to a policy of “concentrating management resources on priority plants”. The following selection criteria were used for determining “priority plants”.

- (1) Sufficient limestone deposits for future supply
- (2) Convincing perspective for future expansion of production and market to keep up with both SP/NSP investment and pollution control investment
- (3) Accessible for bulk shipping by tanker or competitive access to a big market by land transportation

This plant consolidation made it possible to increase the labor productivity of each company as well as efficiently and effectively implement investment not directly related to manufacturing, such as pollution control investment. Plants that were not designated as priority plants were either shut down or split off into separate entities making their own profits, such as by engaging in operations outside of the cement industry.

This production structure rationalization of the 1970s and 1980s was a matter of companies selecting and consolidating their own plants; in other words, internal rationalization. Cement production reached an unprecedented high in 1995, after which the demand for cement began to decline. This meant it would be difficult for cement companies to survive by internal rationalization measures alone. To avert this crisis, the industry underwent some mergers and other forms of reorganization. Onoda Cement merged with Chichibu Cement in 1994 to form Chichibu Onoda, while Sumitomo Cement merged with Osaka Cement to form Sumitomo Osaka Cement. In 1998, Chichibu Onoda merged with Nihon Cement to form Taiheiyo Cement. Ube Industries partnered with Mitsubishi Materials Corporation to establish the joint venture Ube-Mitsubishi Cement Corporation. Following these changes, the

merged companies then carried out further plant consolidation that went beyond the limits of the former companies.

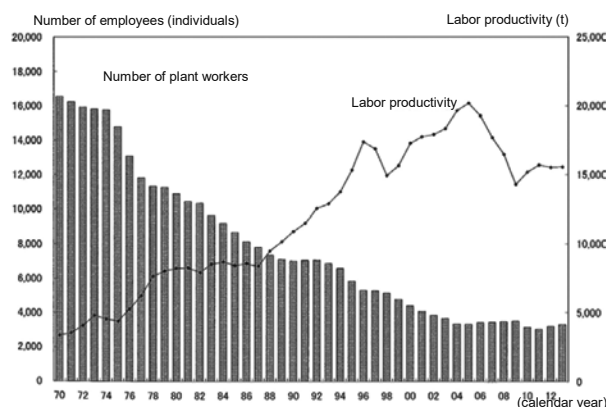


Fig. 5.4 Trends in Cement Plant Labor Productivity¹⁾

Table 5.5 Changes in Cement Plant Numbers and Kiln Numbers⁷⁾

Year	No. of plants	No. of kilns	Cement output (mt-cl/y)	Clinker output (mt-cl)	No. of employees	Labor productivity (t/y, man)
1970	58	226	86.4	54.9	16,549	3,316
1975	58	246	120.8	63.2	14,774	4,275
1980	53	192	126.4	86.3	10,830	7,965
1985	44	98	98.0	70.7	8,617	8,207
1990	41	80	87.2	75.3	6,949	10,834
1995	41	81	97.6	89.1	5,830	15,282
1999	39	75	95.6	74.3	4,758	15,606
2000	37	65	87.2	75.6	4,387	17,227

As shown in Table 5.5, in the three decades from 1970 to 2000, the number of plants dropped to around $\frac{2}{3}$, the number of kilns dropped to around $\frac{1}{3}$ and the number of employees dropped to around $\frac{1}{4}$. During this time, clinker output increased by around 1.4 times, while labor productivity improved by around 5.2 times (Figure 5.4).

Thus, through plant consolidation, cement companies were able to overcome the severe conditions imposed by the shift from high growth to low growth and reduced demand. It should be noted that these administrative efforts were undergirded by technology infrastructure, including plant upscaling through SP and NSP systems and bulk cement distribution systems for transporting cement (see 4.12.3).

5.4 Upscaling and Energy-Saving of the Raw Materials Process

As the SP and NSP systems made the burning process capable of upscaling and more energy efficient, it was only natural that the preceding and following processes of raw materials and finishing had to be capable of upscaling and more energy efficient as well. This report discusses the upscaling of plant raw material receiving facilities and upscaling and energy-saving in the drying and grinding processes.

5.4.1 Upscaling of Raw Material Receiving Facilities: Stacker & Reclaimer Systems ⁸⁾

The upscaling of kilns through the SP and NSP systems inevitably meant that raw materials yards had to increase in scale (storage volume and handling capacity). The measures used to achieve this varied according to the conditions at each plant site. Naturally, a plant near the mountains could have a smaller ore storage area, but the further the plant from the mine, the greater the ore storage area had to be.

Plants with several large kilns capable of a daily output of 5,000 tons or more need facilities that can handle receiving 10,000 tons of limestone per day and delivering to the production line more than 500 tons per hour. One means of solving this is for cement plants to adopt a stacker & reclaimer system, used by ore mines, coal mines, ironworks, power stations and other facilities for handling large volumes of granular material, such as iron ore or coal.



Fig. 5.5 Stacker & Reclaimer ⁹⁾

This system is also called bed-blending. The mined raw material is firstly stacked in alternating layers by the stacker (the arm-shaped device at the left of Figure 5.5). It is then taken up by the reclaimer (the triangle-shaped device at the right of the figure) working perpendicular to the layers. This has the advantage in that it is possible for the raw materials taken up from the stack to have even less variation than the raw material received. In that sense, this system has a positive effect on raw material homogeneity. Another major advantage is that it can operate unattended. In terms of capacity, the conventional crane grab bucket system could shift around 300t/h, whereas the stacker & reclaimer system could shift over 1,000t/h and was more economically advantageous the greater the amount.

With regard to receiving and discharging clay materials, issues were mostly dealt with by expanding and reinforcing pre-SP/NSP systems (e.g. crane grab-bucket system) because of (1) smaller quantities than limestone and (2) stickiness of materials.

5.4.2 Upscaling and Energy-Saving of Raw Material Drying and Grinding Processes

Until the 1960s, raw materials were dried and ground using a system of separate drying and grinding, in which the limestone and clay received were:

- (1) dried in a limestone drier or clay drier (both rotary driers), then
- (2) weighed proportionately with a constant feed weigher (CFW), and then
- (3) fed into a tube mill to be ground together.

The hot air furnaces were set up for limestone and clay separately. When the SP kiln system was introduced, with exhaust gas coming out of the highest cyclone of the suspension preheater at around 350°C, the method was generally adopted of utilizing the residual heat in the exhaust gas to dry the raw materials.

Initially, exhaust gas waste heat drying of raw materials was carried out separately from grinding. Eventually, a system was introduced in which exhaust gas was directed into the raw mill, allowing drying and grinding to be carried out simultaneously. The simultaneous drying and grinding system saved on repairs and maintenance and was also more economical on energy than the separate dryer system. Accordingly, separate dryer systems were rarely used for raw materials processes at new facilities from the 1970s on.

Simultaneous drying and grinding mills took the form of tube mills or vertical roller mills. The tube mill used as an example in this report is the double rotator mill; the vertical roller mill used as an example is the Loesche mill.

(1) Double Rotator Mill ^{6) 10) 11)}

The double rotator mill is a simultaneous grinding and drying ball mill developed by Polysius (Germany). It was first used in a Japanese cement plant in 1963 at the Mitsubishi Cement Higashitani plant in Fukuoka. There were reported to be 28 of these mills in operation in August 1975.

This type of mill is characterized by having a drying compartment on the raw material feed side and a ground material outlet in the center of the mill; it is a combination of an air-swept system (see Note 1) and a closed-circuit system with a separator. The mill itself comprises a drying compartment, 1st and 2nd grinding compartments and a central discharge chamber. When preheater exhaust gas at 330-350°C is used, this type of mill is capable of drying only around 5% of the moisture content in the feedstock. As discussed later, vertical mills were the raw material mill of choice for new facilities from the late 1970s. See cited reference (10) for more details on double rotator mills.

(2) Vertical Mill (Roller Mill) ^{11) 12)}

The vertical mill is a type of mill in which the raw material is fed onto a rotating table and then pressed and ground by multiple rollers. A separator is positioned above the rollers, so that drying, grinding and classifying are integrated into a single machine. This provides the following advantages.

- (1) Smaller installation area and less noise
- (2) More efficient grinding and less power consumed than tube mills
- (3) Since the ground material spends less time within the mill, any variations in raw material proportioning can be dealt with quickly, which also allows more consistent quality
- (4) Drying and grinding can be carried out simultaneously by directing high-temperature exhaust gas through the mill

Due to reason (4) above, this type of mill was widely adopted for raw material grinding and coal grinding. It was very effective in simplifying processes and conserving energy. Section 5.5.5 discusses the adoption of vertical mills into the finish grinding process.

Vertical roller mills include Loesche mills and MPS mills. In Japan, the Ube Loesche mill, manufactured by Ube Industries under license from Loesche (Germany), came to dominate the market. Figure 5.6 shows (1) the exterior view and (2) the internal structure of a large-scale LM32/4 Ube Loesche mill, as well as (3) the vertical mill grinding mechanism.

Operation of the mill is as follows.

Four rollers on a rotating table press against the table by means of hydraulic cylinder. The raw material is fed in from the chute and drops down near the center of the table. It is pushed outwards by centrifugal force and ground as it goes between the table and the rollers. The mill is a simultaneous grinding and drying mill; exhaust gas is fed into the mill by fan through a lower duct. At this point, the exhaust gas is subjected to rotating force

from a blade ring on the circumference of the table. The resulting hot wind blows over the ground material overflowing from the edge of the table. The ground material is blown into a separator at the top of the mill. The coarse particles are sent outwards and drop back onto the table to be ground again. The fine powder passes between the blades of the separator with the gas and is collected by a cyclone collector.

The figures below indicate an example of improved power consumption between a tube mill and a vertical mill for grinding raw materials. ⁷⁾

(calculation prerequisites)

Grinding capacity: 200t/h

Annual operating time: 7,000hrs

(power consumption comparison)

Tube mill: 20-26kwh/t-raw material

Vertical mill: 14-18 kwh/t-raw material

This represents an improvement in power consumption of around 30%. Japan's first Loesche mill was installed at the Ube Industries Isa plant in 1959. This early type was small in capacity and the rollers and table were made from poor materials, meaning that a lot of time was spent on maintenance. Therefore, the spread of the Loesche mill was not so fast. Improvements in both mechanical structure and structural materials allowed gradual upscaling of the system. In the 1970s, a large-scale Loesche mill was developed that had a grinding capacity of over 200t/h. The vertical mill grew rapidly in popularity and by the mid-1970s had become the first choice of raw materials mill for new installations.

As Loesche mills grew in size, it became possible to use one raw materials mill (Loesche mill) per kiln, which significantly simplified the process layout. The "one kiln, one mill" system was first achieved by Ube Industries at the Kanda plant in Fukuoka in 1977.

5.5 Energy-Saving in the Finishing (Cement Grinding) Process

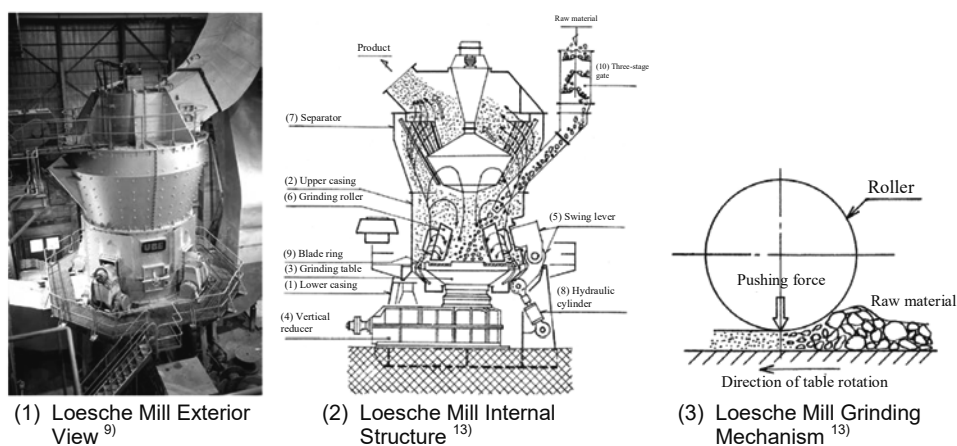


Fig. 5.6 Vertical Grinding Mill (Loesche Mill)

With the advent of SP and NSP kilns, the main contribution to upscaling and energy-saving in the raw materials process was the vertical roller mill, as discussed above. Meanwhile, the first stage of upscaling and energy-saving in the finishing process (1960s and 1970s) was achieved by upscaling of tube mills, adding grinding aids and the use of classifying liners and smaller balls. The second stage (1980s onwards) saw progress through the use of highly efficient separators (such as the O-SEPA) and pre-crushers. Figure 4.13 shows the transitions in the upscaling of finishing tube mills.

The use of vertical roller mills for finishing (cement grinding) was hindered by issues with operation, maintenance and cement quality. In 1988, the Japanese developed the OK Mill, a vertical cement grinding mill. This was a great achievement; the design idea and technology spread throughout the world and various kinds of vertical mills began to be used for cement grinding.

Below is a detailed discussion of the first and second stages of energy-economizing the tube mill in the finishing process. The vertical roller mill for cement grinding is discussed in 5.5.5.

5.5.1 Difference in Powder Fineness Management Indicators between the Raw Materials Process and the Finishing Process

The raw materials process and the finishing process both center around grinding and classifying. In both processes, powder fineness is an important quality control point for the product being sent to the next stage. However, powder fineness can be represented in several ways, such as sieve residue, specific surface area and particle size distribution. Due to the difference in function between the raw materials process and the finishing process, the fineness is represented differently between the two processes. Since understanding the energy conservation initiatives for the two processes requires understanding how fineness is represented for each process, an explanation is given here.

(1) Fineness in controlling the raw materials process: sieve residue

Fineness as a control for the raw materials process is measured by sieve residue, the amount of residue remaining on the standard sieve. Currently, the main measure used is 90 μ sieve residue on a 90 μ JIS standard sieve.

The raw powder produced in the raw materials process is sent on to the following burning process for the clinker formation reaction. If this powder contains coarse granules (e.g. larger than 90 μ), it could come out of the rotary kiln without having reacted properly. Quartz or other siliceous particles contained in siliceous raw

material is hard to grind and is prone to residual coarse particles. If these coarse particles go through the kiln without reacting, a corresponding amount of lime will remain in the clinker as “free lime” (see Note 4 of Chapter 3). This has an adverse effect on the quality of the cement.

In terms of fineness control indicators in the raw materials process, there are some advantages for upscaling and energy saving because (1) it is a simple process mostly measured by sieve residue and (2) the ensuing burning process takes places within the plant.

(2) Fineness in controlling the finishing process: specific surface area and particle size distribution

The end product of the finishing process is cement. The cement is shipped out of the plant in its finished state. The customer mixes it with water at the site of use, where it undergoes a chemical reaction of setting and hardening to finally form concrete. The setting and hardening reaction process is the process of the cement powder being dissolved in water and forming hydrates. Accordingly, the important control indicator for cement fineness is specific surface area (cm²/g).

Another important element in controlling fineness in the finishing process is particle size distribution. Particle size distribution has a major effect on the setting process or the usability of the cement product. Cement with, to some degree, a broad particle size distribution is deemed as being easy to use, while cement with a narrow particle size distribution requires more water to produce fresh concrete of the same softness, resulting in a drop in concrete strength. However, measuring particle size distribution is not easy and it is difficult to carry out measurements as a routine process control. Having said that, if clinker burned under similar burning conditions from similar raw materials is ground using similarly set grinding and classifying machinery, there will be little variation in particle size distribution. Accordingly, 32 μ sieve residue testing is used as an alternative for routine control.

Another important control point in the finishing process is grinding temperature. The grinding temperature affects the dehydration of gypsum added during grinding. The level of dehydration of the gypsum in the cement has a significant impact on the setting of the cement, thereby affecting the usability of the cement. The main factors related to grinding temperature are (1) the temperature of the clinker entering the mill and (2) the heat generated by grinding.

In light of this, a setting test is included in the routine control test items for cement. The results of this test provide feedback for managing particle size distribution (32 μ residue) and cement grinding temperature.

5.5.2 Grinding Aids ^{7) 14)}

Grinding aids are a tertiary material added in trace amounts during the grinding process to accelerate grinding.

In tube mills, grinding efficiency usually decreases significantly in the fine grinding stage. This is due to agglomeration of the fines, for two reasons: (1) agglomerated fines adhere to the mill lining and the grinding media, forming a coating that reduces the impact force of the mill; (2) agglomerated fines get mixed in with the coarse particles by the separator and are recycled through the mill. Grinding aids act to improve the grinding efficiency by preventing this agglomeration.

An important condition for the use of grinding aids is preventing deterioration in product quality. The increased cost of adding grinding aids is outweighed by the reduction in costs achieved by improving grinding efficiency. Accordingly, due to cost versus effect, grinding aids in the cement industry are used exclusively in cement grinding and seldom in raw material grinding.

Research on the use of grinding aids in the finishing process began around 1930 in the United States, with the aim of utilizing lignin recovered from pulp waste liquid. The effect was confirmed and in 1932 a product was marketed in the United States under the brand name RDA. From around the mid-1950s, as the petrochemical industry developed, various developments were made using organic substances with additive effects. At the present time, most of grinding aids used in cement plants are these petrochemical products.

In Japan, the JIS cement quality standard was amended in 1973 to allow the use of aids, considerably later than the United States because of customers' concerns over the durability of concrete. After that, the use of grinding aids prevailed. Diethylene glycol has been widely used in Japan, as well as triethanolamine, amine acetate and other compounds.

These aids are usually used in finishing mills by diluting them with five to ten parts water and spraying them into the mill. The volume of additive is 0.01-0.03% relative to the weight of the clinker. In terms of use effect, the grinding volume is reported to increase by 4-6% for every 0.01% of grinding aid added.

5.5.3 Classifying Liners and Small Balls ^{7) 11)}

Raw materials mills and finishing mills both have liners with lifters for (1) protecting the mill and (2) scraping the grinding media.

The second compartment in a finishing mill is for fine grinding. The use of smaller balls (17-20mm in diameter) is known to improve efficiency by increasing the surface area to enhance the grinding effect. However, with conventional liners with lifters, the small balls would accumulate at the entry to the second compartment, while the medium-sized balls would accumulate at the exit,

creating a reverse classifying effect and significantly decreasing the grinding efficiency. It was therefore difficult to make any dramatic decrease to the size of the balls.

Classifying liners (Figure 5.7) were developed to eliminate this reverse classifying effect. Classifying liners slope towards the mill entry, causing the balls to travel towards the entry point. The greater the ball diameter, the greater the effect of the torque (centrifugal force) of the mill and the closer the ball travels towards the entry. As a result, the balls can be classified successively, with larger balls closer to the entry to the second compartment. The development of classifying liners made it possible to use balls with smaller diameters of 17-20mm. Fine grinding could now be achieved without over-grinding.

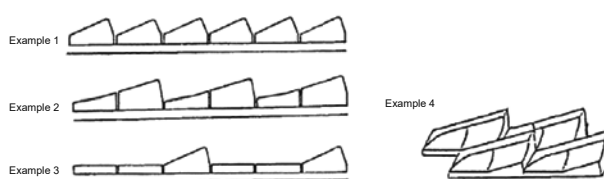


Fig. 5.7 Classifying Liners in the Second Compartment of a Finishing Mill ⁷⁾

(Example 4 is a "lifting" type classifying liner)

The use of classifying liners and smaller balls is reported to have improved grinding power consumption by 1-2kwh/t. Since the coarse grinding at the entry to the second compartment has also improved, the grinding ability of the entire mill is sometimes improved by shortening the first compartment (lengthening the second compartment).

5.5.4 O-SEPA: the Revolutionary Japanese Highly Efficient "Eddy Current Separator"

The O-SEPA was developed from an original idea by Takeshi Furukawa, an employee at the Onoda Cement Central Research Institute. The first working machine completed in 1979 was the revolutionary Japanese highly efficient separator.

Separators used in the cement industry grinding process include the "first generation" of Gayco and Sturtevant separators with internal fans, discussed in 4.6.3, the "second generation" of cyclone air separators with external fans, and the "third generation" O-SEPA separators, now used all over the world. "O-SEPA" was the brand name; therefore, when similar types of separators using the same principle began to be sold worldwide, common names also began to be used, including "eddy current separator", "rotor-type separator" and "high efficiency separator (HES)". In this report, "eddy current separator" is used.

The following provides a discussion of the principle, structure, operational data and separating capability of the

O-SEPA, the original eddy current separator, as well as some typical examples of its use in the cement grinding process.

(1) Principle and Structure of the O-SEPA ^{15) 16)}

The O-SEPA is a type of air separator. The separating principle is the same as that of the first- and second-generation separators. That is, “a machine that separates fine powders and coarse particles by using the fact that the equilibrium relationship between the external forces (gravity, centrifugal force, etc.) acting on solid particles and the air resistance acting on as those particles as they move through the air differs according to particle size and density.”

The major advantage of the O-SEPA is that whereas the first- and second-generation separators only separate particles using a “free vortex” from guide vanes (blades fixed on the outer circumference), the O-SEPA has a secondary separation in addition to the free vortex, using a “forced vortex” from rotating eddy current adjusting blades. Accordingly, O-SEPA type separators should be termed more accurately as “combined free vortex and forced vortex separators”.

Figure 5.8 shows the overall structure of an O-SEPA, while Figure 5.9 shows a horizontal cross-section.

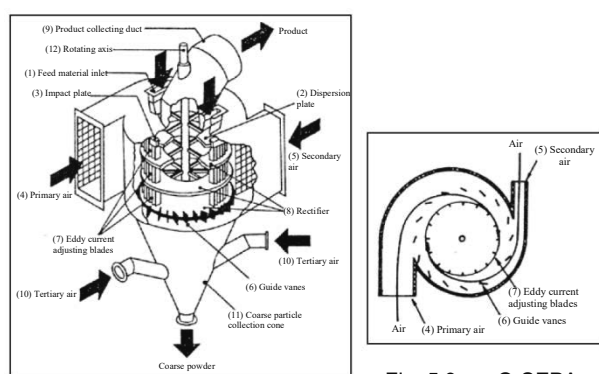


Fig. 5.8 O-SEPA Structure ¹⁵⁾

Fig. 5.9 O-SEPA Horizontal Cross-Section ¹⁵⁾

The air needed for separating can be dust-containing air from a grinding mill, conveyors, outside air or any mixture of these (one advantage of the O-SEPA). The air comes in from the air intakes for primary air (4), secondary air (5) and tertiary air (10). As shown in Figure 5.9, the primary air and secondary air are drawn from the intakes in a tangential direction. These form an eddy current by passing over the guide vanes (6) on a particular angle and are sent into the separating area. The separating area is a space between the guide vanes and the eddy current adjusting blades (7), where the particles are separating into coarse particles and fine particles by the separating effect. The air current forms a tight horizontal vortex through the action of the rotating eddy current adjusting blades and the rectifier (8). This accelerates

until it reaches the circumferential speed of rotation of the eddy current adjusting blades, goes between the eddy current adjusting blades and is expelled into the product collecting duct (9).

Meanwhile, the raw materials to be separated being fed from the raw material inlet (1) travel past the rotating dispersion plate (2) and impact plate (3) and are dispersed into the separating space. The particles are first classified by the swirl current caused by the guide vanes. They then undergo a second classification determined by the balance between the centrifugal force of the swirl current from the eddy current adjusting blades and the speed of the air current flowing towards the center. The fine particles are expelled to the product collecting duct. Incoming air from the tertiary air intake separates any remaining fine particles adhering to the coarse particles collected in the coarse particle collection cone (11).

(2) Operational Data ¹⁵⁾

Table 5.6 shows the operational data taken before and after remodeling a large tube mill (4,000kw) from a cyclone separator to an O-SEPA (N-3000).

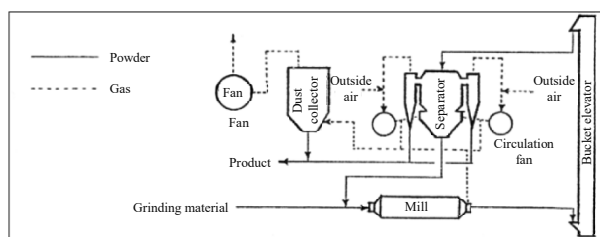
Table 5.6 Comparison of Before and After Remodeling from Cyclone Separator to O-SEPA ¹⁵⁾

	Amount ground (th)	Power consumption kWh/t			Product fineness			Cement temperature		
		Mill	Other machinery	Total	Blaine cm ² /g	90 μm residue %	30 μm residue %	Sprayed t/h	Mill output °C	Fines °C
Cyclone separator (before remodeling)	110.1	35.42	10.06	45.48	3230	1.2	25.9	2.2	135	112
O-SEPA (after remodeling)	126.7	30.78	5.25	36.03	3090	0.8	20.0	1.2	120	84

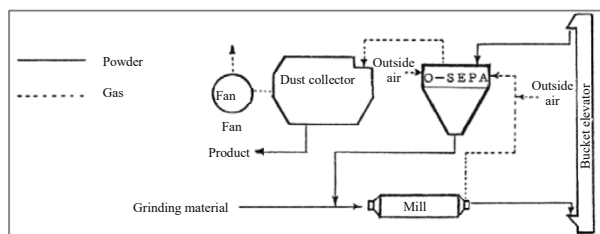
(3) Advantages of the O-SEPA ^{4) 15)}

The O-SEPA has the following advantages.

- Improved separating capability reduces the amount of power used.
- Specific surface area can be reduced with the same cement quality level, reducing the amount of power used.
- Improved particle size distribution and lower cement temperature improves cement quality.
- Improved operational capability makes it easy to switch the types of cement and maintain cement quality.
- Ability to handle large volumes of dust-containing air from a mill and conveyors reduces dust emissions, which means improved working environment and greater longevity of machinery.
- Fewer machines means a simpler flow, fewer machinery breakdowns and more stable operation. For comparison, Figure 5.10 shows the flow diagrams for a cyclone separator and an O-SEPA.
- Far smaller installation space compared to conventional separators, making maintenance easy.



(1) Cyclone Separator



(2) O-SEPA

Fig. 5.10 Comparison of Cyclone Separator and O-SEPA Separator Flow Diagrams ¹⁵⁾

In 1985, international giant Fuller (USA; now merged with FLSmidth) entered into a technology license agreement with Onoda Cement for the O-SEPA technology. The following year, CLE Technip (France) also entered into a technology license agreement. The worldwide spread of the O-SEPA began with these two Western companies and Onoda Engineering (now Taiheiyo Engineering). The O-SEPA has also since been applied in grinding processes for a range of other materials, including blast furnace slag, coal and limestone powder (calcium carbonate), as well as raw materials for fine ceramics (e.g. silicon nitride and silicon carbide) and various kinds of powder fillers.

Following the development of the O-SEPA, companies in Japan and overseas developed other “eddy current” separators using the same principle.

5.5.5 Vertical Mills for Finish (Cement) Grinding: the Forerunner “OK Mill” ^{17) 18)}

Vertical (roller) mills grind the raw materials efficiently, thereby conserving energy. Because of this, various attempts were made by Japanese and Western industry pioneers to use vertical mills for cement grinding as well. However, this was not easy to achieve, for the following three main reasons (issues).

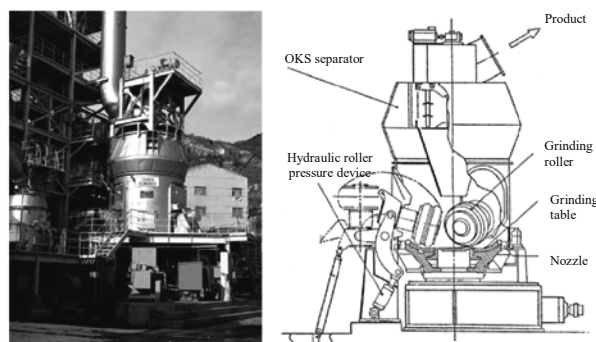
- (1) Operation: The clinker is hard to grind and can cause the mill to vibrate during grinding.
- (2) Maintenance: For the same reason as above, the clinker causes wear and damage to the grinding rollers and table.
- (3) Cement quality: Vertical mills produce a ground product (cement) with a narrow particle size distribution, meaning more water is needed when mixing the concrete, which reduces the strength of the cement.

The “OK mill” jointly developed by Onoda Cement and Kobe Steel broke through these challenges. Following pilot plant testing, the world’s first large-scale vertical cement grinding OK mill (130t/h) started operation in July 1988 at their Ōfunato plant.

(1) OK Mill Structure

The OK mill resolved the issues (1), (2) and (3) above in the following ways ¹⁸⁾ (see Figure 5.11).

- (1) Vibration: The grinding rollers were shaped with an indentation in the center so as to limit the location of the grinding. This reduced the area where the ground powder was being pressed and ground, making it less susceptible to vibration. At the same time, it also increased the grinding efficiency.
- (2) Wear: Shaping the grinding rollers with an indentation in the center so as to limit the location of the grinding also reduced the amount of wear. Improving the metal material used in the rollers also improved the abrasion resistance.
- (3) Particle size distribution: Use of the OKS highly efficient eddy current separator (a modified version of the O-SEPA for vertical mills) made it possible to have independent control over the separator rotation speed, air flow, roller pressure, table dam height and other functions. As a result, it was easy to adjust the range of the particle size distribution to determine the quality of the end product.



(1) OK Mill Exterior View ⁹⁾

(2) OK Mill Structural Diagram ¹⁷⁾

Fig. 5.11 OK Mill

(2) Key to the Success of the OK Mill ¹⁸⁾

Many previous attempts to use a vertical mill in the finishing process had failed. The reason the OK mill succeeded was that it was a vertical mill with a modified O-SEPA built in. The thought process for the development was as follows.

- (1) In a vertical mill, the grinding efficiency has a linear relationship to the pressure of the rollers on the table.
- (2) The higher the pressure, the higher the grinding efficiency but the narrower the particle size distribution of the product.

- (3) The pressure has mechanical limitations as well as the limitation of susceptibility to vibration.
- (4) The table has a dam around the outer edge to adjust the powder depth. The lower the height of the dam, the better the grinding efficiency, but the less stable the operation. Thus, “dam height” has a similar function to pressure in (1) and (2) above, as well as functioning to alter particle size distribution.
- (5) Particle size distribution is usually considered in relation to whether particles are fine or coarse and whether distribution is wide or narrow.
- (6) Both rotary separators (conventional separators used in vertical mills) and eddy current separators regulate these two factors of particle size distribution by airflow and vane rotation speed.
- (7) In both types of separators:
 - * the greater the airflow, the coarser the product
 - * the higher the vane rotation speed, the finer the product
 - * by adjusting the vane rotation speed, the same fineness can be achieved at different airflow levels
 - * the greater the airflow, the narrower the particle size distribution of the product
- (8) The two factors of particle size distribution can be adjusted independently from each other in the eddy current separator, unlike the rotary separator.
- (9) Particle size distribution in cement grinding not only affects the strength of the cement, but also its workability. The narrower the particle size distribution, the better for strength but the worse for workability. In terms of workability, the cement is easy to use if it has similar particle distribution as that produced by a tube mill.
- (10) From the above, in order to “increase grinding efficiency without altering product particle size distribution”, it was “necessary to have a separating mechanism to compensate for the transition in grinding mechanism from tube mill to vertical mill”. Thus, it was necessary to have an eddy current separator with freely adjustable particle size distribution. The OK mill was the forerunner of these.

(3) OK Mill Operating Performance ¹⁷⁾

Tables 5.7 and 5.8 show data comparing the performance of a new OK mill installed at the Taiheiyo Cement Ōfunato plant with a finishing tube mill used at the same plant to grind the same clinker. As shown in the tables, the quality of the OK mill cement, both ordinary and high-early strength, is equal to or slightly higher than conventional mill cement. Power consumption is significantly improved.

Table 5.7 OK Mill Grinding Capability and Power Consumption ¹⁷⁾

Type	Mill	Mill airflow m ³ /min	Separator rotation speed rpm	Product Blaine cm ² /g	Amount ground t/h	Mill power kw	Power used kwh/t		
							Mill	Other machinery	Total
Ordinary	OK mill	4750	71.7	3210	135.5	3000	22.1	5.7	27.8
	Tube mill	-	-	3280	99.2	3300	33.3	5.5	38.8
High-early strength	OK mill	4540	92.6	4390	103.3	2800	27.1	5.7	32.8
	Tube mill	-	-	4350	21.0	950	45.2	7.5	52.7

Table 5.8 OK Mill Ground Cement Quality Data ¹⁷⁾

Type	Mill	Blaine (cm ² /g)	Residue (%)		Setting water (%)	Setting time*		Flow (mm)	Compressive strength (kgf/cm ²)			
			30μ	15μ		Initial	Final		1-day	3-day	7-day	28-day
Ordinary	OK mill	3200	19.3	51.3	28.5	2-19	3-10	256	-	151	255	431
	Tube mill**	3280	20.3	53.2	28.4	2-24	3-29	253	-	142	243	420
High-early strength	OK mill	4350	5.0	34.4	30.8	1-32	2-27	247	181	311	399	485
	Tube mill**	4350	5.2	35.6	30.8	1-47	2-39	250	169	292	385	480

*hr-min. **tube mill

Prompted by the successful development of the OK mill, other types of vertical finishing mill were also developed, fitted with eddy current separators. Vertical cement grinding mills spread throughout the world.

5.5.6 Pre-crushers for Finishing Mills: Energy Conservation Measures with Reduced Demand for Cement ^{4) 7)}

Pre-crushers for finishing mills are devices used at the pre-tube-mill stage in the finishing process with the aim of improving the total power consumption of the process. Pre-crushers can be the roller press type or the vertical mill type. The vertical mill type is a technology developed in Japan.

The roller press type crushes clinker by feeding it between a pair of biting rollers. Developed in Europe, it gained considerable usage for a time due to its low cost. However, it was often not as productive as expected due to roller lifespan and poor maintainability.

The vertical mill type was a simplified version of a highly efficient vertical roller mill without the separator. The first was the CKP, was jointly developed in 1987 by Chichibu Cement and Kawasaki Heavy Industries. After that, the vertical mill type became the main pre-crusher used. Figure 5.12 shows the structure and flow.

The following figures were reported as a result of introducing the vertical mill type pre-crusher.

- (1) Finishing tube mill capacity: 30-60% increase
- (2) Finishing process power consumption: 10-20% improvement

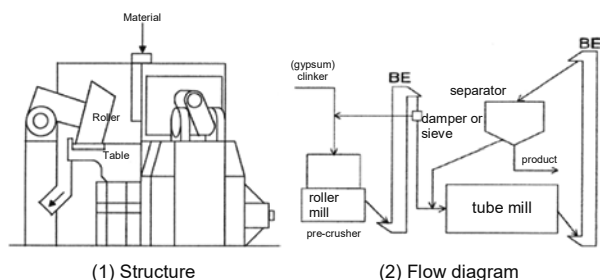


Fig. 5.12 Pre-crusher for a Finishing Mill (Vertical Mill Type)
7)

Following the development and commercialization of the OK mill and other vertical mills for finish grinding, the Japanese cement industry went from maturity to decreased demand. Very few new finishing mills were being built. It was pointless to invest money in converting to a vertical mill for power savings alone. In this cement market environment, pre-crushers could be used to increase the production of existing mills, while improving specific power consumption (kwh/t). This was indeed a technological development suited to the demands of the time. Vertical mill pre-crusher technology was also licensed overseas.

5.6 Waste Heat (Exhaust Heat) Power Generation: Reclaiming and Utilizing Waste Heat to the Extreme^{7) 19)}

Two sources of exhaust gas heat energy from SP and NSP kilns have been discussed previously: (1) preheater exhaust gas (kiln exhaust gas) and (2) clinker cooler exhaust gas. As also discussed, preheater exhaust gas is used for drying raw materials, while cooler exhaust gas is used for (1) secondary air in kiln burning, (2) calciner combustion air, and (3) dry air for coal grinding. Until the 1970s, this was the extent of exhaust gas heat utilization.

With the popularization of the NSP system, the scale of production per kiln increased. With this regard, a new way of waste gas power generation was developed. The heat from the 400°C preheater exhaust gas and the 250°C cooler exhaust was recovered by the waste heat boiler and converted to electricity by a mixed pressure steam turbine and a power generator. This energy-recovering “waste heat power generation facility” grew rapidly in popularity from around 1980. The reason for this was that the power output per ton of clinker averaged around 35-40kW, meaning around 8,000kW per hour in a kiln with a 5,000t/d capacity, equating to investment profit.

NSP kiln systems fitted with waste heat power

generation facilities improved energy utilization efficiency by more than 80% in the burning process. The temperature of the preheater exhaust gas after passing through the waste heat boiler was around 250°C. This dropped to around 100°C after being used for drying raw materials and the like after that. Cooler exhaust gas also dropped to around 100°C after passing through the waste heat boiler. This left next to no further industrial utilization value in either heat source. Any further reduction in heat consumption in the burning process would lead to a drop in waste power generation, meaning it was ultimately not economically viable to invest in new energy conservation measures. This was the result of tireless efforts in waste heat power generation by cement technology developers, ever ambitious to wring blood from a stone in energy conservation.

5.7 Computerized Control^{4) 20)}

This section discusses the development of computerized technology to control processes in cement manufacturing. Computerized control in the cement manufacturing process comprises one large system combining “specific cement manufacturing technology” + “temperature, pressure, chemical composition and other sensor technology” + “communication / information processing devices (hardware)” + “system integration / control technology (software)”. All of those technologies are still evolving rapidly, while the cement industry itself is changing from “an industry that makes cement from natural materials” to “an industry that makes cement from recycled waste materials”. Accordingly, computerized control in the cement manufacturing process is always in the “present progressive form”.

Detailed explanations of technical terms related to computerized control can be found in specialized sources and have been omitted from this report.

5.7.1 Introduction of Computerized Control to the Cement Manufacturing Process^{4) 20)}

In 1958, American company Thompson Ramo Woodridge (TRW) unveiled a control computer. In 1959, Riverside Cement trialed a computer for proportioning raw materials, while in 1964, Colton Plant of California Portland Cement (CPC) trialed computers for controlling the processes of raw materials proportioning and burning. Thus, computers started spreading in use for process control in the United States in the 1960s.

The Japanese cement industry also started introducing computers for process control from the early 1960s. In many cases, the first attempts were to develop computerized control for the raw materials process.

Development for the burning process also began in the 1960s. Computers were used to gather and analyze operational data to examine the characteristics of the burning process. It was difficult to model the cement manufacturing process, particularly the burning process, as there was feedback between input and output, with a lot of interference. It was thought that it would be extremely difficult to implement computerized control for these processes. Many bold attempts were made in research and development to overcome this barrier. By around 1970, companies had some basic methods of computerized control for the burning process more or less complete. Reported examples of development include the following methods ²⁰⁾.

- (1) a static mathematical model inside the kiln
- (2) optimized kiln operation based on time-series statistical analysis
- (3) detection of disturbances such as coating (*anzatz*) falling and optimized operation for recovery

The 1970s saw the development of the NSP system and a transition in fuel from heavy oil to coal. This also had an effect on controls. For example, switching to coal around 1980 involved changing the existing analog instrumentation to a digital one-loop controller.

By around 1990, the transition to NSP and coal burning was mostly complete. Introduction of a distributed control system (DCS) integrated everything into the control room. Earnest efforts were being made to increase productivity by saving labor.

From the 1990s, the variety and volume of waste materials used in cement manufacturing processes started to increase. These were added into the kiln system at various stages according to the composition and characteristics of the waste materials and the limitations on plant layout. It became crucial to coordinate the processing speed with the DCS and the programmable logic controller (PLC) in order to handle variations in material type and control the stopping and starting of the feeder, depending on how the recycled materials were to be used.

Around 2000, the OPC standard (see Note 2) for methods of communication between measurement control devices such as DCS and applications started being used. OPC communication functions meant that computer systems could be built for process control without relying on DCS manufacturers. Faster computing speeds also saw process control computer control cycles drop from minutes in the 1990s down to seconds.

By 2010, cathode ray tube (CRT) operation by DCS and PLC was the norm for measurement control devices. Most were using proportional integral derivative (PID) control. Several controls in the raw materials proportioning process and the burning process used

process control computers for higher order processes and then via a gateway to “set point control” with adjusted DCS loop parameters.

5.7.2 Difficulty of Computerized Control in Cement Manufacturing ²⁰⁾

Most of the fuel and raw materials used in the cement industry are solids or powders of various different forms and characteristics. They are prone to inconsistent behavior, such as adhering together, blockages, segregation (bias and separation of particles or constituent ingredients) and flash (sudden bursts), which presents major difficulties in measurement as well as control. There is no way to measure the exact composition of raw cement materials as they enter the kiln, even if what is sent into the kiln is all natural materials and the composition variance and averages are known. The burning process controls have to be set using predictive values. There are also significant variations and fluctuations in the composition and heat value of recycled fuel and raw materials. There is also the occurrence of solid/gas and solid/liquid reactions at high temperatures in the kiln system (including the preheater and the kiln itself). In other words, cement kilns are a system made up of elements that are difficult to control, including significant disturbances, dead time, distributed constants, non-linear factors and time variations. Even if an attempt were made to use step response testing to try to ascertain certain characteristics, it is a process with a closed loop and slow reaction time. Testing would be very difficult due to the effects of other variables changing during testing and the complex effects of many different changes in input.

Computerized control developers at cement companies continued to battle with these processes and yielded results. Common to all the developments by different companies were the analysis of processes based on the analysis of data taken from years of observing onsite operation (human operation) and problem-solving using an academic approach in collaborating with external experts for joint research and theoretical corroboration. Carrying out joint research with external experts made it possible to expand the scope of operation to other plants and other processes. With a robust design to handle changes in processes and by making parameter adjustments very similar to actual operation, it was possible to create a long-lasting control system.

Cited reference (20) has more detail on specific examples of control systems that were developed.

5.7.3 Computerized Control: Current Situation in 2010 and Future Challenges^{4) 20)}

IT technology is advancing at a rapid pace. The following provides a brief overview of the state of computerized control technology for cement manufacturing in 2010 and the challenges for the future.

Due to increasing variety and volume of recycled resources and greater diversity in the types of coal, the main fuel source, in recent years, proper handling of these has become more complicated. This may have led to less stability in the cement manufacturing process. Changes in demand have meant major changes in production volumes (e.g. producing 4,000t/d with a 5,000t/d kiln). This has made existing control systems less stable and placed a greater load on operators. Many of the recycled resources that require high-temperature disposal are disposed of in the raw materials process and burning process. A major challenge for the future is how to control the composition of raw materials and combustion of fuel while utilizing recycled fuel and raw materials to the maximum extent.

In the finishing process in cement manufacturing, the clinker being ground is a chemical product and varies little in hardness, composition and other characteristics. This meant it was already quite an efficient process in the age of automated control. Consequently, with the introduction of computerized control, it has been far easier to deal with than the raw materials process and burning process.

(1) Raw Materials Proportioning Control^{21) 22) 23)}

The raw materials process uses a combination of online X-ray fluorescence analyses and computerized control. In this regard, the late 1960s saw rapid developments in the proportioning of raw materials and the integration of blending silos. This significantly improved the issue of homogeneity, which had been the weakness of the dry process. Thus, the wet process became a thing of the past (see 4.8).

The main method for analyzing the composition of raw materials proportioned at plants was usually X-ray fluorescence analysis using the glass bead method. Onoda Cement (now Taiheiyo Cement) set up a continuous measuring system using a special powder pressing mechanism to manage the chemical composition of the raw materials. However, this system was mainly for managing trends by continuously checking variations in composition and did not require highly accurate analysis. Because of the development of new systems, discussed below, this system is no longer used; however, it had some outstanding continuous management capabilities for the time.

In the 1990s, recycled materials began to be utilized in the process. As these materials began to increase in variety and volume, they were added in at various stages

in the process depending on the composition and characteristics of the material and the layout constraints of the facility. As a result, the constraints on raw materials proportioning have increased. The greatest challenge now is how to control composition while making maximum use of recycled materials.

The usual glass bead method of X-ray fluorescence analysis was accurate enough, but the process management system was essentially manual operation, from sampling on site to transportation to the laboratory, pre-processing of samples (crushing and melting to form beads) and X-ray fluorescence analysis. This meant that analysis was limited to once every one or two hours, which placed limitations on the consistency of the chemical composition of the raw material proportioning.

By contrast, the main method used today has automated all of the above (on-site automatic sampler → conveying by pneumatic tube → robotic pre-processing of samples → X-ray fluorescence analysis). The analysis data obtained is automatically forwarded to the raw material proportioning system, which performs computerized model predictive control. The proportioning ratio is controlled automatically for every type of raw material. Automating everything enables more frequent analysis than previously (for example, three to four times per hour), thus making it possible to have closer control over the proportioning ratio. With all of the complications with raw materials, this has made a significant contribution to chemical composition stability.

Most cement companies use model predictive control for controlling the proportion of raw materials. This is because model predictive control is easy to implement in control systems with multiple inputs and multiple outputs. It is also very robust and can handle increasing proportions of recycled materials. Conventionally, it was a system of feedback control, analyzing the composition of the output proportion and adjusting the proportions to match target values. An additional control target has been added: using recycled materials as preferentially as possible within the limitations of the composition. Further explanation of model predictive control can be found in specialized sources.

Automated composition analysis systems for process management are also being worked out for the burning process and finishing process. While X-ray fluorescence analysis is the only tool used to analyze composition in the raw materials process, many systems in the burning process and finishing process also use it in combination with powder X-ray diffraction by the Rietveld method (Note 3). This makes it possible to automatically quantify the f-CaO (free lime, indicator of burning degree) and mineral composition of the clinker/cement at the same time as the chemical composition. This is very useful, as the number of operators and quality control personnel can be reduced to take the appropriate action.

(2) Burning Process Controls²⁰⁾

The use of recycled materials has also increased in the preheater part of the burning process. The raw materials pass through the preheater for several seconds, requiring control cycles of seconds rather than the minute cycles in conventional rotary kiln control systems.

Since variations in recycled fuel and variations in the closed loop part of the process have a significant difference on the cycle, there are control mechanisms for adjusting each part of the process. Analyses are carried out to ascertain the degree of impact of these factors, including statistical analysis developed using a multivariable autoregressive model. Knowledge gained from tasks that were done manually, such as starting/stopping the recycled fuel feed and detecting and resolving blockages, is used to optimize and automate the system using an operational support system software package. These tasks were performed by DCS and PLC until the late 1990s. However, with the increase of alternative fuel and raw materials (AFR), it became necessary to increase the frequency of operation and coordinate with continuous control. Since 2000, companies have been introducing operational support systems.

(3) Computerized Control Technology Development Challenges²⁰⁾

In recent years, management has become centralized over networks, including data collection and program modification/correction. Using OPC communication, it has also become possible to use operational support systems and other software packages and development tools.

Meanwhile, the demand for cement started to decline even further from around 2000. Since then, there have been fewer instrumentation and control engineers, with the number halved by 2010. There are even companies now with no development engineers. This means that it is now more difficult to achieve what was previously accomplished by instrumentation and control engineers in the manufacturing industry, that is, to provide the connection between control theory and manufacturing site.

Even with new control theories emerging, there is of course no improvement in controllability if operators do not understand it or how to apply it to processes. Even if the effort is made to produce various new technologies and apply them on site, it is not uncommon for these to drop unnoticed out of use in the cement industry or any other industry. At this time of dramatic changes in usage of recycled materials, the control systems currently in place are also likely to drop out of use if sites cannot keep up with change.

Accordingly, there is a greater need now than ever to

create development systems in which development is done as efficiently as possible using software packages and generic tools. Companies also need to have input from collaborative research with external experts regarding modeling, process analysis and onsite control, with a strong need for process knowledge and operating know-how.

5.8 Overview of Energy-Conserving Technologies since 1970¹⁾

Cement manufacturing uses heat energy and electrical energy. This chapter has discussed the cement manufacturing devices and methods that have been introduced or developed since the 1970s. The main aim for these technologies has been energy conservation. The following discusses how much energy has actually been conserved as a result.

5.8.1 Trends in Heat Energy Consumption

As at 2011, the heat energy used at cement plants is made up of around 73% coal, around 12% petroleum coke, around 14% industrial waste and byproducts, such as waste oil and used tires, and a small amount (around 1%) of fuel oil (heavy oil). Coal is imported from China, Australia, Russia, Indonesia and other countries. Coal has a calorific value of around 27-29MJ/kg when it is burnt. Figure 5.13 shows the heat recovery and utilization in the cement burning process today.

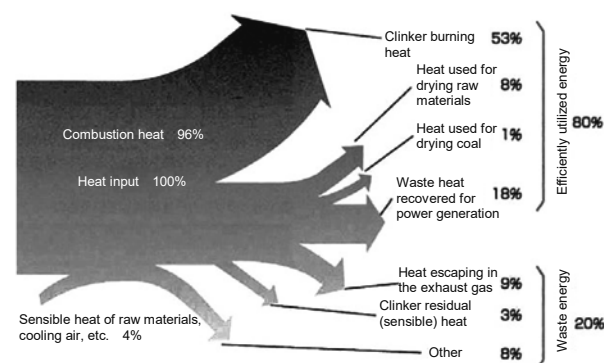
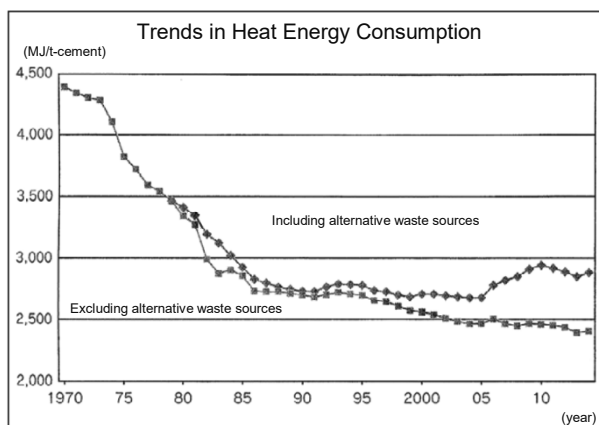


Fig. 5.13 Flow of Heat Energy at a Cement Plant¹⁾

Figure 5.14 shows the heat energy consumed in cement manufacturing (the heat energy needed to manufacture 1 ton of cement). As the figure shows, heat consumption decreased by around 40% in the 20-year period from 1970 to 1990. The main reason for this was the transition to the superior-energy-efficient and highly productive SP/NSP kiln systems from the wet process kilns and dry process kilns with attached boilers, as discussed above. By 1997, all kilns in Japan were SP or NSP kilns.

In recent years, combustible waste (alternative heat energy source) has been utilized as an alternative to fossil fuel in cement manufacturing. The definition of energy

given in Article 2 of the *Energy Saving Act* (formally the *Act on the Rational Use of Energy*), does not include “energy from the combustion of waste”. Therefore, heat from waste sources is represented as zero in the figures for energy consumed in cement manufacturing. The figures including the heat from alternative waste sources are provided for reference. In reality, it is difficult to ascertain the extent to which combustible materials from waste contribute to the burning process as a calorific value.



Note) Research on usage amount of alternative waste sources began in 1980

Fig. 5.14 Trends in Heat Energy Consumption since 1970²⁴⁾

5.8.2 Trends in Electric Power Consumption

Figure 5.15 shows the trends in electric power consumption since 1970.

One of the ways used to effectively utilize waste heat in cement manufacturing is waste heat power generation (see 4.2.2 and 5.6). Waste heat power generation is the generation of electric power using heat energy from exhaust gas. The electric power produced from waste heat power generation is distinct from power from power companies and private thermal power generation. The base figure is calculated by subtracting the amount of waste heat power from the total power consumed by processes. The total power is provided for reference.

As shown in the figure, electric power consumption decreased by around 20% in the 20-year period from 1970 to 1990. This is the result of actively introducing vertical mills with high grinding efficiency into the raw materials process (see 5.4.2), grinding aids into the finishing process (5.5.2), as well as classifying liners and smaller balls (5.5.3), eddy current separators (5.5.4) and pre-crushers (5.5.6).

However, there has been a slight upward trend in recent years, as increasing utilization of waste and byproducts has meant more electricity has been needed for handling (crushing, mixing, transporting, etc.) of those materials.

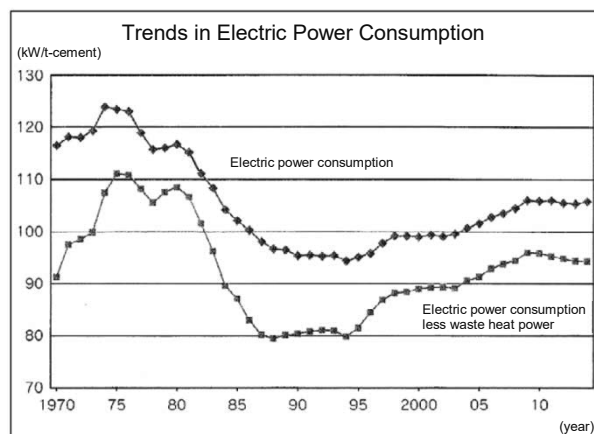


Fig. 5.15 Trends in Electric Power Consumption since 1970²⁴⁾

5.8.3 International Comparison of Energy Consumption

Figure 5.16 shows an international comparison of energy consumption. This is clear proof for future generations of the brilliant history-making achievements in production technology made by the Japanese cement industry in producing the world’s most energy-conserving technology.

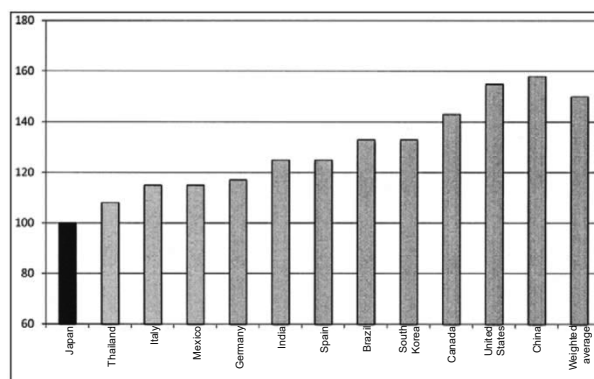


Fig. 5.16 International Comparison of Energy Consumption²⁵⁾

Comparison of energy consumed per ton of clinker (Japan=100, 2003)
Original data from: The International Energy Agency; 2008
Electric energy converted as 1 MWh = 0.086/0.33 toe
(toe: ton of oil equivalent; 1 toe = 41.8605 GJ)

Note 1: Air-Swept (Mill)

In an ordinary mill, the internal airflow has slightly negative pressure to limit external dust emissions. By contrast, the airflow in an air-swept mill is reinforced for cooling, drying and fines removal.

Note 2: OPC (OLE for Process Control)

Unified specifications for international standard inter-application communication interfaces, formulated by the OPC Foundation of the United States.

Note 3: Rietveld Method²¹⁾

A method devised in 1969 by Dutch crystallographer Hugo Rietveld for neutron diffraction. Called XRD/Rietveld when used with X-ray diffraction. Using the XRD/Rietveld method, the theoretical diffraction profile is refined from the X-ray diffraction diagram using the least squares method and the crystalline structure parameters are defined for each mineral. This makes it possible to refine the crystalline structure. In recent years, this method has started being used on samples of cement and other materials containing different kinds of

minerals. Like the crystalline structure, the scale factor, or parameters showing the proportion of different phases, can also be refined. This makes it possible to know how much of which minerals are contained in a sample.

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6 | Environmental Conservation Technology and Measures against Global Warming

This chapter discusses the following two points.

- (1) In the 1970s, environmental regulations were put in place and the cement industry had to comply with strict enforcement. Full use of existing technology as well as new technological developments made it possible to meet the strict controls.
- (2) Global warming became a topic of attention from the 1990s onwards. The cement industry is fated to cause carbon dioxide emissions, not only through the combustion of fuel (fuel-generated CO₂), but also through the decarbonization of limestone (process-generated CO₂). Efforts have been made in the cement industry to form international organizations to jointly research countermeasures.

6.1 Development of Environment-Conserving Technologies

The *Air Pollution Control Act* was established in 1968 and underwent significant amendment in 1970 at the 64th Diet session, otherwise known as the “Pollution Diet”, along with the creation of the *Noise Regulation Act*. Meanwhile, following pollution issues with Asano Cement’s Fukagawa plant in the early 20th century (see 4.11.1), companies and plants installed electrostatic precipitators and bag filters, as well as taking measures to prevent noise. Throughout that process, the technology dealing with “tangible pollution” reached near completion.

However, the Pollution Diet in 1970 was followed by the enactment and later amendment of the *Air Pollution Control Act*, the *Water Pollution Prevention Act* and other laws on preventing noise and vibration. As a result, people began to understand “environmental regulation” in the broadest legal sense, that it covers more than tangible pollution and includes nitrogen oxide emissions, sulfur oxide emissions and heavy metals in the cement.

Most of the sulfur oxide (SO_x) in the cement manufacturing process comes from the sulfur content in the fuel. However, since the cement kiln exchanges heat between the exhaust gas and the raw limestone material, the raw material captures SO_x during the heat exchange process. The SO_x eventually comes out of the kiln as a calcium sulfate compound in the clinker. In SP and NSP kiln systems, the preheater exchanges heat between the exhaust gas and the limestone and acts as a giant

desulfurization unit. This has meant most countermeasures are no longer necessary.

By contrast, a major issue for the cement industry is the inevitable generation of NO_x with high temperature fuel combustion. Burning clinker requires high temperature flames of around 1500°C in the burner, meaning NO_x generation is unavoidable. However, the NO_x is not absorbed at any point before the exhaust gas is emitted from the smokestack into the atmosphere. As a result, there have been some cases of plants having to comply with strict enforcement. Technological countermeasures for NO_x are discussed in 6.1.1 below.

Cement contains very small amounts of heavy metals (such as copper, lead and zinc), for reasons discussed later. As regulations were developed for the *Water Pollution Prevention Act* and water emission standards were adopted ready-mixed concrete plants and precast concrete plants, wastewater from these plants began to be monitored for heavy metals. The need arose for proper management of heavy metals in cement. See 6.1.2 for details on countermeasures for heavy metals in cement.

6.1.1 Nitrogen Oxide: the NSP Trump Card ¹⁾

Nitrogen oxide (NO_x) from cement kilns is produced as fuel is combusted in the kiln. NO_x from the combustion furnace is categorized by occurrence mechanism as “thermal NO_x”, generated as nitrogen in the air oxidizes during combustion, and “fuel NO_x”, generated as trace amounts of NO_x in the fuel are combusted (oxidized). Most of the NO_x from cement kilns is thermal NO_x generated by high temperature combustion.

As at 2014, the national NO_x emission standard for cement kilns was 480ppm (O₂: 10% conversion) for facilities predating 1975 and 250ppm for new facilities built since 1975. However, there are also cases of additional regulation according to local bylaws. In 1977, when the NO_x regulations for cement kilns were announced, some plants and kilns were identified as exceeding 480ppm.

The NO_x occurrence mechanism in cement kilns is due to the interaction of three factors: (1) the maximum temperature of the combustion flames, (2) the duration at maximum temperature and (3) the combustion air ratio. These three factors are also important for burning high quality clinker. One of the toughest challenges for cement plants has been that compliance with NO_x regulations is

at odds with producing high quality cement. Companies have worked hard to comply with NOx measures in order to survive, while the industry has worked on initiatives such as joint development of low-NOx burners. As a result of these efforts, the following NOx-reducing measures have been found to be effective.

- 1) Conversion to NSP: Combustion is separated between the rotary kiln and the calciner, thus reducing NOx by lowering the fuel ratio of the rotary kiln, which requires a high temperature range.
- 2) Use of low-NOx burners: An improved burner structure that (1) stabilizes and enlarges the NOx reduction area in the flame, and (2) ensures uniform pulverized coal spread and final burnout performance.
- 3) Elaborate operation management: Using the NOx reading at the furnace outlet as the performance indicator. If the NOx reading is high, working to reduce the NOx by adjusting the burner flame or using low air ratio combustion.
- 4) Utilizing waste material with denitrification (reduction) effects, such as biosolids.
- 5) Addition of denitrification agents: Adding agents such as ammonia or urea to the high temperature gas in the preheater.

Ultimately, at the present time, all companies have adopted full measures for 1), 2), 3) and 4) according to their own situations. Some are using 5) for any NOx in excess of the regulated readings. As at 2014, all cement kilns in Japan were SP or NSP, with NSP systems accounting for 83% of the total number of kilns and 86% of the production capacity.

6.1.2 Heavy Metals in Cement

The raw materials in cement are limestone, which has basic properties, and clay, which has acidic properties. The main components of clay are silicon dioxide SiO_2 , aluminum oxide Al_2O_3 and ferric oxide Fe_2O_3 . Slag (from copper or similar) is used as a source of Fe_2O_3 to adjust the ratio between these three components. Sometimes, the slag can contain trace amounts of heavy metals (such as lead or chromium), which remain in the cement product after the burning process.

In the 140-year history of the Japanese cement industry, there have been no reports of heavy metals in cement having a harmful effect on humans. However, as regulations were developed for the *Water Pollution Prevention Act* in the 1970s and water emission standards were adopted ready-mixed concrete plants and concrete products plants, wastewater from these plants began to be monitored for heavy metals. This is because there is a possibility that the heavy metals in cement could leach into the wastewater from cleaning up leftover concrete or into the water used to clean the floors and facilities at

ready-mixed concrete plants and precast concrete plants. Cement is also used for improving soft ground and stabilizing landfill waste. Accordingly, improved soil from earth mixed with cement must be certified as complying with regulations on heavy metals in the soil. Thus, cement companies have had to carefully manage heavy metals in the cement.

There are three main points for heavy metal countermeasures:

- (1) Heavy metals brought into the manufacturing process remain contained in the cement produced.
- (2) Accordingly, limiting the amount coming in also reduces the amount coming out.
- (3) The presence of heavy metals has very little effect on the quality of the cement (strength or setting).

Given the above, companies have dealt with the matter by setting voluntary standards for the amount of heavy metals contained in incoming raw materials so that no problem will occur.

With the aim of becoming an industry that contributes to resource recycling, active efforts have been made to incorporate various kinds of industrial waste and municipal solid waste as alternative raw materials and fuel sources. The issue of heavy metals has become a major issue for cement companies, requiring active rather than passive efforts. Technology development has continued in that direction. This is discussed further in Chapter 8.

6.1.3 Use of Bag Filters for Kiln Exhaust Gas

In the past, electrostatic precipitators (EPs, Cottrell precipitators) were used for dealing with kiln exhaust gas at cement plants. In recent years, there have been issues with interrupted operating stability and deterioration with EPs as the variety and volume of recycled materials used as fuel and raw materials has increased, with increasing risk to plant operation. Meanwhile, the use of low-heat power generation has dropped the final exhaust gas temperature to around 100°C. Along with the development of aramid fiber and other heat-resistant fibers, this has created the conditions necessary to use bag filters for kiln exhaust gas. In 2005, Taiheiyo Cement improved plant operation by dismantling and removing the existing EP at its Kumagaya plant and converting to bag filters. After that, the use of bag filters for treating kiln exhaust gas has steadily spread throughout the industry.

6.2 Measures against Global Warming ²⁾

The Earth Summit held in June 1992 prompted an increase in global awareness of the issue of global warming. In Japan, various initiatives commenced in the industrial, transportation and civic affairs sectors to

implement Kyoto Protocol reduction targets. In the cement industry, the energy conservation policies that had been worked on as a means of reducing manufacturing costs clearly resulted in reduced combustion-generated CO₂ emissions. However, the challenge for the cement industry was process-generated CO₂ produced in the limestone decarbonization process. Cement industry initiatives against global warming on this basis are outlined below. Greenhouse gases produced during cement manufacturing are almost entirely CO₂. Other greenhouse gases are generated in such trace amounts that they are scientifically negligible.

6.2.1 Measures to Reduce Greenhouse Gas (CO₂) Emissions

In 2014, the amount of CO₂ generated in the manufacture of Portland cement at cement plants in Japan was 0.73 kg-CO₂/kg-cement. This was generated from: (1) fuel combustion (around 45% of CO₂ emissions) and (2) limestone decarbonization (around 55%). At present, the cement industry has taken the following technical measures to reduce these emissions.

- (1) Thorough energy conservation
- (2) Utilization of decarbonized calcareous waste as a raw material
- (3) Utilization of biomass (plant-based) waste as a fuel source
- (4) Utilization of blended cement
- (5) Utilization of additives

(1) Thorough Energy Conservation

As previously mentioned, there have been constant efforts on this matter since the dawn of the industry, with particularly notable progress in energy conservation since the 1970s. Energy consumption is ranked among the best in the world, as discussed in 5.8.

(2) Utilization of Decarbonized Calcareous Waste as a Raw Material

(3) Utilization of Biomass (Plant-Based) Waste as a Fuel Source

Technological developments for items (2) and (3) are discussed in Chapter 9. In many cases, this utilization is limited by some of the constraints below.

- (i) The volume produced is often limited
- (ii) The area of utilization (acquisition) is often limited
- (iii) The chemical composition of the waste material can also limit the amount used

However, like (1) energy conservation, waste utilization is also linked to saving cement manufacturing costs. Technological developments to increase this utilization will definitely continue in the future.

Let us turn our attention to reducing CO₂ emissions by using combustible waste as an alternative fuel source for cement plants. Waste plastic is made from fossil fuels and combusting it increases CO₂. In that sense, it is different from biomass and other carbon neutral waste. However, using waste plastic and other combustible waste as an alternative fuel source for cement manufacturing produces less CO₂ than incinerating it. The reason for this is shown in Figure 6.1. When combustible waste is incinerated, it simply releases CO₂ into the atmosphere. If it is utilized in the burning process at cement plants, the heat produced by the waste can serve to replace some of the fossil fuel energy (of course not all of it). The CO₂ emissions from the cement plant remain the same, but the overall CO₂ emissions are reduced.

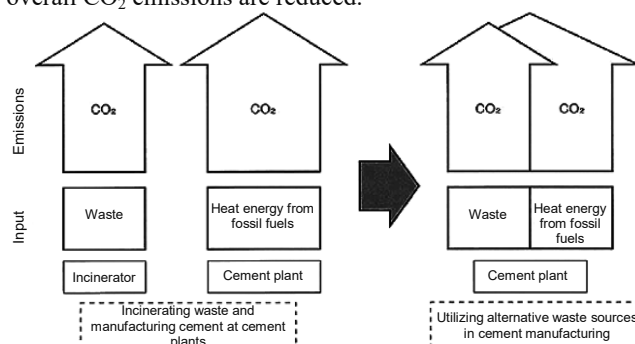


Fig. 6.1 Reduction in CO₂ Emissions by Using Alternative Waste Sources in Cement Manufacturing ²⁾

(4) Utilization of Blended Cement

Chapter 8 discusses the types and content of blended cements in the JIS standards. Since this cement is made of a blend of Portland cement and blast furnace slag or fly ash, the CO₂ emissions per ton of cement are reduced as far as the proportion of admixtures blended in.

Cement companies around Japan have a supply system in place for blended cement. However, the customer decides which cement to buy and use. In 2012, blended cement (blast furnace slag cement, silica cement, fly ash cement) accounted for around 25% of all cement produced. Figure 6.2 shows the trends in the blended cement production ratio.

Waste disposal is becoming a significant revenue stream for the Japanese cement industry. Companies and plants are incorporating waste products as fuel and raw materials as much as they are able to without affecting the quality of the cement. Consequently, provided that: (1) there is no growth in demand for cement, (2) the level of waste disposal technology remains the same, and (3) the proportion of blended cement increases, an environmental trade-off relationship will occur, in which there will be a negative impact on the amount of waste disposed at cement plants, incinerator disposal will increase and the lifespan of landfill sites will decrease.

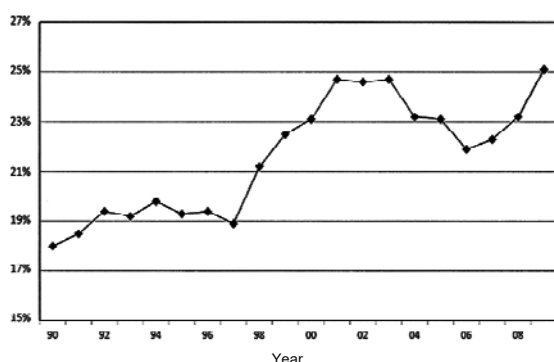


Fig. 6.2 Blended Cement Production Ratio Trends ³⁾

Developments in waste disposal technology in the cement manufacturing process are an important initiative as a countermeasure against global warming.

(5) Utilization of Additives

One genuine effort against global warming by the Japanese cement industry when the JIS standards were revised in 1979 was adding up to 5% of additives to Portland cement in keeping with industry demand. Four types of additives were approved in the JIS standards: blast furnace slag, fly ash, siliceous admixtures and limestone. This made it possible to reduce CO₂ emissions by up to 5% per ton of Portland cement manufactured.

6.2.2 Global Cooperation Initiatives by the Cement Industry to Reduce Greenhouse Gas Emissions

Cement industries in different countries joined forces to face the following global warming issues:

- (1) The cement industry is an energy intensive industry.
- (2) The cement manufacturing process produces not only fuel-generated CO₂, but also CO₂ from limestone decarbonization.

While global warming is a global issue that affects the entire world, government policies against it vary greatly due to each country seeking to protect and foster its own industries. Policies also differ between developed and developing nations. Similarly, companies in the cement industry vary in scale from so-called multi-national corporations to local manufacturers with one plant. Plants also vary in location from urban areas to remote deserts, and in production scale, from a thousand tons per year to several hundred thousand tons per year.

Given this situation, efforts were made at international collaboration with common awareness of common issues regarding global warming in relation to the cement industry. A number of international connections began to

form from the 1990s onwards. Below are two representative examples of this international collaboration.

(1) Asia-Pacific Partnership on Clean Development and Climate (APP) ²⁾

The APP was proposed by the United States in July 2005 and entered into by Japan, the United States, Australia, China, Korea and India. The partnership was launched with government and private participants from each country, with the aim of combatting environmental issues, energy security and climate change by developing and sharing clean, efficient technology. In October 2007, Canada joined as the seventh participating country. Under the APP, governments and industries worked together on issues related to the growing demand for energy, air pollution, energy security and greenhouse gas.

Of the eight sectors taking part, the cement sector was hosted by Japan. The Cement Association teamed up with the government (Ministry of Economy, Trade and Industry) to introduce energy-saving technologies and explain how to calculate CO₂ emissions from cement plants to the developing countries participating in the APP.

The APP ceased its activities in April 2011, but the Japanese cement industry adopted a policy of contributing to the reduction of energy used in cement manufacturing around the world and to the establishment of a resource-recycling society. It promised to publicize (1) its energy usage for cement manufacturing, (2) its energy-saving technologies (facilities) and (3) its waste utilization.

(2) The World Business Council for Sustainable Development (WBCSD) and the WBCSD Cement Sustainability Initiative (CSI) ⁴⁾

Taiheiyo Cement, Japan's largest cement company, has taken an active role in planning the activities of the World Business Council for Sustainable Development (WBCSD) and the Cement Sustainability Initiative (CSI), launched in 1999 as an industrial committee of the WBCSD. It has joined forces with cement companies around the world to promote initiatives for sustainable development in the cement industry to handle social and environmental issues effectively.

The following guidelines (recommended criteria for compliance by cement companies worldwide) provide a summary of the actual results achieved by the CSI to date.

- (1) CO₂ and Energy Accounting and Reporting Standard for Cement Industry
- (2) Guidelines for Co-Processing Fuels and Raw Materials in Cement Manufacturing

- (3) Health and Safety in the Cement Industry: Guidelines for Measuring and Reporting
- (4) Health and Safety in the Cement Industry: Examples of Good Practice
- (5) Guidelines for Emissions Monitoring and Reporting in the Cement Industry
- (6) Environmental and Social Impact Assessment (ESIA) Guidelines
- (7) Guidelines on Quarry Rehabilitation

The main achievement in relation to global warming has been (1) “Cement CO₂ and Energy Protocol: CO₂ and Energy Accounting and Reporting Standard for the Cement Industry”.

The burning process is not the only source of CO₂ emissions from cement industry activity. CO₂ is emitted by mining machinery during the mining of raw materials and by transportation as the cement is transported from the plant to the customer. CO₂ is emitted at the electricity source. It is emitted when purchased raw materials (such as slag or gypsum) are manufactured and when they are transported. It is extremely wide-ranging. Accordingly, the cement industry established the accounting and reporting standard to determine the criteria for boundaries and calculation methods so that companies could calculate the CO₂ emissions associated with their activities. This made it possible for any cement company in the world, from multi-national companies to local manufacturers, to easily calculate their own CO₂

emissions using the same criteria, which also made it possible to compare the figures published by each company. This system established the calculation methods used by companies around the world for reporting emissions to governments and for setting CO₂ reduction targets.

Although Taiheiyo Cement is Japan’s only member of the CSI, it is in reality an accurate representation of the Japanese cement industry. It shares the CSI matters for discussion and points of agreement with the other companies in Japan through the Japan Cement Association.

References

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http://www.env.go.jp/en/water/wq/ine/pdf/tool/3_guideline-fixed%20sources-jp.pdf
- 2) Japan Cement Association, *Introduction to Cement & Concrete*, 2013.
- 3) Japan Cement Association website, October 2015.
- 4) Taiheiyo Cement Corporation website, June 2015.

7 | Advances in Cement Chemistry

Consistently producing good quality products has always been the unchanging mission of not only the cement industry, but the manufacturing industry overall. This report on the history of cement manufacturing technology has mainly discussed technological developments for the purpose of consistent production in Chapters 2 through 5. However, in order to produce good quality cement, knowledge of cement chemistry and wisdom based on that knowledge play an important role. This chapter discusses the developments in cement chemistry from the invention of modern cement to the present day, while Chapter 8 outlines the development history of functional cement, that is, the diversification of cement types. Chapter 9 leads into the industry's progression towards becoming a core industry in a resource-recycling society. The development of functional cement, or the technology to dispose of waste in the cement burning process, was made possible by first having a foundation in cement chemistry.

In terms of academic disciplines, cement chemistry spans a very broad range of related fields. It encompasses inorganic chemistry as well as synthetic chemistry and is also strongly linked to analytical chemistry. There are many fields that focus on mineralogy and crystallography, as well as rheology. Of the wide range of fields that make up cement chemistry, this report focuses on cement chemistry that is directly cement manufacturing technology.

Japanese researchers began submitting papers to international journals and similar in these fields from around the 1930s. World-leading Japanese researchers began to emerge successively from around the 1960s.

There are two main categories of reactions in cement chemistry: the burning chemical reaction and the hydration reaction.

1) Burning chemical reaction: important research for "manufacturing" cement

A chemical reaction carried out during the burning of ground and proportionately mixed raw materials of limestone and clay at 1400-1500°C. The burning chemical reaction is a solid phase reaction with a partial liquid phase. The main topics of research are the solid phase reaction at high temperatures and the characterization of minerals contained in the clinker formed as a result of the reaction (see Note 1).

2) Hydration reaction: important research for "utilizing" cement

Cement obtained by mixing and grinding clinker with around 3% gypsum hardens when mixed with water. The

process of cement reacting with water and hardening is a hydration reaction. The main topics of cement chemistry research are the hydration reaction process and the characterization of hydrates.

This chapter provides a simple introduction to the basic details of the burning chemical reaction, the hydration reaction and their reaction products within the scope necessary for understanding cement manufacturing technology. Assuming this basic knowledge, this chapter outlines advances in cement chemistry from the invention of modern cement to the present day.

7.1 Burning Chemical Reaction and Clinker Minerals

7.1.1 Chemical Changes in the Burning Chemical Reaction Process ^{1) 2)}

Table 7.1 shows the average volumes (2011) of raw materials (raw material consumption) needed to manufacture one ton of ordinary Portland cement.

Table 7.1 Raw Material Consumption ¹⁾

	Unit: kg
Limestone	1,191
Clay	223
Silica	75
Iron-oxide etc.	27
Gypsum	39
Total	1,555

The powdered raw materials are burned in a rotary kiln after having been proportioned, dried and ground at fixed ratios, then sent through a preheater (SP/NSP). The burned clinker is cooled in a clinker cooler (see Chapter 5).

During the process from preheater to kiln to cooler, the compounds in the raw materials undergo gradual chemical changes with the increase in temperature until finally becoming the required chemical compound. Figure 7.1 shows the process of this change.

Large volumes of 3,000 to 10,000 tons of raw materials are burned per day at high temperatures. To produce good quality cement from the finished clinker requires accurate proportioning technology and temperature control technology. Ensuring a consistent high quality product requires a round-the-clock production management system.

7.1.2 Clinker Minerals ^{1) 2)}

Optical microscopy of burned and cooled clinker reveals the granules are a variety of mineral aggregates around 10-60µm in size (Figure 7.2).

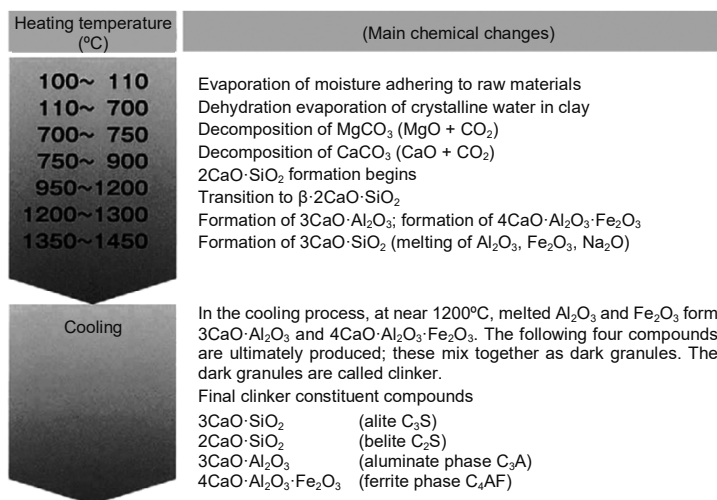


Fig. 7.1 Chemical Changes in the Burning Process ¹⁾

There are four main minerals (chemical compounds) that make up the clinker: alite (Figure 7.2 A), belite (B), aluminate phase and ferrite phase. Combined, these are termed “clinker minerals”.

Alite and belite are both calcium silicate and account for 70-80% of the clinker. Aluminate phase and ferrite phase are also called “interstitial phases” (I in the figure) because they serve to fill the gaps between the other two compounds. These account for 15-18% of the clinker.

Table 7.2 shows the chemical formulas of these compounds. Formulas shown in () are unique abbreviations used in cement chemistry (see Note 2).

Table 7.2 Chemical Compounds in Clinker ¹⁾

Structural chemical compounds in clinker		Chemical formula	Comments*
calcium silicate	alite	$3\text{CaO} \cdot \text{SiO}_2$ (C_3S)	Contains trace amounts of aluminum, iron, magnesium, sodium, potassium, titanium, manganese, etc.
	belite	$2\text{CaO} \cdot \text{SiO}_2$ (C_2S)	
interstitial phases	aluminate phase	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$ (C_3A)	Contains trace amounts of silicon, magnesium, sodium, potassium, etc.
	ferrite phase	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ (C_4AF)	

*Each compound usually contains other compounds as listed in the comments column.

These four chemical compounds have different characteristics, as mentioned below. Cement is developed for different purposes by altering the composition ratio of the clinker. This is discussed in Chapter 8. The following is a brief discussion of the characteristics of each constituent mineral in clinker.

Fig. 7.2 Clinker Photomicrograph ³⁾
(A: alite; B: belite; I: interstitial phases)

(1) Alite

C_3S (tricalcium silicate) is a crystal solid solution (see Note 3) containing trace amounts of Mg, Na, K and Fe. It is the most important compound in Portland cement. Ordinary Portland cement contains around 50% alite. It has a high hydration rate and shows good strength development from 1-day to 28-day in age (age → see Note 4). It also releases a lot of heat in hydration.

Appears under microscope as columnar or hexagonal-plate-shaped colorless crystals around 10-60μm in size (Figure 7.2 A).

(2) Belite

C_2S (dicalcium silicate) is a crystal solid solution containing trace amounts of Mg, Na, K and Fe. Ordinary Portland cement contains around 30% belite. It has a lower hydration rate than alite and takes longer to reach full strength, but releases less heat in hydration.

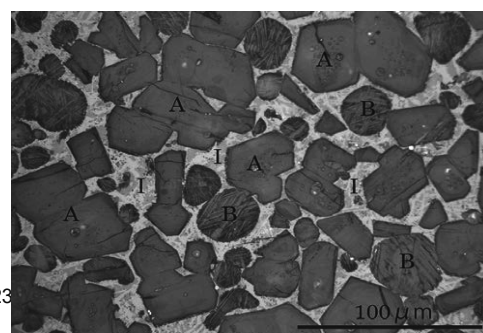
Appears under microscope as pale yellow or light brown clumps around 20-60μm in size (Figure 7.2 B).

Alite and belite are both more active in high temperature transformation (see Note 5) than low temperature transformation. Both also have good hydration and strength development. Accordingly, it is important to burn as long as possible at high temperatures to increase high temperature transformation and then cool the clinker to prevent the transition to low temperature transformation (see Note 5). This is an important point for manufacturing technology and an important role for the clinker cooler.

(3) Aluminate phase

Aluminate phase is one of the minerals that make up the interstitial phase in clinker. It is a solid solution containing Na, K and Mg and has a chemical makeup very close to C_3A (tricalcium aluminate). It reacts very quickly with water and instantaneously sets while releasing a lot of hydration heat. Gypsum is added as a setting regulator to inhibit this instantaneous reaction (see 7.5.1). Aluminate phase affects setting, 1-day strength and hydration heat.

Ordinary Portland cement contains around 10% aluminate phase, although some products,



such as moderate-heat Portland cement, for use in dams or other mass concrete applications are produced with less aluminate phase to control hydration heat (see 8.3.1).

Aluminate phase also reacts with sulfate to produce expansive ettringite (see 7.5.1 (2) and Figure 7.4). This degrades the composition of the concrete or mortar and causes the structure to deteriorate. Therefore, companies are also producing sulfate resistant cement, which has less aluminate phase to improve sulfate resistance (chemical resistance) (see 8.3.1).

(4) Ferrite phase

Ferrite phase is one of the minerals that make up the interstitial phase in clinker. It is a solid solution containing Na, K and Mg and has a chemical makeup very close to C_4AF (tetracalcium aluminoferrite). Ordinary Portland cement contains around 10% ferrite phase. While it has very little impact on the cement hydration reaction (setting, strength), it plays very important role in the burning process, as it forms a liquid phase and promotes chemical reaction. In other words, ferrite phase contributes more to energy conservation during manufacturing than it does to cement quality. The light gray color of cement powder is also mainly due to iron in the cement. White cement is cement that contains very little iron or ferrite phase.

(5) Other minerals in clinker

Observation of clinker under microscope reveals other minerals, such as (1) free lime (f-CaO) or (2) alkali sulfate $((Na,K)_2SO_4)$, depending on the raw materials and burning conditions.

f-CaO is unreacted quicklime. Clinker burned normally contains less than 1% f-CaO. Since quantitative analysis of f-CaO can be easily performed by chemical analysis or instrumental analysis, it has been used as a quick means of determining the quality of the clinker on site.

7.1.3 Moduli for Controlling Cement Composition Proportion ^{4) 5)}

As already mentioned, the typical chemical structure of cement (clinker) includes SiO_2 , Al_2O_3 , Fe_2O_3 and CaO. Varying the mixing ratio of these four compounds can direct most cement properties, such as clinker burning conditions, end-product cement strength, hydration heat and drying shrinkage. Consequently, cement plants mainly control the proportioning ratios of these four compounds in the cement raw materials.

In this sense, it is more efficient and effective to manage the quantitative ratios between the four compounds than to adjust and manage the amounts of

these individual chemical compounds separately.

Accordingly, three indicators called moduli are used to control the chemical composition of the raw materials. The target moduli are set according to the types and productivity (burnability, grindability) of the cement product to be manufactured, and then the proportion of raw materials is regulated to maintain these. The three moduli are managed together because there are four main compounds. The unit weight of each raw material can be determined by the solution to a four-variable simultaneous equation, using the values of each modulus and the condition that the total mass after burning is 1 ton.

Table 7.3 shows the moduli currently used by cement plants to manage the composition of Portland cement. Explanations are given below.

Table 7.3 Moduli for Regulating Cement Composition ⁴⁾

	Name	Chemical formula
Hydraulic modulus	H.M. = Hydraulic Modulus	$\frac{CaO - 0.7 \times SO_3}{SiO_2 + Al_2O_3 + Fe_2O_3}$
Silica modulus	S.M. = Silica Modulus	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$
Iron modulus	I.M. = Iron Modulus	$\frac{Al_2O_3}{Fe_2O_3}$
Activity index	A.I. = Activity Index	$\frac{SiO_2}{Al_2O_3}$
Lime saturation degree	L.S.D. = Lime Saturation Degree	$\frac{CaO - 0.7 \times SO_3}{2.8 \times SiO_2 + 1.2 \times Al_2O_3 + 0.65 \times Fe_2O_3}$

(1) Hydraulic Modulus (HM)

Of the four main compounds in Portland cement clinker, CaO is basic and the other three (SiO_2 , Al_2O_3 and Fe_2O_3) are acidic. In other words, the clinker burning chemical reaction is a salt formation reaction between acid and base at high temperature. The hydraulic modulus represents the ratio between the amount of acids and bases and is the most important of the cement moduli.

High HM raw mix generally require high burning temperature and adequate time, thus consuming more fuel. Insufficient burning can often lead to unreacted free lime remaining in the clinker. Since high HM cement is high in C_3S , it tends to have high early strength and high hydration heat.

Ordinary Portland cement clinker in Japan is currently produced with a HM value of 2.0-2.2.

(2) Silica Modulus (SM)

A ratio representing the quantitative relationship between acidic compounds. A high silica modulus means a lower amount of liquid phase to aid the burning chemical reaction and requires a higher burning temperature. This can damage the kiln lining as a result. However, high SM clinker is lower in interstitial phases and higher in belite, which produces cement that is low in heat generation and superior in late-age strength. Conversely, low SM means high liquid phase content, which can build up the coating on the interior wall of the

kiln, causing concern over obstructing the flow of raw materials (coating trouble).

Ordinary Portland cement clinker in Japan is currently produced with a SM value of 2.4-2.8.

(3) Iron Modulus (IM)

The ratio representing the quantitative relationship between Al_2O_3 and Fe_2O_3 . Raw mix with low IM can easily produce clinker minerals even when burned at low temperatures. Due to the low amount of C_3A and high amount of C_4AF , the cement has low early strength, but low hydration heat and high sulfate resistance. By contrast, high IM cement has more C_3A and hardens more rapidly. Consequently, it has high early strength, but high hydration heat and low sulfate resistance.

Ordinary Portland cement clinker in Japan is currently produced with an IM value of 1.9-2.1.

(4) Activity Index (AI)

Most cement plants in Japan manufacture cement by managing HM, SM and IM. However, some use the activity index (AI) instead of SM, while others control the Fe_2O_3 amount rather than using the IM.

Ordinary Portland cement clinker in Japan is currently produced with an AI value of 3.8-4.2.

(5) Lime Saturation Degree (LSD)

The chemical compound values for the moduli (1) to (4) above are simply the percent by weight figures for the chemical compounds in the clinker. They do not take the acid/base chemical equivalent into allowance. In that sense, they are practical ratios or indicators for simple process control and have little chemical significance.

By contrast, the lime saturation degree (LSD) is a ratio based on the chemical equivalence of the respective compounds contained in each clinker mineral phase.

This formula calculates the maximum CaO (saturated CaO) amount that can bond with the acid component. The coefficients for the compound denominators were first proposed by Hans Kuhl (Germany) and explored further by later researchers. The coefficients used currently were determined based on research by F.M. Lea and T.W. Parker (UK).

$$\text{CaOmax} = 2.8\text{SiO}_2 + 1.2\text{Al}_2\text{O}_3 + 0.65\text{Fe}_2\text{O}_3$$

When a raw mix with an LSD near 1.0 is fully reacted, all of the SiO_2 turns into C_3S , producing high early strength clinker. By contrast, burning a low LSD mix produces slow strength development clinker that is low in C_3S and high in C_2S .

LSD is used for setting compound ratios when

developing new types of cement. Some plants also use LSD instead of HM.

The standard LSD value of ordinary Portland cement clinker currently produced in Japan is 0.92-0.96.

7.2 Hydration and Hydrates¹⁾²⁾

Cement with water added and well mixed in is called cement paste (see Figure 1.1). If left in this state, cement first becomes moldable like clay, but then gradually hardens with time so that molding becomes more difficult. As more time passes, it finally sets hard. This is because the compounds in cement react with water to form new compounds called hydrates. The chemical reaction between cement and water is also called hydration. The process of cement paste gradually becoming harder and more difficult to mold is called setting, while the process of set cement becoming even harder is called hardening.

Figure 7.3 shows the process concept of cement reacting with water to form hydrates. The figure shows how hydration begins on the surface of the cement particles that come into direct contact with the water. As the reaction progresses, the unreacted portion grows smaller. The cement particles are covered over by the hydrate product, which binds together and hardens.

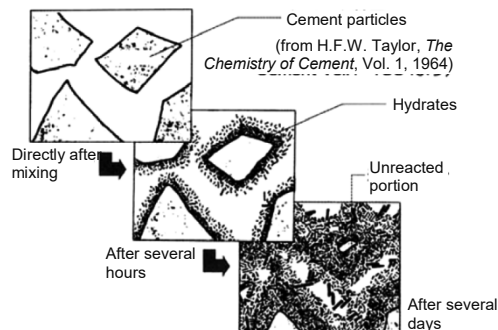


Fig. 7.3 Portland Cement Hydration Process¹⁾

Understanding about hydration and hydrates is very important when using cement. Ready-mixed cement plants measure and mix cement, gravel, sand, water and other additives, transport it to construction sites by mixer truck and pour it into formwork on site. The cement setting time and early stage hydration ensures time for the concrete to be transported and worked.

The poured concrete hardens with time. Once it has hardened to a certain point, the next scheduled task can proceed. For example, if it is a concrete foundation, things can be erected on top of it and machinery can be installed. The time until the concrete can begin to be used is determined by the strength development of the cement, that is, the cement hardening time.

Thus, from the perspective of using cement, the

important qualities are:

- (1) having a consistent setting time that is with a user-friendly range
- (2) having an adequate and consistent strength development

It is obvious that knowledge of hydration and hydrates is extremely important to cement manufacturers and users.

Hydration is an exothermic reaction, releasing the heat of hydration. This is discussed in 7.3.

Figure 7.4 shows the basic reaction formula for cement hydration. Cement hydration is an extremely complex chemical reaction in which multicomponent solids called clinker minerals react after dissolving in a liquid phase (water) and then precipitate as new tiny multicomponent hydrates (0.1 μm or less). A full explanation would require a very lengthy description. This report focuses on the necessary scope for understanding cement manufacturing technology, as per the discussion on hydration and hydrates below.

It should be noted that Figure 7.4 shows the formation of $\text{Ca}(\text{OH})_2$ as one of the alite/belite hydrate products. The presence of this $\text{Ca}(\text{OH})_2$ makes the hardened form of cement (mortar and concrete) basic.

7.2.1 Early Hydration and Setting Stage

The four types of clinker minerals (compounds) discussed in 7.1.2 start to chemically react immediately on contact with water. Alite C_3S and aluminate phase C_3A

are the quickest to react. Aluminate phase is especially quick to react and can set within a matter of minutes (flash setting). This can cause the mortar or concrete to set while still being worked.

To inhibit this flash setting, around 3% gypsum is added to the clinker when it is ground into cement. Gypsum dissolves in water and reacts with aluminate phase to produce a compound called ettringite (see Figure 7.4). The ettringite covers the aluminate phase, thereby preventing the aluminate phase from coming into contact with the water, thus slowing down the speed of hydration. Setting is delayed from several minutes without gypsum to several hours with gypsum added.

Meanwhile, like aluminate phase, alite phase also has a very quick initial reaction, but temporarily slows down later hydration. Although there are various theories on what causes this delay mechanism, it is not yet fully understood.

Testing methods for setting are regulated by JIS R 5201 *Physical Testing Methods for Cement*. JIS R 5210 *Portland Cement* stipulates that the initial setting for these testing methods is “60 minutes or more”, when stiffness begins, and the final setting is “within 10 hours”, when it can no longer be molded. Ordinary Portland cement on the market today is designed to have the initial setting at around two and a half hours and the final setting one hour later.

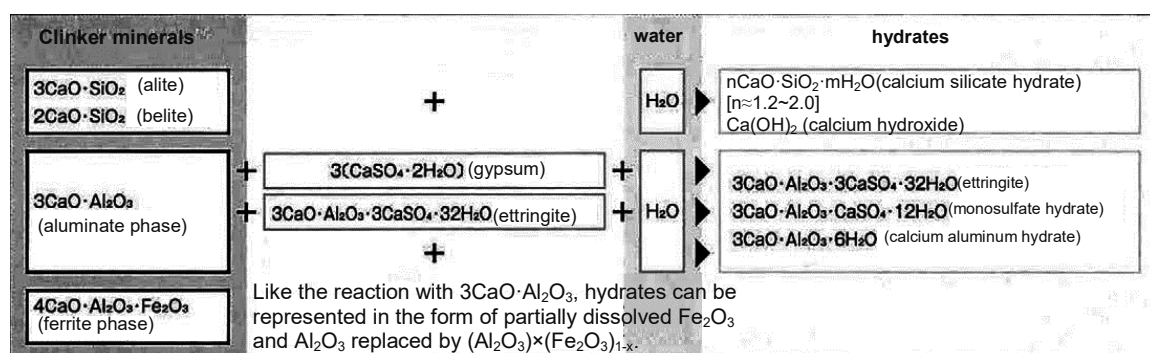


Fig. 7.4 Cement Hydration ¹⁾

7.2.2 Strength Development and Hardening Stage

The process from cement setting to hardening involves hydrates formed by hydration binding three-dimensionally and becoming denser as areas where water and air are present become filled. As it ages, it becomes denser and harder, thus developing the strength of cement and concrete.

Hardening is complete once the respective minerals that make up the clinker have finally formed hydrates. Hydration of cement particles usually begins on the surface and it can take a long time to fully hydrate. However, the particles do not have to be fully hydrated when the hardened substance exhibits the required strength. Hydrates on the surface of cement particles should form strong, physical, three-dimensional bonds with nearby hydrates. Accordingly, in terms of hydration, it is sufficient that water penetrates cement particles to a certain depth from the surface to produce hydrates. However, the amount of water added to cement at construction sites is not generally determined by the amount needed for hydration, but by the amount needed to produce the appropriate softness (consistency) for use at the construction site. As a result, the amount of water used in concrete is usually more than the amount needed for cement hydration.

7.3 Heat of Hydration ¹⁾

The chemical reaction between cement and water to produce hydrates is an exothermic reaction. The total amount of heat generated from the time the cement is mixed with water to a certain point in age is referred to as the heat of hydration at that age.

The amount of hydration heat varies depending on (1) the mineral composition (chemical composition) of the cement, (2) the fineness of the cement particles and (3) the amount of water mixed with the cement. The most important of these factors is (1) the clinker mineral content.

The heat of hydration has both positive and negative effects on the concrete. For example, in cold climates, concrete is wrapped in heat insulated material when it is poured and the heat generated from hydration is used as a means of insulated curing. By contrast, in mass concrete used in dams and large piers, the elevated temperature from the heat of hydration creates a temperature difference between the surface and the internal area and can lead to cracking (temperature cracks). Consequently, low hydration heat cement has been developed for mass concrete (see Chapter 8).

JIS R 5203 *Testing Methods for Heat of Hydration of Cement* regulates the methods for testing the heat of hydration of Portland cement. Ordinary Portland cement tested using those methods has a hydration heat of

318-336J/g at 7 days and 370-396J/g at 28 days.

7.4 Advances of the Cement Chemistry on the Burning Process and Clinker Minerals

“Ancient cement” used at sites dating to the Neolithic period was used for several thousand years throughout Ancient Egypt, Greece, Rome and China, up until the Industrial Revolution. It developed very little as a material, always made from mixtures of local materials and never going beyond the passing down of traditions by artisans (see 2.1).

Cement chemistry research based on scientific methods began in the mid-18th century, following the invention of “hydraulic mortar” by John Smeaton (UK) (see 2.2). At the time, the only research methods available were wet chemical analysis and optical microscopes. However, early researchers proposed bold hypotheses on chemical reactions of the burning process and clinker minerals based on close observations and devoted their efforts to empirical demonstration.

In the 20th century, the development of various analysis instruments, such as X-ray diffractometers and electron microscopes, made it possible to accurately observe, measure and analyze clinker mineral crystalline structures and hydrate microstructures. Cement chemistry research expanded rapidly in breadth and depth.

7.4.1 Chemistry of the Burning Process and Clinker Minerals: Advances to the Late 19th Century ^{5) 6) 7) 8)}

This section discusses the development history of “cement chemistry as cement manufacturing technology” during the 150-year period from the invention of modern cement in the mid-18th century to the end of the 19th century, focusing on the chemists who made significant contributions to cement chemistry.

- (1) John Smeaton (UK) invented “hydraulic mortar” in 1756, as mentioned in Chapter 2. Since it would have been difficult to achieve high temperatures with the burning technology of the time, the burning temperature is estimated to have been low, at around 1000°C. Consequently, in light of what is known in current cement chemistry, the so-called cement (clinker) minerals would probably not have formed. However, the SiO₂ and Al₂O₃ in the clay would probably have been activated by the calcination effect and increased the reactivity with CaO.
- (2) In 1796, forty years after Smeaton, James Parker (UK) invented Roman cement, as also mentioned in Chapter 2. This Roman cement is produced by burning clay-containing limestone (marl) in a limekiln at an estimated 1100°C and then crushed. It

would have hardened sooner and been more water resistant than the cement used since ancient times (a mixture of slaked lime and volcanic ash). It was widely used in the United Kingdom until the early 19th century, on projects such as tunnels under the River Thames.

- (3) Inspired by the invention of these “hydraulic materials” by Smeaton and Parker, from the late 18th century on, university professors, specialist chemists and other experts began researching how hydraulic cement could be made from clay-containing limestone.
- (4) In 1810, the Dutch Society of Sciences offered a prize for the submission of a paper that would answer the question, “What is the chemical cause, in virtue whereof clay-containing limestone makes generally more solid and durable masonry than shell lime, and what are the means of improving shell lime in this respect?”

Johann Friedrich John (1782-1847, Germany) claimed the prize in 1815 with a paper reporting the following:

- (1) When he immersed lime from burned clay-containing limestone in water to dissolve all the free lime and treated the residue with nitric acid, he discovered “a very intimate combination of part of the lime with silicic acid, alumina and iron-oxide” during burning.
- (2) Burning shell-lime mixed with an appropriate amount of clay yields the same result as clay-containing limestone.
- (5) In 1818, Louis-Joseph Vicat (1786-1861, France) announced his invention of a method for producing artificial hydraulic lime. Until then, hydraulic mortar had been made by either (1) mixing powdered brick or pozzolan with quicklime, a method used since ancient Roman times, or (2) burning clay-containing limestone (Smeaton’s invention). Vicat invented a third method: adding clay to quicklime or limestone and burning it. Although Vicat’s paper was published after John’s, mentioned in (4) above, the date it was sent for printing confirms that it was a separate invention from John’s.

The term “hydraulic” (Fr: *hydraulique*) was also first used by Vicat. He also invented the Vicat needle used in current JIS standard setting tests for determining the setting time of cements, as well as a method of testing cement erosion using a magnesium sulfate solution.

- (6) In 1824, Joseph Aspdin (UK) invented and patented Portland cement, 30 years after Parker’s Roman cement.

It should be noted that based on Aspdin’s patent,

there could be some doubt that he was the inventor of cement, for the following two reasons.

- (1) Prior to Aspdin, Smeaton had already burned hydraulic lime, while Vicat and John had proven that hydraulic lime could be produced by burning lime mixed with clay.
- (2) Aspdin’s patent is missing two important points from the current definition of Portland cement. It does not mention (1) the ratio range between the lime and the clay or (2) burning the proportioned raw materials until partially melted.

The burning temperature for Aspdin’s first Portland cement is estimated to have been around 1200°C. Although this would have caused the quicklime and the clay to react and produce small amounts of belite, interstitial phases and other cement minerals, there would probably have also been large amounts of quicklime in it as well. This means it would have had very little difference in quality from Roman cement.

- (7) In 1830, The Dutch Society of Sciences offered another prize for papers. The topic was to discover the ideal properties of hydraulic cement and to define the chemical bonding compound that causes hardening.

Johann Nepomuk von Fuchs (1774-1856) of Germany submitted a prize-winning paper within only two months of the prize being announced. In this paper, Fuchs concluded that the hydraulic properties of hydraulic mortar were mainly due to chemical bonding between silicic acid and lime.

- (8) Isaac Charles Johnson (1811-1912), manager of the J.B. White Roman cement plant in England, gained permission from his company to produce his own version of the new cement developed by Aspdin. In 1844, his independent research that (1) there is a ratio of lime and clay that produces good quality cement, (2) raw materials should be burned until partially melted and (3) proper mixing of raw materials is a basic condition for producing a homogenized product. Thus, he established the basic principles of Portland cement manufacturing, which are still valid today.

Due to Johnson’s manufacturing condition for Portland cement of burning limestone and clay at high temperatures of at least 1250°C until partially melted, cement minerals dramatically improved in quality, from the belite + interstitial phases of Aspdin-era cement to adding alite as well ⁸⁾.

In the 20 years between Aspdin’s patent and Johnson’s “new cement”, the Aspdin product

seems to have lacked any consistent quality. Johnson in later years requested the British Portland Cement Association to recognize him as the true inventor of Portland cement, but his request was denied. Instead, the Association acknowledged him as having improved Portland cement.

In 1924, the British and American cement associations jointly erected a plaque commemorating the centenary of the invention of Portland cement in Leeds, Aspdin's birthplace. The plaque inscription settled the dispute, citing Aspdin as the inventor.

- (9) In the late 19th century, various researchers began to hypothesize that clinker is made up of calcium silicate, calcium aluminate or other compounds. One pioneering researcher who attempted to scientifically (chemically) verify these hypotheses based on empirical testing was Henry Le Chatelier (1850-1936, France), known for Le Chatelier's principle of chemical equilibrium. Le Chatelier focused on theory and made some significant achievements, not only in cement chemistry, but also in the wider cement manufacturing industry.

One of Le Chatelier's major contributions to cement chemistry was the introduction of mineralogical techniques to cement chemistry, namely, the use of polarization microscopes. In his 1882 thesis *Recherches expérimentales sur la constitution des ciments et la théorie de leur prise*, Le Chatelier confirmed the existence of four types of compound mineral phases in clinker (four crystals and one glass phase) based on polarization microscopic examination of clinker flake specimens. He identified the most commonly occurring phase as $3\text{CaO} \cdot \text{SiO}_2$ (C_3S). He appears to have used chemically synthesized C_3S as a reference for identification.

- (10) Alfred Elis Törnebohm (Sweden) made the following two new contributions to cement chemistry with a paper published in 1897.
- (1) Naming the clinker minerals observed under microscope
 - (2) Isolating these minerals using heavy liquid separation

He confirmed "four crystals and one isotropic phase (probably glass)" under microscope and named these, in order of occurrence frequency, *alit*, *belit*, *celit* and *felit*. He created the names using A, B, C and F with the prefix "-lit" added, from

Greek *lithos* (stone). These names are still currently used to refer to these minerals.

Törnebohm was unaware of Le Chatelier's paper, published ten years previously. He later clarified which of the mineral phases recorded in Le Chatelier's paper corresponded with the minerals he had named. While the two made the same observations regarding the clinker mineral phases observed under microscope, they took different views on the chemical compositions of the different mineral phases. Neither view was correct from today's perspective, but that is inevitable given the limitations of the analysis methods of the day.

- (11) Wilhelm Michaelis (1840-1911, Germany) was a contemporary of Le Chatelier and made a substantial contribution to advances in cement chemistry. He majored in chemistry at vocational college and then worked as a chemist at a mineral research facility and a cement plant. In 1872, he and his partners founded an industrial chemical testing laboratory for testing building materials. He became the head of the laboratory in 1877. Michaelis made a wide range of contributions to cement manufacturing technology, including (1) proposing the "hydraulic modulus" for cement manufacturing, (2) discovering the setting regulating effect of adding gypsum to clinker, (3) theorizing on the hydraulic properties of cement, and (4) making various proposals on cement quality testing and standards.

Michaelis published the idea of the hydraulic modulus (HM) in 1885. Hans Kuhl (1879-1969), who succeeded him as the head of the laboratory, proposed the silica modulus (SM) and iron modulus (IM) in 1913. These basic indicators for adjusting cement raw material blends are widely used to this day (see 7.1.3).

The discovery of the setting regulating effect of adding gypsum was epoch-making, as mentioned in 3.4, and shall be discussed in further detail in 7.5.1. Further contributions related to (4) cement quality testing and standards are discussed in 8.2.1.

7.4.2 Chemistry of the Burning Process and Clinker Minerals: Advances from the Early 20th Century

In the 20th century, the development of various analysis instruments, such as X-ray diffractometers and electron microscopes, made it possible to accurately observe, measure and analyze the chemical compositions and crystalline structures of clinker minerals. Research on the burning process and clinker minerals had reached approximate completion by the end of the 20th century.

(1) Quick and Easy Determination Methods for Quality of Clinker on Site: Determining Free Lime Quantity ⁷⁾ and Measuring Volume Weight

The invention of rotary kiln burning has made it possible to burn several thousand tons of clinker per day in one kiln. However, it can take at least three days to one week to find out the results of the quality standard testing for the cement produced in a day. It is very likely that making adjustments on site after the results are known will be too late. Accordingly, there is a need for quick determination of the clinker quality on site that has come out of the kiln and the cooler. Methods proposed include (1) determining the quantity of free lime and (2) measuring volume weight (weight per liter). Both methods are still currently used as measurements that can be performed by workers on site.

A qualitative analysis of free lime in clinker was proposed in 1909 by A. H. White (USA). This method involved dissolving fine clinker powder in a solution of phenol and nitrobenzene and observing the solution under microscope.

This prompted various other studies on quantitative analysis methods. In 1915, W. Emley (USA) proposed a method of “extracting free lime in a solution of glycerin alcohol and determining the quantity using ammonium acetate”. In 1930, W. Lerch & R. H. Bogue (USA) improved this method and promoted it as a quick means of gauging burning degree that could be used at cement manufacturing sites. It was also adopted in the Japan Cement Association testing standards (JCAS/I-01 *Determination method for free calcium oxide*). The JCAS prescribes two methods: the glycerin alcohol method and the ethylene glycol method.

Volume weight measurement is a method involving separating out the coarse particles (e.g. sieve holes 10mm or higher) and fine particles (e.g. sieve holes 5mm or lower) from the clinker coming out of the clinker cooler and then measuring the weight of the medium particles by packing them into a container with a fixed volume. This method is widely used at plant sites because of the simple, easy measurement that makes it possible for the burning state of the clinker to be read and recorded numerically as a volume weight value. This method is thought to have been used for quite a long time, although it is not known when it began.

Automated measuring methods for both free lime and volume weight have been developed in recent years. These play an important role today as indicators that allow the burning degree to be determined quickly on site.

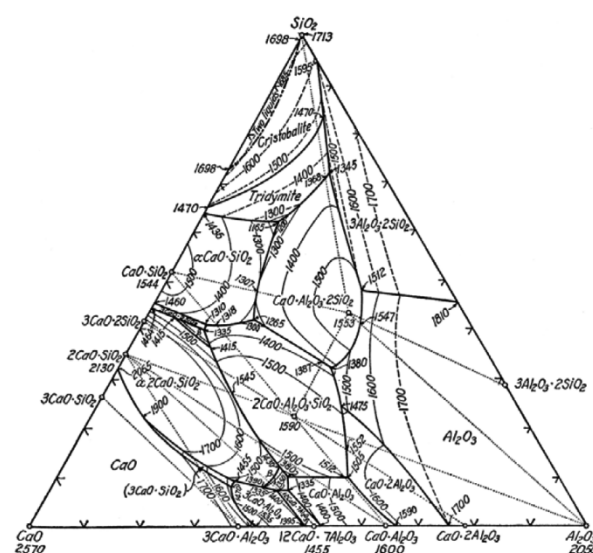
In terms of methods for measuring burning degree at chemist level, Dr. Yoshio Ono proposed a method of determining the burning degree of clinker under optical microscope in the 1960s. “Ono’s Method” became widely

used in many countries around the world. Ono’s Method is discussed in (6) below.

(2) Creating Phase Equilibrium Diagrams for Clinker Minerals ⁷⁾

From 1906 to 1915, many researchers at the Geophysical Laboratory of the Carnegie Institution of Washington, United States, took part in researching the phase equilibrium of lime, alumina and silica minerals for single oxide systems to binary-oxide and ternary-oxide systems, and successively producing phase diagrams. From that, G.A. Rankin & F.E. Wright published a phase equilibrium diagram for a $\text{CaO-SiO}_2\text{-Al}_2\text{O}_3$ ternary system (Figure 7.5), which accounts for up to 90% of Portland cement clinker.

Since then, a number of other researchers have published other clinker mineral phase diagrams for systems containing Fe_2O_3 and systems containing MgO , Na_2O , K_2O and other trace compounds. Reference (9) records almost all of these phase diagrams.



this method was expected to be useful for identifying, qualifying and quantifying substances, it was not used in actual analysis until the 1930s onwards.

In 1938, J.D. Hanawalt, H.W. Rinn & L.K. Frevel (USA) proposed a method of sorting X-ray diffraction data for quantifying and identifying. This was linked to the ASTM cards and provided a robust and universal analysis method for fine powder X-ray diffraction. Amidst these advances in technology related to X-ray diffraction, W. C. Hansen & R. H. Bogue (USA) published a paper on using X-ray diffraction to identify clinker minerals in 1926. In 1927, E. A. Harrington (USA) used X-ray diffraction for crystal structure analysis and, with the assumption that C_3A has a cubic crystalline structure, calculated its crystal lattice constant.

These studies were followed by later developments in X-ray diffractometers and the creation of ASTM cards, the Powder Diffraction File and other databases. X-ray diffraction began to be used in cement chemistry as a very useful and effective means of (1) identifying and quantifying minerals and (2) clarifying mineral crystal structures. After that, research on the characterization of clinker minerals expanded to greater depths and breadths.

(4) Proposal of a Method of Calculating Clinker Mineral Composition ⁷⁾

In 1929, Bogue proposed a method of calculating the clinker mineral composition by replacing the clinker chemical analysis value (weight %) with a simple formula (the Bogue formula). This formula assumes that “the four main cement compounds CaO , SiO_2 , Al_2O_3 and Fe_2O_3 ultimately become the four solid phases C_3S , C_2S , C_3A and C_4AF ” and ignores any trace compounds other than the four main compounds.

The formula is still widely used today because it is simple and convenient for finding out the relationship between the chemical composition and the approximate value of each mineral. In many countries, in order to maintain quality under the national standards, the amounts of particular clinker minerals shown by the Bogue formula are used as indicators. They are sometimes used to prescribe maximum or minimum values. JIS R 5210 *Portland cement* also prescribes maximum or minimum values based on the Bogue formula for mineral compositions in moderate-heat cement, low-heat cement and sulfate-resistant cement (see Chapter 8).

(5) Use of EPMA in Clinker Mineral Research ¹¹⁾

An electron probe micro analyzer (EPMA) is a device that detects and identifies constituent elements in microscopic regions (around $1\mu m^3$) irradiated by electron beams and analyzes the ratio (concentration) of each

constituent element. It can analyze solid specimens almost non-destructively.

The device was marketed in the late 1950s and gained a lot of attention among cement chemistry researchers. At the 5th International Congress on the Chemistry of Cement held in Tokyo in 1968 (see 7.6.2), Gorō Yamaguchi (University of Tokyo professor) and Shigehide Takagi (Onoda Cement) presented their results in a principal paper entitled “Portland Cement Clinker Analysis”, in which they applied EPMA to clinker characterization and analyzed the character of each phase of clinker minerals ¹¹⁾. This paper brought some closure to research on the character of clinker minerals.

(6) Japanese Technology “Ono Method”: Determining Clinker Quality by Optical Microscopy ^{2) 12)}

Despite the fact that the burning process is the most important process in cement manufacturing, it is extremely difficult to ascertain hour-by-hour changes in temperature distribution, movement of raw materials and the burning chemical reaction at different points within the kiln. Cement raw materials are burned in a partially melted state and do not fully melt in the kiln. This means that the heating and cooling of the kiln during the entire burning process is reflected in factors such as clinker particle size distribution, clinker structure and clinker mineral formation. The optical properties of clinker minerals vary in complex and diverse ways.

Dr. Yoshio Ono (Onoda Cement) simplified the burning process into “heating rate”, “maximum temperature”, “high temperature holding time” and “cooling rate”, as shown in Table 7.4. He found that these correspond respectively to four optical properties of clinker minerals under microscope: “alite particle diameter”, “alite birefringence”, “belite particle diameter” and “belite color”. This made it possible to estimate the “heat history” or burning conditions of clinker by a simple means of observing the optical properties of clinker minerals under optical microscope. It also made it possible to estimate the JIS 28-day mortar strength of cement.

Table 7.4 Clinker Burning Conditions and Alite/Belite Characteristics ²⁾

● Burning conditions ▲ Optical properties				
	Excellent (4)	Good (3)	Average (2)	Poor (1)
● Heating rate	Fast	←		→ Slow
▲ Alite particle size (μm)	15-20	20-30	30-40	40-60
● Maximum temperature	High	←		→ Low
▲ Alite birefringence	0.010-0.008	0.007-0.006	0.006-0.005	0.005-0.002
● High temperature holding time	Long	←		→ Short
▲ Belite particle size (μm)	25-40	20-25	15-20	5-10
● Cooling rate	Long	←		→ Short
▲ Belite color	Clear	Pale yellow	Yellow	Opaque yellow

The Ono method of clinker microscopy has the following advantages:

- (1) Measuring is possible using only an optical (polarization) microscope, a portable and relatively inexpensive tool that can be used anywhere at any cement plant.
- (2) Plant technicians can make measurements and determinations by learning the basics of cement chemistry.
- (3) Determining the burning state of the clinker can even predict the strength of cement made from that clinker.

Thanks to these advantages, the Ono method of clinker microscopy received a great response all over the world. The American Portland Cement Association (PCA) named it “Ono’s Method” and invited Dr. Ono to hold courses for cement companies all around the United States. This prompted courses in Ono’s Method in Japan and the rest of the world. In 1980, the PCA acknowledged Dr. Ono’s achievements at its annual general meeting. Ono’s Method is a great achievement that created direct links between basic research and manufacturing sites.

7.5 Hydration and Hydrates: Formation and Characterization¹⁾²⁾

Present-day cement/concrete has the following fortes:

- (1) It is a high-strength, fireproof and durable construction material.
- (2) It exhibits practical strength within a few short days or weeks.
- (3) It can also be freely molded.
- (4) Its functionality can be further increased by reinforcing it with steel or other material.

Of the above fortes of cement/concrete, (2) and (3) are due to hydration and its reaction products. Not only is the chemistry of hydration and hydrates very academically interesting, it also plays a very important role in practical applications in the form of concrete.

However, this hydration often produces hydrate products that are minute particles (microns or less) with poor crystallinity, containing many different ions or elements. Until the popular use of electron microscopes began in the mid-20th century, it was difficult to understand the true nature of the hydration phenomenon.

Nevertheless, early pioneers in the field kept up their efforts, making detailed observations of the phenomena they could see, and came close to the true nature of hydration and hydrates. From the late 20th century onwards, instrument analysis using electron microscopes and X-ray diffraction was added to the findings of early researchers to bring successive clarification to the matter of hydration and hydrates. However, hydration is a complex reaction system, as mentioned below, and even today there is still much that is unknown about it.

- (1) Cement constituent minerals are complex solid solutions, as mentioned in 7.4 above.
- (2) The hydration reaction is a heterogeneous reaction series between solid and liquid, involving numerous water-soluble compounds (such as Na_2O , K_2O , SO_3 and $\text{Ca}(\text{OH})_2$).
- (3) The hydration products that cause setting and hardening are often minute particles with poor crystallinity, containing many different ions or elements.
- (4) Hydrates can exhibit many kinds of bonding states, including covalent bonds, ionic bonds and hydrogen bonds, as well as having many bonding points with each other or with aggregates.

This section briefly touches on important events in the history of cement manufacturing technology, namely, the addition of gypsum, perhaps the greatest invention since the invention of modern cement, the related hydration of C_3A and the hydration of C_3S and C_2S , which control the final strength of the cement.

7.5.1 The Role of Gypsum in Hydration and the Hydration of C_3A

- (1) The Invention of Gypsum as a Setting Regulator¹³⁾

Modern Portland cement has around 3% gypsum added. This regulates the setting time of the cement to make it easier to use in construction. When Aspdin invented Portland cement (1824), it was simply made up of ground clinker. The cement product set very rapidly. From around the mid-1800s in the United Kingdom, those rapid-setting properties were compensated for through spray weathering. In the United States, a method of regulating setting by spray weathering was patented in 1870. In Japan, from the late 19th century to the 1920s, factories had weathering areas for spray weathering, as discussed in 3.2.3.

The idea of mixing in gypsum to achieve consistency in cement setting was thought up by Wilhelm Michaelis (Germany) in 1870 (see 7.4.1 (11)). Michaelis noticed the delayed setting effect of gypsum by observing phenomena such as the following. A plant in Stettin, Germany, received complaints from users accustomed to rapidly-setting cement that the cement was taking longer than usual to set. The plant manager Hugo Delbruck (1825-1900) investigated and found that the slow-setting cement was stronger than the rapid-setting cement. On hearing this, Michaelis determined that the reason for the slow setting of the cement was the high sulfur content in the coke used, that is, the production of CaSO_4 in the clinker. This is said to have led to the invention of adding gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). However, at the time it was forbidden to add any other additives into cement, so adding gypsum would have been done in secret. In 1883, the German Cement Association officially endorsed the addition of gypsum to cement, allowing the addition of up

to 2% gypsum.

However, the addition of gypsum was unknown outside of Germany in the 1880s. In the United States, Atlas successfully burned cement in a rotary kiln (1890, see 3.3.1), but the cement produced was very rapid-setting and hindered the wider adoption of the rotary kiln. To resolve this issue, the company employed French technician P. I. Giron. Giron believed that the burning of gas in the rotary kilns reduced the sulfur content in the clinker. Taking clues from French road paving, in which gypsum was dissolved in water when using cement, Giron resolved the issue by adding gypsum to the cement. This led to the widespread adoption of rotary kiln burning¹⁴⁾.

It seems that other companies in the United States had been secretly adding gypsum to their cement as well. C. Baumberger, president of San Antonio Portland Cement in Texas, mentioned in conversation that microscope observation and analysis of white particles found in cement ordered from Germany had shown them to be gypsum and that the use of gypsum solved the issue of rapid setting¹⁵⁾.

Asano Cement engineer Fuyuzō Sakauchi was the first in Japan to use gypsum in cement at the Asano Fukagawa plant after returning from studying in Germany in 1888. However, even in Japan this came under criticism at the time as “adulteration” (see 3.4).

As this movement progressed, the improvements made by adding gypsum spelled the end of weathering, which had previously been used to prevent cement from setting too rapidly. The discontinuation of weathering meant it made possible to manufacture cement that set consistently without sacrificing strength. The addition of gypsum to cement was a truly significant discovery in the history cement manufacturing technology.

(2) Effects of Gypsum on Hydration of Cement¹⁶⁾

Following Michaelis’ discovery of adding gypsum to cement in 1870, researchers immediately turned their attention to the hydration of gypsum-added cement.

In 1892, Michaelis himself identified calcium sulfoaluminate hydrate double salt as the hydration product of cement and gypsum. He named the product “cement bacillus”. This discovery was the first step in clarifying the cement hydration reaction with gypsum present. Later, this calcium sulfoaluminate hydrate $C_3A \cdot 3CaSO_4 \cdot 32H_2O$ became known as ettringite, named

after the Ettringen region in Germany where it is produced as a naturally-occurring mineral (Figures 7.4, 7.6, 7.7).

A huge amount of research followed on the mechanism of action of cement setting with gypsum and the related C_3A hydration reaction. The collected views up until the early 1950s are summarized by R. H. Bogue (USA) in cited reference (7), while research results up until 1995 are summarized by H. F. W. Taylor (UK) in cited reference (17).

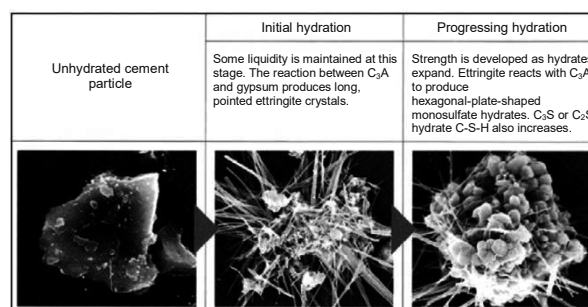


Fig. 7.6 Portland Cement Hydrate Formation Process¹⁾
(Original photographs: Sōichi Muroi)

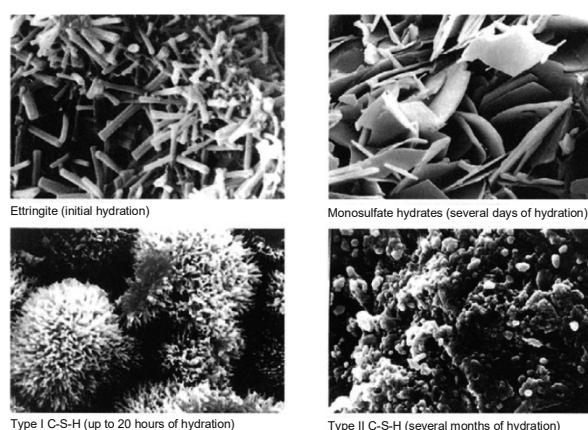


Fig. 7.7 Typical Hydration Electron Micrographs¹⁾

(3) Optimum Amount of Gypsum to Add¹⁶⁾

The initial aim of adding gypsum was to regulate setting. It was later found to have various positive and negative effects on cement properties other than setting.

Attention was first drawn to abnormal expansion taking place after hardening. Observing and experimenting with various phenomena showed this to be related to the amount of gypsum. In 1886, Germany amended its cement standard, noting that “cement containing more than 3% gypsum may exhibit abnormal expansion”. The cement standard was revised to limit SO_3 content (up to 2% at the time). After that, other countries also began to set maximum limits for SO_3 content. In Japan, SO_3 content was limited to no more than 2.0% in

the 1898 *Japanese Imperial Portland Cement Test Methods*.

In 1938, G. Mussgnug (Germany) and G. Haegermann (Germany) reported that a certain amount of gypsum will maximize mortar strength and that increasing the amount of gypsum reduces drying shrinkage^{18) 19)}. W. Lerch researched this even further, reporting in 1946 that (1) there is an “optimum added amount” for gypsum that will maximize strength and minimize expansion and shrinkage, and (2) the optimum added amount of gypsum is higher in cements that are high in C_3A and Alkalis²⁰⁾. In 1950, H. S. Meissner et al. proposed a “method of estimating the optimum added amount of gypsum” by measuring the residual gypsum in mortar²¹⁾. In 1955, Yamauchi & Kondo et al. (Tokyo Institute of Technology) reported that adding gypsum could improve the sulfate resistance of cement²²⁾.

As a result of these studies, it was shown that cement quality could be improved by slightly increasing the amount of gypsum over the maximum limit set by the existing standards. In the United States, several revisions were made from 1946 to increase the maximum allowable amount of SO_3 in cement. In 1958, the United Kingdom standards were revised in a similar direction. The current JIS standard for SO_3 in ordinary Portland cement is not more than 3.5%.

(4) False Setting^{16) 23)}

Depending on the cement, a phenomenon sometimes takes place in which mild stiffness occurs within 5-10 minutes of pouring. If mixing continues further, it will soften again and then go back to normal setting. This phenomenon is called “false setting”. Many research papers have been published on false setting since the early 20th century. The conclusion is that it is caused by (1) dehydration of gypsum due to the heat of cement, or (2) cement weathering.

Occurrences of (1) dehydration of gypsum are mainly caused by increased cement temperature during the finish grinding process. Various measures have been adopted to counteract this in the manufacturing process. Issues with (2) occur after product shipping from the plant. Protecting cement from weathering is an important factor in cement handling, such as transportation and storage.

In any case, there is very little issue in using false setting cement for concrete.

7.5.2 Silicate Phase (C_3S , C_2S) Hydration²³⁾

With silicate phase hydration in Portland cement, C_3S hydrates rapidly while C_2S hydrates considerably more slowly, but both produce calcium silicate hydrates and $Ca(OH)_2$. S. Brunauer & L. E. Copeland et al. (USA) stated in 1958 that when hydrated at a normal temperature, C_3S and C_2S produce $3CaO \cdot 2SiO_2 \cdot 3H_2O (C_3S_2H_3)$ similar to natural tobermorite²⁴⁾.

Later, a number of researchers began studying calcium silicate hydrates (abbreviated as C-S-H hydrates). The ratio between the C-S-H compounds was found to be affected by factors such as hydration time and hydration temperature. As $CSH_n-C_3S_2H_n$ ($n=1-2.5$) had the same structure, these were represented as CSH (I). C_2SH_n had a different structure and was generally represented as CHS (II) to distinguish it from CSH (I). The research on the hydration of calcium silicate hydrates up to 1995 are summarized by H. F. W. Taylor in cited reference (17) (see Figure 7.7). Table 7.5 shows a summary of the properties of cement clinker mineral hydrates. Chapter 8 discusses the diversification of cement types made possible by utilizing the different properties of these minerals.

Table 7.5 Properties of Cement Clinker Mineral Hydrates²⁵⁾

Properties		Alite (C_3S)	Belite (C_2S)	Aluminate phase (C_3A)	Ferrite phase (C_4AF)
Development of strength	Early	High	Low	Moderate	Low
	Late	High	High	Low	Low
Heat of hydration		High	Low	Very high	Moderate
Chemical resistance		Moderate	High	Low	Moderate
Drying shrinkage		Moderate	Low	High	Low

7.6 Contribution of Japanese Researchers to Cement Chemistry

The domain of cement chemistry is mostly academic in the field of science. Consequently, unlike in other fields, such as engineering, it is difficult to evaluate the Japanese contribution to cement chemistry in terms of economic effect. The extent to which a researcher is cited by other researchers is sometimes used as an indicator to measure contribution in the field of science. Accordingly, this report shows the prominence and success of Japanese researchers using two indicators: (1) the number of Japanese researchers cited in two highly authoritative textbooks in the field of cement chemistry; and (2) the number of research papers presented at international conferences in relation to cement chemistry.

7.6.1 Contributions of Japanese Researchers in Cement Chemistry Textbooks

The following world-renowned textbooks on cement chemistry are also known to the Japanese as “Bogue’s book” and “Taylor’s book”.

- (1) “The Chemistry of Portland Cement”, Robert Herman Bogue, Reinhold Publishing, 1955
- (2) “The Chemistry of Cement”, Vol. I & II, H. F. W. Taylor, Academic Press, 1964
- (3) “Cement Chemistry, Second Edition”, H. F. W. Taylor, Thomas Telford, 1997

Below is a comparison of the number of Japanese researchers out of the total number of researchers of papers cited in “Bogue’s book” (1) and “Taylor’s book” (3).

Total number of researchers cited 651
Of which are Japanese 7
(Number of Japanese papers) 19

(Only the first author of joint papers has been counted. Also see note below.)

By contrast, the following is a comparison from the 1997 edition of “Taylor’s book”.

Total number of researchers cited 1535
Of which are Japanese 112
(Number of Japanese papers) 45

This shows that the international presence of Japanese cement chemistry researchers grew dramatically in the four decades from 1964 to 1997. “Taylor’s book” cited 20 papers by Dr. Iwao Maki (Nagoya Institute of Technology) and 14 papers by Dr. Hiroshi Uchikawa (Taiheiyo Cement). This number of citations is world class for any researcher.

(Note) Since Bogue’s book (1) and Taylor’s book (3) differ in citation list style, the comparison is between the number of Japanese researchers out of the total number of researchers for (1) and between the number of Japanese papers out of the total number of papers for (3).

7.6.2 The Growing Presence of Japanese Researchers at the ICCC

The International Congress on the Chemistry of Cement (ICCC) is an international conference for researchers and engineers of cement chemistry. The first congress was held in London in 1918. It has been held every four to six years since the 1960s.

The second congress was held in Stockholm in 1938. There were no Japanese presentations at the first or second congress. The third congress was held in London again in 1952, this time with Dr. Shōichirō Nagai

(University of Tokyo) and Dr. Katsuzō Koyanagi (Chichibu Cement) noted in the minutes as taking part in the discussion on the principal papers. The fourth congress was held in Washington DC in 1960. Although none of the 20 principal papers were by any Japanese researchers at this congress, Japanese researchers had begun to make their presence known, presenting 6 of the 48 supplementary papers. The decision was made at this congress that the next one would be in Tokyo.

The fifth congress was held over five days at the Tokyo Bunka Kaikan (Ueno) in October 1968. Japan had grown in international status in the world of cement chemistry that it was invited to be the host country. At this congress, 5 of the 20 principal papers were presented by Japanese researchers. The Tokyo congress was held at the peak of research on clinker minerals and cement hydrates, facilitated by developments such as electron microscopes and EPMA^s ²⁶⁾.

Following the Tokyo congress, the sixth was held in Moscow (1974), the seventh in Paris (1980), the eighth in Rio de Janeiro (1986), the ninth in New Delhi (1992), the tenth in Gothenburg (Sweden, 1997), the eleventh in Durban (South Africa, 2003), the twelfth in Montreal (2007), the thirteenth in Madrid (2011) and the fourteenth in Beijing (2015). The Japanese have continued to present papers at every congress.

Note 1: Characterization

Seeking the answer to the question, “What is this really?”
In the case of cement chemistry, this refers to exploring and clarifying the crystalline structures, chemical compositions and physical/chemical properties of clinker minerals and hydrates.

Note 2: Abbreviations Unique to Cement Chemistry

C: CaO; S: SiO₂; A: Al₂O₃; F: Fe₂O₃; H: H₂O. For example, C₃S means 3CaO·SiO₂ in chemical formula. In this report, these abbreviations will be used where appropriate.

Note 3: Solid Solution

The melting together of two solid phases with different physical properties to become one is called a solid solution. A solid solution may be formed over the entire compositions or over a limited part of it only.

Note 4: Age

Age refers to the passage of time since adding water to cement. Up to seven days is called “early strength”, while over 28 days is called “long-term strength”.

Note 5: Transformation and Transition

Refers to the state in which a material has the same chemical composition but different physical properties or molecular arrangement due to differences in temperature, pressure or formation conditions. The shift from transformation A to transformation B is called transition.

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8 | Trends in Cement Standards and the History of the Cement Types and Blended Cements

It goes without saying that standards are extremely important in any industry, both for business transactions and for technological improvements. In particular, standards are of very high importance in the cement industry for the following two reasons:

- (1) Cement is the most important constituent ingredient in concrete. Concrete structures are expected to have a service life of 50 to 100 years or more. The only expectation consumers have for cement is that it performs the core function in the concrete. Cement standards could also be called cement manufacturers' promise to their customers.

This also means that when cement standards are to be revised or amended, consumers are very vigilant about safety and confidence. Due to concerns over safety and user confidence, it took some time for the technical research results on the addition of gypsum and the use of grinding aids to be reflected in the standards, as previously mentioned (see 3.4 and 5.5.2).

- (2) For manufacturers, "making JIS standard cement" is the entire reason the company exists. This is because the end use for around half of all cement is for public works, and the specification documents from the public agencies placing orders for those works generally require the use of JIS standard approved cement.

There is another important point related to standards. The cement manufacturing and distribution system in Japan comprises mass transportation from large-scale coastal plants by large ships to terminals in consumer areas (see 4.12.3). This highly rationalized manufacturing and distribution system makes it possible to have a surprisingly low price for a heavy chemical product. Incidentally, the price of cement in 2013 was around $\text{¥}10,000/\text{t} = \text{¥}10/\text{kg}^{(1)}$ for ordinary Portland cement. This manufacturing and distribution system was established on the idea of "fewer product types, mass production, bulk distribution". Accordingly, it is difficult to benefit from such a manufacturing and distribution system except for cement for large-scale use. Therefore, there is sometimes little hope for achieving a standardized commercial product from a business point of view, even if it is a long-awaited new technology or new material. There are even some product types that are already established under the standards, but are not actually being manufactured or marketed because of high manufacturing and distribution costs.

Given the business conditions such as the above

surrounding cement standards, Chapter 8 discusses the trends in the Japanese cement standards accompanying changes in the market and technological advances, as well as retracing the history of the types of cement and blended cement.

To provide an understanding of trends in standards and diversification of cement types, Section 8.1 introduces (1) JIS regulated cement on the Japanese market, (2) special non-JIS-regulated cement on the Japanese market, such as found in cement company catalogs, and (3) the JIS summaries (items) related to cement testing methods.

Section 8.2 discusses the course of events that led to the establishment of the cement standards based on the German example and follows the trends in cement regulations in Japan from the establishment of the 1905 *Japan Portland Cement Testing Methods* through to the 2010s.

Section 8.3 retraces the origins and innovations for each of the main cement types introduced in 8.1.

8.1.1 JIS Standards Related to Cement as at 2015²⁾

The Japan Industrial Standards (JIS) related to cement currently (as at April 1, 2015) comprise five standards relating to product quality and four standards relating to test methods.

(1) Product Quality Standards (five standards)

* Portland Cement: JIS R 5210

1 Ordinary Portland cement; 2 High-early-strength Portland cement; 3 Ultra-early-strength Portland cement; 4 Moderate-heat Portland cement; 5 Low-heat Portland cement; 6 Sulfate-resistant Portland cement

* Blended Cement

1 Portland blast-furnace slag cement: JIS R 5211
2 Portland pozzolan cement: JIS R 5212
3 Portland fly-ash cement: JIS R 5213

Types A, B and C of each of these; nine types in total

* Ecocement: JIS R 5214

Ordinary and rapid-hardening, two types in total

For reference, the cement compositions are shown in Figure 8.1. For details on the standards, see cited reference (3).

(2) Test Method Standards (four standards)

Standardized test methods enacted to assess the properties of cement include physical tests to determine

factors such as strength and fineness, chemical analysis and X-ray fluorescence analysis to determine chemical composition, and hydration heat tests to determine the heat of hydration. These standards are used to confirm the qualities designated by the cement quality standards. The results obtained using these test methods are recorded in a cement test results table.

JIS R 5201 Physical Testing Methods for Cement
 JIS R 5202 Methods for Chemical Analysis of Cements
 JIS R 5203 Determination of the Heat of Hydration of Cement (Solution Method)
 JIS R 5204 Chemical Analysis Method of Cement by X-ray Fluorescence

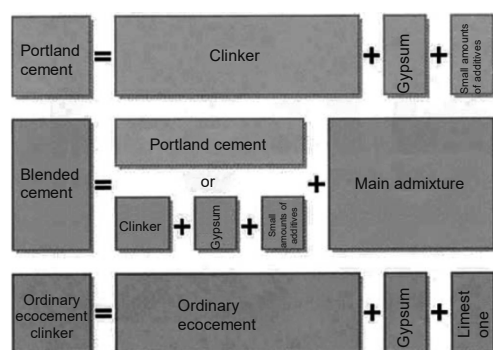


Fig. 8.1 Composition of JIS Regulated Cement ²⁾

8.1.2 Special Cement ²⁾

Some cements are used where a quality is required that falls outside of the scope regulated by JIS R 5210. These are generally termed special cements. Since these cover a broad range, some typical examples are shown in Figure 8.1. This report discusses “belite cement” and “white cement”, which are relatively higher in production. The former is discussed in 8.3.1 (4) and the latter in 8.3.1 (7).

Table 8.1 Types of Special Cement ²⁾

Classification	Cement Type
Based on Portland cement	Expansive cement Binary low-heat cement Ternary low-heat cement
Portland cement with modified composition or fineness	Belite cement White Portland cement Ultrafine particle cement Oil well/geothermal well cement
Different composition from Portland cement	Ultra-rapid hardening cement Alumina cement

8.2 Origin and Trends of Cement Standards

8.2.1 Origin of Cement Standards ⁴⁾

The world’s first cement standards were established in Germany in 1878. This was pioneered by Hugo Delbruck (1825-1900) and Wilhelm Michaelis (1840-1911). Delbruck took the lead in bringing the German cement

industry together, while Michaelis produced the draft standards.

Delbruck and Michaelis are also mentioned in 7.5.1 (1) with the discovery of adding gypsum (1870). Delbruck was the manager of a plant in Stettin, Germany, that had complaints of cement setting slowly where it had previously set rapidly. He proved that slow-setting cement was stronger than rapid-setting cement. This led to the discovery by Michaelis of adding gypsum. Although the Stettin plant under Delbruck was run down and in financial difficulty, he used science to improve the plant’s facilities and operations and rebuilt it into a highly profitable plant.

Having successfully rebuilt the Stettin plant, Delbruck earned reputation and credibility in the industry. He founded the German Cement Manufacturer’s Association in 1877 and served as its first chairman until 1899. One of the five items in the association’s founding charter (and the most important in hindsight) was the establishment of standards for procuring and testing Portland cement. Michaelis produced and presented the draft. In 1872, Michaelis established the Chemical Industrial Testing Laboratory for the purpose of testing construction materials.

The German cement industry in the 1860s had no unified methods for cement testing. Each plant devised their own tests to carry out. The industry was in disarray, with even the weight of one barrel of cement varying depending on whether it was net weight, whether the barrel was wrapped, whether German pounds were used or whether English pounds were used. Wanting to lay a foundation for the future prosperity of the industry, Delbruck brought order to this chaos and set to founding an industry association.

The proposal reviewed by the Cement Manufacturers’ Association was promulgated by German (Prussian) government ordinance and was adopted for all Portland cement supplied for government projects. This official standard was the forerunner for the cement standards now used all over the world. It regulated the following five items and their test methods.

(1) The weight of one barrel; (2) setting time; (3) soundness; (4) fineness; (5) 28-day strength.

8.2.2 The Origin and Later Development of Cement Standards in Japan ^{5) 6)}

The first cement standard in Japan was the Ministry of Agriculture and Commerce Notice No. 35 *Japan Portland Cement Testing Methods*, promulgated on February 10, 1905. Details on the situation before this standard was established are given in 3.6.2 and 3.6.3 and are not

repeated here. This notice by the Ministry of Agriculture and Commerce is viewed as Japan's first industrial standard. Subsequent cement standard trends can be grouped into the following three broad stages.

(1) 1900s to the 1950s

Advances in cement chemistry and developments in analysis methods and testing equipment added to the depth of the standards. Changes were also made to the standards due to industrial controls during the Pacific War.

(2) 1960s to the 1980s

Standards were added to as cement types became more diverse.

(3) 1990s to the present

As the cement industry became globalized, revisions were made to maintain consistency with ISO international standards. Other revisions were made to ensure the cement industry fulfilled its role as a contributing industry in a sustainable resource-recycling society.

Ministry of Agriculture and Commerce Notice No. 35 *Japan Portland Cement Testing Methods* was simply a standard for government purchasing. However, the promulgation of Japanese Engineering Standard No. 28 (JES 28) in 1927 placed the cement standards at national standard level. With the passing of the Industrial Standardization Act in 1949, the cement standards became Japanese Industrial Standards (JIS).

As previously mentioned, the cement JIS standards included product quality standards to determine standards of quality and test method standards for testing the quality. Demand from society and advances in technology resulted in further types of cement being produced. Standard quality test items and standard values were modified as cement quality improved. Test method standards were also modified as science advanced to ensure they remained universal. The main revisions are summarized below. For details, see cited references (5) and (6).

(1) 1927 revision

Under this revision, more details were stipulated on testing temperature, specimen regimen and methods for testing setting and strength. The standard sand was also changed from Tokyo sand to Sōma sand (see (4) below). The changes were widespread, including revised terminology, such as “elongation resistance” changed to “tensile strength” and “pressure strength” changed to “pressure resistance”.

(2) Major revisions of the test method for mortar strength (1941)

There were major revisions in 1941, including changing the test method for mortar strength, the most important characteristic of cement quality, from the existing hard method to the soft method and changing from measuring tensile strength to measuring bending strength. Accordingly, it is difficult to compare previous test data with modern values accurately.

(3) Standards under wartime industrial control

During the Second World War, it was not possible to manufacture high quality cements, such as high-early-strength cement and moderate-heat cement, due to poor coal quality and shortages of manufacturing materials. However, there was increased production of blast-furnace cement and pozzolan cement, as these required less coal and materials. For a time, these cements accounted for a third of all cement produced. Following an appeal to rationalize the use of cement, standards were created for lower-strength, non-structural cements, such as masonry cement and non-construction cement. These cements then emerged on the market. The standard for non-construction cement (enacted in 1942) stipulated manufacturing by mixing and grinding “Portland cement clinker, quenched blast-furnace slag, cement kiln dust, pozzolanic materials, gypsum, lime and other materials having equivalent properties”. Production ceased after the war and the standard was abolished in 1956.

(4) Standard sand

In cement strength testing, cement strength varies according to the type of sand used. The standard sand used for mortar testing in Japan was Tokyo sand from the late 19th century to the late 1920s. In 1927, the standard sand was changed to sand from Sōma in Fukushima. This was changed again in 1941 to sand from Kumipo in Korea. Since this was no longer accessible after the war, the standard sand changed again in 1947 to sand from Toyoura in Yamaguchi. In April 1997, the standard sand was changed once more to Australian sand, in order to conform to the international standard (ISO 679). Standard sand conformance testing and quality checking is usually carried out by the Japan Cement Association.

(5) Minor additives

In 1979, the stipulation was added that ordinary Portland cement could contain “up to 5% minor additives” to economize resources. There were four approved additives: blast-furnace slag, siliceous materials, fly ash and limestone. Later, a JIS amendment in 2009 allowed the addition of minor additives to high-early-strength cement and ultra-early-strength cement.

(6) Regulating alkali content in cement ^{7) 8)}

In 1986, new regulations were enacted for low-alkaline Portland cement in order to control alkali-aggregate reaction. Depending on humidity level and other conditions, bases (Na^+ , K^+) contained in cement can sometimes react with certain types of minerals in the aggregate, causing volume expansion. This phenomenon, known as “alkali-aggregate reaction”, can cause local volume expansion in concrete, causing cracks and weakening the concrete. In extreme cases, the concrete can even break apart. In order to avoid this risk, low-alkaline Portland cement was stipulated for when alkali-aggregate reactive aggregates must be used.

While the alkali-aggregate reaction has long been known about in the West, little care was taken in Japan, the belief being that “aggregates in Japan do not cause alkali-aggregate reaction.” However, since 1983, concrete structures have been found to have been weakening due to the reaction, particularly in the Kansai area. This brought the issue to attention that alkali-aggregate reaction also happens in Japan, with greater attention paid to the alkali content of cement.

As a result, when the JIS R 5210 *Portland cement* standard was amended in 1986, a section was added on low-alkaline cement, setting the upper value at 0.6% for the total alkali content, expressed as the total Na_2O and K_2O converted to Na_2O .

The stipulated total alkali value of “0.6% or less” in low-alkaline cement was determined as follows. The problem of alkali-aggregate reaction had long been known in the United States. American studies in the 1940s confirmed that “almost all damage to concrete due to alkali-aggregate reaction can be prevented if the alkali content of cement is 0.6% or less”. The American standard set the alkali value at 0.6% for low-alkaline cement. Many countries in Europe also set the alkali value at 0.6% for low-alkaline cement. With Japanese research results also reporting that 0.6% was safe, Japan also set the value at 0.6%.

However, the cement manufacturing and distribution system in Japan involves large-scale transportation of cement from large coastal plants to terminals in consumer areas. This made it very difficult to supply both ordinary Portland cement with no alkali restrictions as well as low-alkaline cement.

Accordingly, the standards were revised in 1992 to establish a new standard “full alkali” value for all Portland cement. The upper alkali content value of full alkaline cement was set at 0.75% or less. This meant consumers had a guarantee that all JIS approved Portland cement had an alkali content of 0.75% or less, meaning

that low-alkaline cement would only be ordered when absolutely necessary. This effectively resulted in almost no further demand for low-alkaline cement.

Of the cement standards around the world, only a very small minority (only Japan as at 2005) stipulate the alkali content for all Portland cement. The alkali-aggregate reaction is affected by the total alkali content of the concrete rather than the alkali content of the cement. The other materials used to make up the concrete (gravel, sand, water, additives, agents, etc.) should also have an equal part to play. However, in Japan, this is achieved through material regulation (see Note 1), only by regulating cement, as cement manufacturers are generally larger at enterprise scale than other concrete-related material suppliers ⁸⁾. This idea was carried over into the later regulation of chloride ions (see following section).

(7) Chlorine ⁸⁾

In 1992, new standards were enacted to regulate the amount of chlorine ions in order to improve the durability of reinforced concrete.

Following on from the issue in the 1980s with concrete breaking down due to alkali-aggregate reaction, as mentioned previously, the issue of salt damage to concrete was aired on NHK Television in 1983. In 1984, a television program was produced called *Concrete Crisis* (NHK), raising doubts about the durability of concrete.

The demand for concrete had grown dramatically with the rapid economic growth from the 1960s onwards. This led to shortages of aggregates, particularly fine aggregates (sand). In areas around the Seto Inland Sea, sand taken from the sea floor was used in concrete without being washed properly. As a result, the reinforcing steel in the concrete corroded, causing issues with the durability of the concrete.

Given the situation, investigation began on regulating the maximum amount of chloride ions in concrete to prevent the reinforcing steel from rusting. In the West, the maximum allowable amount of chloride ions was 0.6kg/m^3 for regular concrete and half that at 0.3kg/m^3 for pre-stressed concrete of particular importance. In Japan, the amount was set at 0.3kg/m^3 for regular concrete as well. This maximum allowable amount multiplied by the ratio of constituent materials in the concrete meant cement could contain an upper limit of 0.02% chloride. This was stipulated in JIS R 5210 in 1992. This was a very strict figure, one-fifth of the 0.1% upper limit given in the EN standards.

Later, as the cement industry sought to contribute to a sustainable resource-recycling society, there was some movement towards easing up on the chloride ion limit to

make it easier to utilize industrial waste. After considering the chloride content of poured concrete in real conditions, among other factors, the allowable amount of chloride ion in cement was eased to 0.035% in 2003.

Generally, chloride penetrating concrete from external sources, such as seawater or snow melting agents, after the concrete structure is built has a greater impact than the chloride ions contained in the concrete.

8.3 Diversification of Concrete Types: Cement Innovations for which there are JIS Quality Standards

With cement types diversifying, it goes without saying that “cement with desired functions and qualities could be produced consistently” as (1) cement chemistry theories advanced and (2) cement manufacturing facilities developed. Most new product developments from the 1960s onwards were developed based on cement chemistry theories.

Below is a discussion of the development of Portland cement and blended cement for which there are JIS quality standards. Ecocement is discussed in Chapter 9 “Evolving to become a Contributing Industry for the Sustainable Resource-Recycling Society”.

8.3.1 Development of Cement Regulated by JIS *Portland Cement*

Cement regulated by JIS R 5210 *Portland Cement* includes (1) ordinary Portland cement, (2) high-early-strength Portland cement, (3) ultra-early-strength Portland cement, (4) moderate-heat Portland cement, (5) low-heat Portland cement and (6) sulfate-resistant Portland cement, as well as their respective low alkali versions. Since this whole report covers the history of cement manufacturing technology, the history of ordinary Portland cement is omitted here. This section covers the development of the cement types from (2) high-early-strength Portland cement onwards. More detail is given to low-heat Portland cement in particular, as it has grown in use since the 1990s as cement for high-performance concrete. Although white cement is not stipulated by that name in the JIS, its history is also included in this section because it has been manufactured and sold in Japan for almost a century and conforms to the JIS standard for Portland cement.

(1) High-early-strength Portland cement ⁹⁾

This cement exhibits the three-day strength of ordinary Portland cement in one day. After modern Portland cement was invented in the late 19th century, it spread in use, with various new applications found for it. Design

and construction considerations led to demand for Portland cement with higher initial strength. Spindel of the Austrian State Railways devoted himself to this research. He refined the manufacturing process, and by heavily burning highly calcareous raw material and by finely grinding the clinker obtained, succeeded in producing high-early-strength Portland cement in 1913.

Later, this cement began to be manufactured in different countries around the world. The first instance in Japan was a trial manufacture of “high quality cement” in 1926 by Osaka Yogyō (now Sumitomo Osaka Cement). In 1929, Asano Cement started marketing it under the name of “Asano Velo-Cement”. After that, other companies began producing and marketing it under different names, such as “fine Portland cement” and “high quality Portland cement”. High-early-strength Portland cement was standardized in 1938 (by a Ministry of Commerce and Industry Notice).

(2) Ultra-early-strength Portland cement

This cement exhibits the seven-day strength of ordinary Portland cement in one day. It was developed in Japan using cement chemistry expertise for use on emergency construction projects. Production began in 1969 and the product was standardized under the JIS in 1973. However, technology was later developed that made it possible to produce “ultra-early-strength concrete” by using concrete additives rather than ultra-early-strength cement. As a result, ultra-early-strength cement is no longer produced, although there is a standard for it.

(3) Moderate-heat Portland cement ¹⁰⁾

This cement has more belite (C_2S) and less alite (C_3S) and aluminate phase (C_3A) than ordinary Portland cement, resulting in a lower heat of hydration. This cement offers superior long-term strength and is used in dams and other mass concrete applications.

It was discovered around 1930 in the United States that “increasing the amount of belite in cement and reducing the amount of alite, interstitial phases, particularly C_3A solid solution, reduces the heat of hydration”. The first use of “low-heat cement” based on this finding is thought to have been the Pine Canyon Dam project (California, USA) in 1932. It was also used for the well-known Boulder Dam (Hoover Dam) in 1933.

In Japan, the cement was first manufactured and marketed in 1934 by Asano Cement as “Asano Mascon Cement”. Its first use in a project is thought to have been the building of the dam for the Tsukabaru Power Station in Miyazaki in 1934. The cement was standardized under

the JIS in 1953.

Until the 1970s, the only “low-heat cement” in Japan was the JIS “moderate-heat” cement. From the 1980s, “low-heat cement” and “belite cement” emerged, making it possible to choose from “moderate-heat”, “low-heat” or “belite” cement accordingly when a concrete design required lower hydration heat. “Moderate-heat cement” was produced to order for large-scale dams or other such projects.

(4) Low-heat Portland cement and belite cement ¹¹⁾ ¹²⁾

JIS “low-heat Portland cement” has a lower heat of hydration than moderate-heat Portland cement. In terms of its composition, it is stipulated as containing 40% or more belite (C_2S) and 6% or less aluminate phase (C_3A). It is a high-performance cement, exhibiting the functions (1) to (7) listed below. Accordingly, the product is sometimes designed with a clinker composition ratio or specific surface area that deviates from the JIS standards, depending on usage conditions and purpose. This non-JIS cement is called “belite cement” and is treated as “special cement” (see Table 8.1). In other words, low-heat Portland cement is a type of belite cement.

The history of belite cement can be traced back to the “low-heat cement” stipulated in the American ASTM standards as “Type IV”. Following the two oil crises of the 1970s, the spotlight fell on belite from an energy-saving perspective, as it has a lower burning temperature and requires less heat for decarbonizing than does alite. Germany and the United States led the development research on high belite cement. While this was happening in the West, Japan was researching high belite cement with the focus on “low heat”. Thus, research and development of high belite cement began in Japan through improvements to the clinker itself, based on demand for cement manufacturers to produce low-heat cement for use in large-scale concrete applications such as the Akashi Kaikyō Bridge in the 1980s.

At the same time, urban concrete structures were being made taller, requiring higher strength concrete. However, high-strength concrete requires increased cement per cubic meter. Therefore, using ordinary Portland cement would create a lot of hydration heat, causing issues such as temperature cracking and decrease of long-term strength. To overcome this, research began on the use of low-heat high belite cement in high-strength concrete. The results showed that high performance AE water reducing agents worked effectively in high belite cement, with superior fluidity and long-term strength. Low-heat

Portland cement and other belite cement began to be used in the production of high-strength concrete.

The first product on the market was commercialized in 1992 by Chichibu Cement as “High Flow Cement”. “Low-heat Portland cement” was standardized under the JIS in 1997.

Although there are prior examples of belite cement overseas, the present-day high-performance product is the cement developed in Japan. To provide an outline of this development based on cement chemistry, the characteristic features of low-heat Portland cement are summarized below.

1 Effective in preventing temperature cracking

Since the hydration heat is low, there is little rise in the adiabatic temperature of the concrete. This and the low heat release rate effectively prevent cracking from thermal stress.

2 Superior long-term strength development

Since it is high in belite (C_2S), which offers superior long-term strength development, it continues to increase in strength for a long period of time.

3 Optimum for high-strength and high-fluidity concrete

Low-heat cement has fewer interstitial phases, which tend to absorb admixtures, and therefore the amount of both unit water content and high-performance AE (see Note 4) to add can be reduced. Consequently, it is suitable for making high-strength, high-fluidity concrete (see Notes 2 and 3). The development of cement that is not only low-heat but also capable of high-strength and high-fluidity, coupled with improvements in high-performance AE water reducing agents, led to the development of high-strength and high-fluidity concrete.

4 Superior chemical resistance

Since it contains little aluminate phase (C_3A), which is low in chemical resistance, this cement has higher chemical resistance against substances such as sulfates.

5 Low autogenous shrinkage (see Note 5)

Since it contains little aluminate phase (C_3A), which is a primary cause of early volumetric change, it is less prone to autogenous shrinkage than other types of cement.

6 Effective in preventing neutralization

Since it is a clinker-type cement rather than a blended low-heat cement made using admixtures of blast-furnace slag powder or fly ash, the alkalinity of the concrete is retained for longer, thus sustaining the neutralization-preventing effect for longer.

(5) Sulfate-resistant Portland cement ¹³⁾

This cement is highly resistant to sulfates. It is used in sulfate-rich environments, such as in the sea, in the ground near hot springs, sewers, industrial drainage and at chemical plants.

When hardened Portland cement is exposed to sulfates in soil, groundwater, running water or seawater, it erodes. Studies on cement that resists this erosion effect began in Europe and North America in the late 19th century. This was later backed by theoretical evidence from cement chemistry, leading to the creation of sulfate-resistant Portland cement.

C₃A (3CaO·Al₂O₃) in Portland cement reacts with sulfate to produce ettringite (see 7.5.1 (2) and Figure 7.4). The ettringite produces very high crystal growth pressure, which breaks down the structure of the concrete and mortar, thus weakening the structure. Consequently, sulfate-resistant Portland cement is made using far less C₃A (4% or less under the JIS), which increases the chemical resistance of the cement against sulfate. The JIS standard was announced in 1978.

(6) Low-alkaline Portland cement ⁷⁾

This cement has a total alkali content of 0.60% or less. This is stipulated as being allowed for use when the material used in the concrete “cannot be deemed harmless” in regards to alkali-aggregate reaction. See 8.2.2 (6) for the course of events leading to the enactment of this standard.

(7) White (Portland) cement ¹⁴⁾

“White cement” is literally pure white cement. However, since it differs very little from ordinary Portland cement in terms of its chemical and physical properties, it can be represented as “JIS ordinary Portland cement”. It is widely used, mainly for interior and exterior finishes on buildings, artificial marble, colored cement and concrete landscape products.

In terms of manufacturing, it differs from ordinary Portland cement in the following three important ways.

- 1 For the raw materials, limestone and clay are chosen that are very low in iron oxide, manganese oxide or other color-producing components. These components must be kept to a minimum in the clinker.

- 2 The iron component is in the ferrous (Fe⁺⁺) phase in the atmosphere of the burning zone. The clinker must be rapidly cooled in order to prevent the iron component from entering the ferric (Fe⁺⁺⁺) phase and producing color in the cooling process.
- 3 Ball mills are used for grinding both the raw materials and the clinker. To prevent the iron contamination, ceramic grinding media are used rather than iron grinding media.

The world's first white cement was manufactured at a plant in Heidelberg, Germany, in the 1880s. This was around 60 years after Aspdin's invention of Portland cement. The first white cement in Japan was produced at Onoda Cement's Onoda plant in Yamaguchi in 1916. The demand for it steadily grew after that, except during the war and for a time after it. White cement began to be produced by a couple of companies in Japan. By the late 1970s, as much as 500,000 tons were being produced per year. However, Japan later lost its competitive edge for exports to the Middle East and East Asia, which had accounted for more than 50% of production. As at 2015, white cement was only being produced by Sanyo White Cement (Itosaki, Hiroshima), a subsidiary of Taiheiyo Cement. For details on the chemical and physical properties of white cement, see cited reference (14).

8.3.2 Development of Cement Regulated by JIS Blended Cement ¹⁵⁾

There are three types of blended cement regulated by the JIS: blast-furnace slag cement, pozzolan cement and fly-ash cement. These all share the common properties of high long-term strength, high chemical resistance and low hydration heat. These effects are due to the latent hydraulicity of blast-furnace slag cement and the pozzolanic reactivity of pozzolan cement and fly-ash cement. Before discussing these cements in detail, the following is a simple explanation of latent hydraulicity and pozzolanic reactivity, which are important to understanding the functions of blended cement.

<Latent Hydraulicity> ¹⁶⁾

Granulated blast-furnace slag is a white or brown pumiceous particulate substance. It is formed by rapidly water-cooling of molten slag from a steelworks blast furnace.

Granulated blast-furnace slag does not harden by simply being mixed with water; however, a hardening hydration does begin due to the presence of alkali and other basic substances. This is called “latent hydraulicity”. The bases play a role as “stimulating agents”.

Granulated blast-furnace slag latent hydraulicity becomes evident as the stimulant bases cause the pH level

of the solution to rise above 12. Granulated blast-furnace slag that is stimulated by stimulants elutes Si, Ca, Mg, Al and other ions, which produce hydrates. The eluted substances maintain the pH level of the solution, while ions continue to dissolve and hydrates continue to form. The structure hardens as the blast-furnace slag hydration progresses.

Portland cement clinker functions as a stimulating agent because the hydration reaction produces Ca(OH)_2 and the pH level of the solution rises above 12. As a result, blast-furnace slag mixed with Portland cement is used as blast-furnace slag cement.

<Pozzolan Reactivity> ¹⁷⁾

Pozzolan refers to a fine powder admixture of natural or artificial siliceous materials, primarily made up of silica (SiO_2) or silica and alumina (Al_2O_3). While it does not harden of its own accord when mixed with water, it reacts with calcium hydroxide (Ca(OH)_2) in the presence of water at normal temperature and hardens into an insoluble substance. This phenomenon is called the “pozzolanic reactivity”. It is similar to but distinct from the above-mentioned latent hydraulicity. It is similar in that the alkalinity causes the elution of SiO_2 , which reacts with CaO to harden. However, it differs in that latent hydraulic materials harden due to their own CaO after the reaction has commenced, whereas pozzolan contains no CaO and requires the necessary CaO to be provided externally for producing hydrates and hardening.

High-early-strength Portland cement and ordinary Portland cement produce high amounts of calcium hydroxide (Ca(OH)_2) through hydration. This Ca(OH)_2 serves little purpose in strength development. It is also more soluble than calcium silicate or calcium aluminate hydrates and is more likely to dissolve on prolonged contact with water. Accordingly, adding pozzolan containing soluble silica or alumina to Portland cement stabilizes it by mixing with the Ca(OH)_2 produced by hydration to form calcium silicate and calcium aluminate hydrates. This ultimately contributes to improved impermeability of the hardened concrete, greater chemical resistance, lower heat of hydration and improved long-term strength.

Pozzolan can be categorized as natural or artificial. Artificial pozzolan includes fly ash, silica fume and rice husk ash. Natural pozzolan can be categorized as substances mainly made up of silica and alumina, such as volcanic glass and clay, and substances mainly made up of silica, such as opals and diatomaceous earth.

(1) Blast-furnace slag cement ¹⁸⁾

This cement is made up of blast-furnace slag powder from steelworks mixed with Portland cement. It has high long-term strength, low heat of hydration and good seawater and chemical resistance. It is mainly used in major civil works such as dams and harbors.

Blast furnace slag is produced by rapidly cooling slag with water and then grinding it to make a glassy granular slag (water-granulated slag). Emil Langen, director of an iron and steelworks in Germany, studied the reaction between this water-granulated slag and lime. He discovered the latent hydraulicity of water-granulated slag in 1862.

Around 1870, Wilhelm Michaelis (see 7.4.1 (11)) published the finding that “mixing Portland cement with a pozzolan, such as volcanic ash, or water-granulated blast-furnace slag improves the properties of the Portland cement”. In other words, he made the following two discoveries.

- 1 The known pozzolanic reactivity effect and latent hydraulic effect caused by quicklime or slaked lime worked exactly the same way with Ca(OH)_2 eluted from Portland cement.
- 2 After the concrete hardens, the residual Ca(OH)_2 in the concrete is drawn out by the pozzolan and blast-furnace slag, thus preventing concrete from deterioration by carbonation with CO_2 in the air.

Following this discovery by Michaelis, Godhard Prussing (Germany) manufactured the first blast-furnace slag cement in 1882 at the Vorwölle plant in Germany by mixing Portland cement with 30% water-granulated blast-furnace slag. There appears to have been some intense discussion at the time between the inventor and the German cement association regarding the purity of the cement.

In 1901, blast-furnace slag cement containing 30% or less slag was named “*Eisen Portlandzement* (iron Portland cement)” in Germany. The product was standardized in 1909. In 1907, Prussing’s son Paul produced blast-furnace slag cement containing 60-70% blast-furnace slag (*Hochofenzement*). This was standardized in 1917.

In Japan, Yawata Steel Works began researching this in 1910 as an effective way to utilize blast-furnace slag. Industrial production commenced in 1913 and an integrated production system from clinker was completed by 1918.

A standard was also created in 1926. Under the JIS modified in 1960, there are three types of blast-furnace slag cement, depending on the amount of slag contained: A (30% or less), B (more than 30%, up to 60%) and C (more than 60%, up to 70%).

(2) Pozzolan cement ⁹⁾

This cement is blended with natural silica admixtures (stipulated under the JIS as material containing 60% or more SiO₂). While pozzolanic reactivity improves concrete's permeability, durability and chemical resistance, proper care needs to be taken as the concrete has poor early strength and is susceptible to drying shrinkage.

While this type of cement can be traced back to the "lime mortar from slaked lime mixed with pozzolan" used from Greek and Roman times and throughout the Middle Ages, Michaelis was the first to come up with the idea of using Portland cement instead of slaked lime, as mentioned in the previous section on blast-furnace slag cement. By the end of the 19th century, "Portland pozzolan cement", high in good-quality pozzolan, was being sold in large volumes in Germany, Italy and other countries.

In Japan, Onoda Cement supplied a blended cement made by mixing three parts cement to one part volcanic ash in 1899 for use on a dock at the Sasebo naval port. The purpose was to improve chemical resistance (sulfate resistance) of the cement.

In the 1910s, a type of blended cement was produced by mixing calcined granite powder. Later, from around 1935, this began to be produced by a couple of cement companies under brand names such as "silicate cement". In 1940, a standard was created for this "silica blended cement". The name was changed to "pozzolan cement" through a revision of the standard in 1947. There are three types of this cement regulated under the current JIS, depending on the amount of admixture contained: A (10% or less), B (more than 10%, up to 20%) and C (more than 20%, up to 30%).

(3) Fly-ash cement ⁹⁾

This cement is blended with high-quality fly ash (fine coal ash) produced from the combustion of coal, mainly at thermal power stations. High-quality fly ash is a type of artificial pozzolan. Due to the pozzolanic reactivity, it improves the properties of the cement, such as greater long-term strength, lower susceptibility to drying shrinkage and permeability and better chemical resistance. Since the particles are spherical, it also improves the workability of the concrete. It is mainly used in major civil works such as dams and harbors.

Research on the use of fly ash as an artificial pozzolan

admixture in concrete began in the United States around 1914. The research became more active around 1937, with the first large-scale use starting around 1940 for dam concrete.

Research in Japan began around 1950. Production of Portland cement blended with fly ash began in 1956 under the name "pozzolan cement". Under the JIS amendment in 1960, it was regulated as "fly-ash cement". Like other blended cements, three types are regulated, depending on the amount of fly ash contained: A, B and C.

8.4 A Change in Lead Roles: The Lead Role in High-Performance Concrete Changes from Cement to Chemical Additives ^{11) 19)}

There are two ways cement itself can be made to achieve a specific function or performance: (1) improvements in the clinker minerals, and (2) adjustments to the cement particle size or shape. Thus far, Chapter 8 has discussed the development of different types of cements with various functions by "improvements in the clinker minerals". However, it can be seen that improving the function and performance of cement this way has reached a limit. Very little clinker-based cement function development is now being carried out anywhere in the world.

In 1995, Dr. Hiroshi Uchikawa (then a consultant for Chichibu Onoda Cement and a guest professor at Nagaoka University of Technology) published a paper in *Cement and Concrete* entitled "A Change in Lead Roles" ¹⁹⁾. The paper had a major impact on those in the cement and concrete industry, with the argument that "the lead role in concrete is no longer cement, but chemical additives".

The use of concrete admixtures, particularly chemical additives, will play an important role in the future as a means of improving concrete and giving it new functions. The main methods used in the development of concrete with new functions will be using adequate admixtures, improving the performance of additives and adjusting the size and shape of cement particles.

The knowledge thus far gained in cement manufacturing technology and cement chemistry will play a significant role in laying the foundation for new technology developments that will see the cement industry achieve its new mission for the 21st century, that of contributing to a sustainable resource-recycling society. This will be discussed in Chapter 9.

(Note) Concrete admixtures fall outside of the scope of "cement manufacturing technology" covered in this report, but are touched on briefly in 1.1 and

2.4 above. For more details on concrete admixtures, see cited reference (20).

Note 1: "Material Regulation" and "Performance Regulation"
Standards can determine "material regulation", which stipulates different materials, and "performance regulation", which allows free selection of materials to maintain performance or qualities. The current JIS cement standards are essentially material regulations. The stipulation on the alkali content of cement (0.75%) is effectively unrelated to the stipulations for other materials that make up concrete (water, aggregate, admixtures, agents, etc.). By contrast, if "performance regulation" was used, the standard could stipulate, for instance, "to prevent alkali aggregate reaction, the total concrete alkali content converted to Na₂O should be no higher than 3kg/m³". Making standards regulate performance allows users broader options for working techniques and materials used. It also allows suppliers to provide materials suited to the market (demand). This ultimately results in the conserving of resources and energy. Accordingly, there is a global trend of standards moving towards performance regulation.

Note 2: High-Strength Concrete ²⁾
The compressive strength of regular concrete, JIS ready-mixed concrete for example, is up to a "nominal strength of 45", or 45N/mm². Anything that is stronger than this is called high-strength concrete. Using high-strength concrete allows for smaller cross sections of reinforced concrete, resulting in a weight reduction. For this reason, high-strength concrete is widely used in bridges, tanks, high-rise buildings and precast products.

Note 3: High Fluidity Concrete ²⁾
Concrete that has greater fluidity to improve its workability is called high fluidity concrete. High fluidity concrete not only offers greater fluidity, but also superior material separation resistance. These result in greater filling of formwork, superior strength and durability after hardening. High fluidity concrete allows greater confidence in concrete quality, reduces labor on site, improves the working environment by reducing the noise of pouring and compacting, and also allows greater rationalization of the construction system.

Note 4: High Performance AE Water Reducing Agents ¹⁰⁾
Also called superplasticizers, these are additives (surfactants) that significantly increase the fluidity of concrete. Using these agents offers the same workability as regular concrete, but reduces the unit water content, resulting in high-strength concrete.

Note 5: Two Types of Concrete Shrinkage:
<Drying Shrinkage>
This phenomenon refers to the shrinking of concrete as it dries due to the evaporation of water added during the working of concrete that was not needed for hydration.
<Autogenous Shrinkage>
This phenomenon refers to the reduced volume (shrinkage) of hydrates compared to the original volume (cement + water) following the hydration reaction of cement. Normally, the amount of autogenous shrinkage is around 1/10 of the amount of drying shrinkage. Autogenous shrinkage can be a problem in high-strength concrete made using water reducing agents.

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9 | Evolving to a Contributing Industry for the Sustainable Resource-Recycling Society

The Japanese cement industry has been using large volumes of industrial waste and byproducts (see Note 1) as alternative fuel and raw materials (AFR) since the 1970s. The industry initially used industrial waste as a means of reducing costs. But, as it later expanded from industrial waste to include municipal waste and other general waste, the cement industry took on a new and highly valued role of contributing to society with growing awareness of global environmental issues and landfill sites in increasingly short supply.

Chapter 9 discusses the 21st century development of the cement industry from a “key industry providing construction materials” to a “core industry supporting a sustainable resource-recycling society”, based on developments in cement manufacturing technology and expertise in cement chemistry built up throughout the 20th century ¹⁾.

Section 9.1 outlines the kinds of waste materials recycled by the cement industry and why this is possible. Section 9.2 discusses the main new technologies that have been developed to allow greater varieties of waste to be recycled by cement plants in greater volumes. Section 9.3 discusses the contributions to post-earthquake waste disposal made by the Taiheiyo Cement Ōfunato plant (which was itself badly damaged in the earthquake and tsunami) and other cement plants in the Tōhoku/Kantō area following the Great East Japan Earthquake in 2011.

9.1 The Resource Recycling System Centered around Cement Plants ^{2) 3)}

In 2012, the Japanese cement industry recycled 28.5 million tons of waste and byproducts as alternative fuel and raw materials (AFR). This very large volume is more than double the amount of waste going into landfill in Japan (around 13 million tons in 2012). The following discusses the kinds of waste and byproducts recycled by cement plants and how this is possible.

9.1.1 Types of Waste and Byproducts used in the Cement Industry ³⁾

Manufacturing cement clinker requires raw materials primarily containing calcium, silicon, aluminum and iron. Previously, most of these had to come from natural materials. However, if waste and byproducts contain these compounds, it is possible to use them in place of natural raw materials (alternative raw materials). It is also

possible to use waste tires, waste oil and waste plastic as auxiliary fuel (alternative fuel) for cement burning, due to their high calorific value (see Table 9.1).

Table 9.1 Typical Composition of Main Waste Materials and Byproducts ³⁾

Cement raw material (waste and byproducts)	Calcium oxide CaO	Silicon dioxide SiO ₂	Aluminum oxide Al ₂ O ₃	Ferric oxide Fe ₂ O ₃
Coal ash	5~20%	40~65%	10~30%	3~10%
Incineration ash	20~30%	20~30%	10~20%	~10%
Biosolids	5~30%	20~30%	20~50%	5~10%
Casting sand	~5%	50~80%	5~15%	5~15%
Waste tires			~10%	5~20%
Blast-furnace slag	30~60%	20~45%	10~20%	~5%

The cement industry developed the technology to use various waste matter and byproducts as alternative fuel and raw materials (AFR) (Figure 9.1). In 2012, the total amount of waste and byproducts accepted by cement plants reached around 28.5 million tons per year, corresponding to 481kg of waste/byproduct used per ton of cement (Figure 9.2, Table 9.2). Of these, the most commonly used materials were blast-furnace slag and coal ash, as shown in Table 9.2. Around one third of blast-furnace slag generated and around half of the coal ash emitted by coal-fired power plants is used by the cement industry as an additive or raw material.

9.1.2 The Reason the Cement Manufacturing Process is Suited for Waste Disposal ³⁾

The cement industry recycles a great variety of waste matter as raw materials or fuel for cement manufacturing. This recycling is possible due to the following manufacturing advantages.

- (1) Cement kilns have a very high burning temperature, meaning dioxins, fluorocarbons and other harmful substances break down and become harmless.

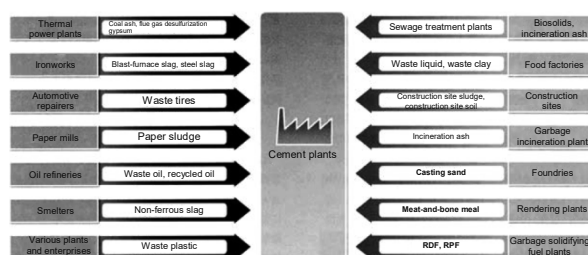


Fig. 9.1 The Resource Recycling System Centered around Cement Plants ³⁾

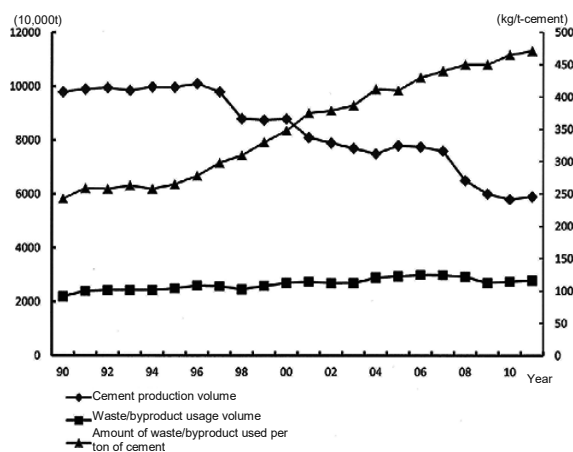


Fig. 9.2 Trends in Waste/Byproduct Usage Volume and Cement Production Volume ³⁾

- (2) The cement industry effective energy utilization rate is very high at 80% (see Figure 5.13), a far higher energy utilization rate than incinerating waste with an incinerator.
- (3) The ash left over from burning waste matter forms part of the raw materials for cement, burned in a rotary kiln to produce cement clinker. Accordingly, the utilization of waste at cement plants does not involve the generation of secondary waste

However, cement kilns need to be closed for several consecutive weeks of the year (scheduled closure) for repair and maintenance of the firebrick lining inside. Although storage of blast-furnace slag, coal ash, incineration ash, waste tires and waste plastic during that time is not a major problem, there needs to be adequate advance consideration on how to manage the receiving of biosolids and raw garbage during the closure period. This is easy to handle for plants with multiple kilns, but plants with only one kiln have to divert it to another plant owned

by the company. In some cases, they may have the option of diverting it to a plant owned by another company through inter-plant cooperation.

Certain types of waste matter, such as incineration ash and waste oil, can contain heavy metals or other harmful substances. Consequently, cement plants make thorough checks on the following to verify safety before making on contracts to accept waste.

- 1 There is no possibility of harmful substances being released into the atmosphere during the cement burning process.
- 2 There is no possibility of harmful substances being eluted in wastewater or into the soil when the cement is used as concrete or as a soil stabilizing material by the user.

It takes all the manufacturing technology know-how and the cement chemistry knowledge that have been built up over the years to carry out these tests and checks. Even after a plant has started accepting waste, frequent strict checks are carried out to ensure the waste being delivered is in accordance with the contract agreement and to ensure the emissions and the product quality meet the control criteria.

The following discusses newly developed technologies for safely utilizing large volumes of waste matter in the cement manufacturing process.

Many of the waste materials and byproducts given in Table 9.2 can be used directly in the cement manufacturing process without any particular pre-processing. For example, this includes blast-furnace slag, coal ash, byproduct gypsum, casting sand, steel slag, waste tires and coal waste.

Table 9.2 Main Applications and Usage Volumes of Waste and Byproducts used in the Cement Industry ⁴⁾
(unit: 10,000t)

Type	Main application	1990	1995	2000	2005	2010	2011	2012	2013
Blast-furnace slag	additive, raw material	12,228	12,486	12,162	9,214	7,408	8,082	8,485	8,995
Coal ash	raw material, additive	2,021	3,103	5,145	7,185	6,631	6,703	6,870	7,333
Sludge	raw material	312	905	1,906	2,526	2,627	2,673	2,987	3,206
Construction soil	raw material	-	-	-	2,097	1,934	1,946	2,011	2,407
Byproduct gypsum	raw material (add-in)	2,300	2,502	2,643	2,707	2,037	2,158	2,286	2,401
Combustion residue (other than coal ash), soot, dust	raw material	478	487	734	1,189	1,307	1,394	1,505	1,405
Non-ferrous slag	raw material	1,233	1,396	1,500	1,318	682	675	724	770
Wood chips	thermal energy	-	-	2	340	574	586	633	657
Casting sand	raw material	169	399	477	601	517	526	492	461
Waste plastic	thermal energy	-	-	102	302	418	438	432	460
Steel slag	raw material	779	1,181	795	467	400	446	410	423
Waste oil	thermal energy	141	107	120	219	275	264	273	273
Waste clay	thermal energy	41	94	106	173	238	246	253	273
Recycled oil	thermal energy	0	126	239	228	195	192	189	186
Waste tires	raw material, thermal energy	101	266	323	194	89	73	71	65
Meat and bone meal	raw material, thermal energy	-	-	0	85	68	64	65	63
Coal waste	raw material, thermal energy	1,600	1,666	675	280	0	0	0	0
Other	-	361	379	431	468	595	606	835	887
Total	-	21,763	25,097	27,359	29,593	25,995	27,073	28,523	30,265
Amount used per ton of cement (kg/t)	-	251	257	332	400	465	471	481	486

Note) Construction soil is included under "Other" until 2001.

9.2 Waste Recycling Technology in the Cement Industry²⁾

There has been growing demand since the 1990s for cement plants to process waste that is difficult to recycle using conventional waste disposal technology. Cement companies have redoubled their efforts in research and development of environmental technologies. This section discusses technology developments by the Japanese cement industry and the main recycling technologies implemented.

9.2.1 Alternative Fuel from Waste Tires²⁾

Since 1978, Nihon Cement and Bridgestone have been jointly researching the effective utilization of waste tires in the cement manufacturing process. Suspension preheaters were fitted with feed chutes for waste tires. The calorific value of these tires contributed up to 15% of the total fuel used. The technology was then developed to feed the tires directly into rotary kilns without crushing them first. The technology was patented³⁾, paving the way for large volumes of waste tires to now be effectively utilized by cement plants (Figure 9.3).



Fig. 9.3 Cement Kiln Whole Tire Conveying Device³⁾

This technology has the following five distinguishing characteristics.

- 1 Little concern over preheater coating buildup or cyclone blockage. In addition, no hindrance to stable long-run operation because of no increase of exhaust gas temperature.
- 2 Cost-effective and no issue with noise or vibration from crushing, as waste tires are used as they are without processing
- 3 No secondary pollution from incinerating waste tires. In addition, the NO_x emissions from conventional cement burning are reduced.
- 4 No effect at all on the quality of cement produced
- 5 Even tires containing steel can be used as they are (iron content used as a raw material)

9.2.2 Chlorine Bypass^{6) 7)}: A Major Invention that Paved the Way for Large-Volume Waste Disposal at Cement Kilns

The chlorine, alkalis, sulfur and other volatile substances brought in from the cement raw materials and fuel circulate within the kiln and preheater. This circulation eventually builds up concentrations of especially the chlorine content to around 150 times greater, producing a low-melting-point substance that forms a coating on the inner wall of the preheater. This results in issues such as ventilation resistance and cyclone blockage, thus hindering the stable operation of the kiln.

While advances were being made in using waste matter aimed at environmental conservation and effective utilization of resources, it also meant an increasing amount of volatile substances, particularly chlorine, was being put into the cement burning system. Technology needed to be developed that would effectively eliminate this chlorine, both for stable kiln operation and for increasing the amount of waste intake.

Under these circumstances, Chichibu Cement developed a unique “chlorine bypass system” that would effectively remove the chlorine from the kiln and preheater system. The first system was installed on a kiln at the Chichibu plant at the Chichibu plant in 1990.

The chlorine bypass system uses a carefully-designed probe (flue gas aspirator) to draw some of the gas out of the kiln. This gas is then rapidly cooled to the solidification point for chlorine compounds, allowing the chlorine compounds to solidify and be extracted and removed. The system has the following features:

- 1 Since it is specifically positioned at and extracts from the point where the most chlorine compounds condense and where there is low dust concentration, the majority of the chlorine brought into the system can be removed with an extremely low extraction rate. Meanwhile, it does not readily attract dust containing useful cement compounds, meaning very little thermal loss.
- 2 Since the extracted gas is immediately cooled to below 300°C, there is little chance of dioxins reforming.
- 3 The system has a cyclone apparatus for the appropriate particle size separation, which returns particles with low chlorine content to the kiln. As a result, the remaining amount of chlorine-containing dust taken out of this system is less than 0.1% of the amount of clinker produced. This small amount can be absorbed into the process by adding it to the cement in the finishing process.

The development of the chlorine bypass system significantly increased the industry’s capability to process waste matter containing chlorine. For example, waste plastic high in vinyl chloride was often refused in the past, but is now far more commonly accepted by plants with

chlorine bypass systems installed. Previously, the amount of chlorine entering the kiln system was limited by the constraining factor of preheater coating buildup and other “process issues”. Now, the JIS regulation on chloride ions has become restriction against processing waste by cement kilns (see 8.2.2 (7)). Not only is this system installed on all kilns owned by its developer Chichibu Cement and Taiheiyo Cement after the companies merged, it is also being widely adopted by other cement companies in Japan and overseas through the technology licensees Taiheiyo Engineering and Technip (the main engineering company in France). This system dramatically reduced the process issue of cyclone blockage due to buildup of low-melting chlorides, the drawback with the SP and NSP systems. It is one of the greatest Japanese inventions paving the way for high-volume waste disposal by cement kilns.

9.2.3 Alternative Fuel from Waste Plastic ^{2) 8)}

While “waste plastic” is a simple term, there is an endless variety of plastic waste, of all different types, shapes and contamination levels. Therefore, it is a general practice that the local governments and companies that discard plastic work together with the cement plants that collect the plastic to determine the methods of intake and the facilities for intake, such as crushers. The following discusses the case of Tokuyama, which developed the technology to incorporate waste plastic as an auxiliary fuel for rotary kilns, and the case of Taiheiyo Cement, which developed the technology to utilize waste plastic as an auxiliary fuel for preheater calciners.

In 1992, Tokuyama (Yamaguchi Prefecture) became the first cement manufacturer to start developing technology to use waste plastic as fuel as a means of recycling plastic. The company developed the technology to blow large volumes of crushed plastic into the front of the rotary kiln quite stably and in 1999 set up a waste plastic fuel conversion (crushing) plant (crushing capacity: 15,000t/year). This technology won the company the Award of the Director-General of the METI Industrial Science and Technology Policy and Environment Bureau in 2002. Later, the company successively expanded its plant facilities as the demand grew to accept more waste plastic. As at 2015, the plant had expanded to be capable of crushing and burning 125,000 tons of waste plastic per year.

The other example is that of the Taiheiyo Cement Kumagaya plant (Saitama Prefecture) developing the technology to accept waste polyethylene film.

This technology was developed for use as auxiliary fuel for suspension preheater calciners. Combustion testing was conducted by electric furnace, while thermal analysis was carried out by heat flux simulation to determine the spatial combustion conditions. As a result,

the following knowledge was acquired.

- 1 Polyethylene with very little fixed carbon content combusts in the form of gasified combustion, equivalent to droplet combustion.
- 2 The blowing speed is important to the spatial combustion of polyethylene particles in the calciner. At 20m/sec, if the polyethylene particle mass exceeds 0.5mg, the particles collide with the furnace wall. At 10m/sec, the particles can have a mass of up to 3.5mg; at 5m/sec, it can be up to 4.0mg.

Based on the above preliminary experiments, waste plastic pre-processing facilities were established in 1999. Once initial issues with contamination and crushed material consistency were resolved, the facilities have continued to operate stably.

9.2.4 Technology to Use Biosolids for Alternative Fuel and Raw Materials (AFR) ²⁾

Cement companies use biosolids as AFR in accordance with different factors, such as plant location and available sewage treatment facilities. The biggest issue is dealing with the smell and matters of hygiene. In addition, the kiln system needs to have strict arrangements in place for dealing with these issues during operation stoppage periods. Biosolids are usually transported directly from sewage treatment facilities to closed tanks at the cement plant by closed-tank trucks, such as arm-roll trucks. The biosolids are then fed directly into the kiln.

9.2.5 Technology to Use Municipal Waste for Alternative Fuel and Raw Materials (AFR) ²⁾

Most municipal waste is incinerated, with the incineration residue (incineration ash) disposed of into landfill. However, with the shortage of landfill site becoming an issue in the 1990s, there was a pressing need to develop the technology to reuse municipal waste. The following three technologies were developed to use municipal waste as AFR, in response to social demand. All of these later went into operation at actual plants and have contributed significantly to a sustainable resource-recycling society.

- (1) Ash washing system
- (2) Ecocement
- (3) AK system

All of these three technologies were developed in Japan and contribute to a sustainable resource-recycling society. In future, as other countries and regions experience issues with municipal waste as Japan has, there will be opportunities to license these technologies overseas.

(1) Ash washing system ²⁾

Figure 9.4 shows a flow diagram of a typical ash washing system.

When incineration residue is used as a raw material for Portland cement, the biggest issue is the chloride content of the incineration residue. Incineration residue can be categorized two ways: bottom ash (incineration ash, primary ash) and fly ash (dust and soot). Bottom ash has a low chloride ion content of around 0.4-3%. By using the “chlorine bypass” that reduces vaporized chlorides, it is possible for cement kilns to use this ash directly in the cement without dechlorinating it. Meanwhile, fly ash has a high chloride ion content of around 5-20%, meaning it cannot be used directly in the cement kiln without pre-processing; it needs to be dechlorinated before being used in the cement kiln. Noting that most of the chlorides in fly ash are soluble, researchers at Chichibu Onoda (now Taiheiyo Cement) started developing the technology to dechlorinate fly ash by washing it. The following is an overview of the course of this development.

Waste incinerators include stoker furnaces and fluidized bed furnaces. Laboratory testing of fly ash from each type of furnace from several different incineration plants showed that while almost all of the chlorides could be removed from some types of fly ash by washing alone, depending on the fly ash, some chlorides formed insoluble Friedel’s salt ($3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{CaCl}_2 \cdot 10\text{H}_2\text{O}$) that showed a low dechlorination rate when only washed with water. However, Friedel’s salt was known to break down in acidic solutions. Experiments verified that washing fly ash suspension while blowing it with carbon dioxide had a high dechlorination rate. It was also found that blowing it with kiln exhaust gas would not only break down the Friedel’s salt, but would also cause the eluted calcium ions to bond with the carbonate ions, forming calcium carbonate. It was thus proven that the carbon dioxide in the kiln exhaust gas could be used to achieve a high

dechlorination rate even on fly ash containing Friedel’s salt. It was also confirmed that all heavy metals except mercury were below detectable levels in the secondary filtrate generated from washing and filtrating fly ash and then blowing it with kiln exhaust gas to adjust its pH level to between 7.2 and 10.2.

It was shown that the longer the fly ash was humidified, the further the solidification progressed due to the hydration reaction, and the higher the Friedel’s salt content. Accordingly, waste incineration plants were requested to supply fly ash to cement plants in a dried state.

Based on laboratory testing of the above, a fly ash washing and dechlorinating test plant was designed and then built at the Kumagaya cement plant in 1998 (Figure 9.5). Fly ash from the Kumagaya Sanitation Center with a 15% chloride ion concentration was treated by washing and dechlorinating. The resulting cake contained a chloride ion concentration of 0.5% or less, thus achieving a dechlorination rate of 97%.



Fig. 9.5 Ash Washing Facility ¹⁰⁾

The washing and dechlorinating filtrate was neutralized with kiln exhaust gas.

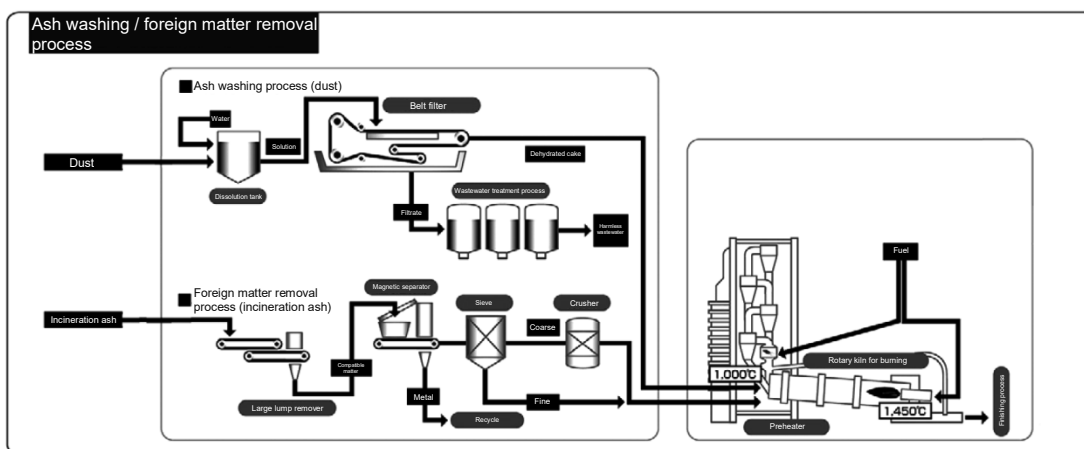


Fig. 9.4 Ash Washing System Flow Diagram ⁹⁾

Other treatments to further ensure its safety included treatment with liquid chelate, advanced filtration using sand filtration and treatment with mercury chelate resin. With analysis of the wastewater confirming that all values complied with regulatory values, “fly ash washing system” technology was implemented. The filter solids after washing and the solids produced by precipitating, separating and filtering the pH-treated filtrate were used as cement raw material, with the treated wastewater drained into the sewage system.

(2) Ecocement ²⁾

Like “ash washing”, “ecocement” was developed with the aim of recycling the incineration ash from municipal waste and biosolids into cement raw material.

When municipal waste incineration ash is used as cement feedstock, the chlorides in the ash can detrimentally affect the quality of the final cement product, as discussed previously. The first step in developing ecocement was to develop rapid-hardening ecocement using chloride as a constituent element in calcium chloroaluminate ($11\text{CaO} \cdot 7\text{Al}_2\text{O}_3 \cdot \text{CaCl}_2$). However, having only a rapid-hardening product meant limited applications for the product (cement). Development continued with the aim of developing a more versatile cement. Isolating and removing chlorides and heavy metals during the manufacturing process resulted in the development of “ordinary ecocement” with a chloride content lowered to a level similar to that of ordinary Portland cement.

Test production of ecocement was taken on as a MITI (now Ministry of Economy, Trade and Industry: METI) “lifestyle industrial waste processing/utilizing technology research” project in 1994. Research and development began on “ecocement production technology to utilize general municipal waste”, with funding provided by the

government. Based on the test production results, the fully industrial Ichihara Ecocement Plant commenced operation in 2001 in Ichihara, Chiba Prefecture, as the world’s first ecocement facility. The plant can produce around 110,000 tons of ecocement per year, with incineration ash feedstock provided from the waste of 1.5 million people, around quarter of the population of Chiba Prefecture. In 2006, the Tokyo Tama Ecocement Facility started operating in Hinode, Nishi-Tama, Tokyo, processing the ash from incineration plants for 25 cities and 1 town in the Tama area of Western Tokyo. It produces 110,000 tons of ecocement per year from its primary raw material of waste incineration residue (around 90,000 tons per year) generated in the Tama area (population around 3.9 million). Figure 9.6 shows a photograph of the Tokyo Tama Ecocement Facility, while Figure 9.7 shows a flow chart of the facility.

Incineration ash (primary ash) and incineration fly ash (dust) from the municipal waste incineration plants is received by the ecocement plant, where it is blended, dried and ground in a vertical mill with the limestone and other natural raw materials. Once powdered, it is pumped into the raw material homogenizing tank. The homogenized raw material is sent to the rotary kiln to be burnt at 1350°C or higher to form clinker, the semi-processed form of cement.



Fig. 9.6 Tokyo Tama Ecocement Facility ¹¹⁾

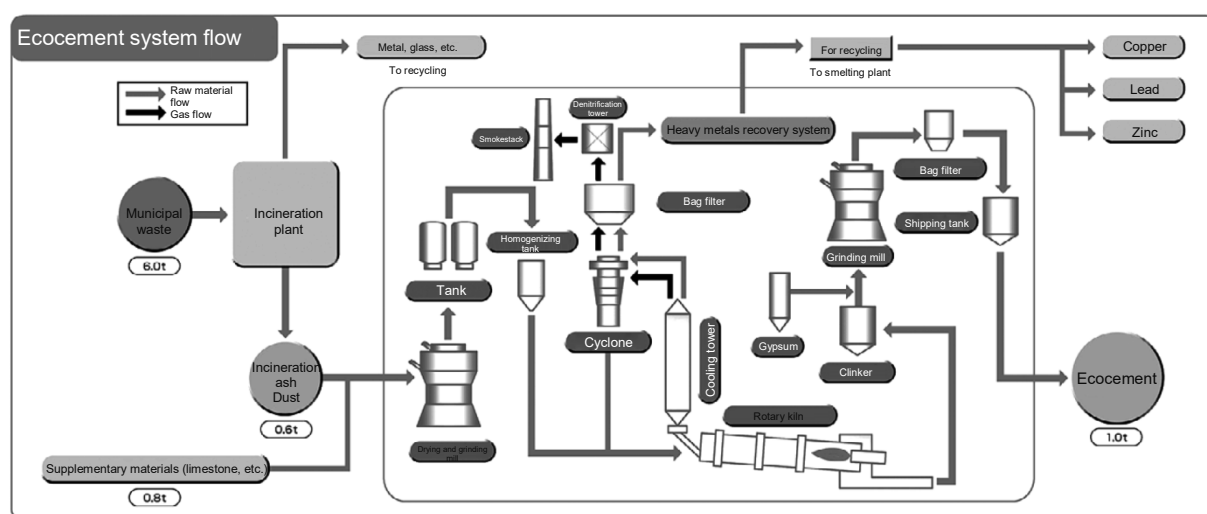


Fig. 9.7 Ecocement Manufacturing Process ⁹⁾

The clinker is blended with gypsum to produce ecocement. The exhaust gas from the burning process is cooled in the cooling tower and the dust is removed by cyclone and bag filter. The nitrogen oxide is removed in the denitrification tower and is released into the atmosphere. Since the dust collected in the bag filter contains chlorides containing heavy metals, it is sent to the heavy metals recovery system (discussed later in 9.2.6) and recycled as “artificial ore” containing copper, lead and zinc.

The ecocement manufacturing process differs significantly from that of ordinary Portland cement in the following three ways.

- 1 The raw materials are fed directly into the kiln rather than through a preheater, in order to decompose the dioxins immediately.
- 2 The cooling tower prevents dioxins from resynthesizing.
- 3 Heavy metals are recovered and chlorides removed through a chloride volatilization process, allowing the heavy metals to be extracted from the heavy metal chlorides and recycled.

Ecocement manufactured by the above process was standardized under the JIS in 2002. It has two types: “ordinary ecocement”, which has properties similar to ordinary Portland cement, and “rapid-hardening ecocement”, which has rapid hardening properties.

The quality standards for ordinary ecocement are largely the same as for ordinary Portland cement. The only difference is the upper limit for sulfur trioxide (SO_3) and chlorine ion content. Even in terms of the upper limit for chlorine ion content (0.035% or less for ordinary Portland cement, 0.1% or less for ecocement), it is generally possible to take the view that “ordinary ecocement is almost identical in quality to ordinary Portland cement”, considering that the standard for chlorine ion content in ordinary Portland cement in Europe is 0.1% or less (EN 197:2000), although some attention should be paid to the chlorine ion content of the concrete.

Rapid-hardening ecocement hardens more rapidly than high-early-strength Portland cement. Although it demonstrates high-early-strength properties and can be used in the area of unreinforced concrete, as at 2015 it is not in production.

(3) AK System ²⁾

The ash washing system and ecocement are technologies that use incineration residue of municipal waste from incineration plants as cement raw materials. However, in recent years, there have been concerns over dioxins and it has become more difficult to construct incinerators. The Applied Kiln (AK) System was developed by Taiheiyo Cement to enable cement plants to

accept municipal waste in its original state for cement raw materials. The system has been operating commercially since 2002. The following is a summary of this development.

The municipal waste decomposing process at the core of the system is based on rotary kiln aerobic fermentation technology owned by Bedminster AB (Sweden), which has achieved results in the United States and other countries. While prior investigation showed that there were significant advantages to using the company’s rotary kiln Eweson Digester for the municipal waste cement feedstock process, the following had to be validated before introducing the technology.

- (1) Can the technology process Japanese waste the same way?
- (2) Some Japanese operations also have the capacity to process only municipal waste without biosolids. Does the technology demonstrate the same effect when processing only municipal waste?

In order to validate the technology, validation testing was carried out in December 1999 using a Bedminster-owned facility (located in Sweden). The main waste used for the testing was collected from the area near the testing facility, modified to be similar in composition to general combustible waste from Hidaka, Saitama Prefecture, where the first actual plant was planned. The testing facility waste was put into plastic bags and deposited directly into the digester. After three days of fermentation processing, the contents had all come out of the bags and the bag-breakdown effect was deemed adequate. Corrugated cardboard and disposable diapers were also deposited directly into the digester and came out broken down into pieces after processing. Due to this superior ease of handling, the shredding down effect was also confirmed. The coliform count of the fermentation product was less than 2.5×10^2 MPN/g (dry weight), fully compliant to the US EPA safety standard for composted product pathogenicity of 1.0×10^3 MPN/g (dry weight). This suggested that the increase in temperature in the digester (45-50°C after one day) could sterilize the pathogens in municipal waste. The test results confirmed that the Eweson Digester could be used in the municipal waste cement feedstock process. A technology license contract was signed with Bedminster in July 2000 for the Eweson Digester and the know-how to operate it.

Based on this fermentation technology, Taiheiyo Cement established its own AK system technology with the basic design ideas below.

- 1 Garbage from both household and industry is accepted directly by the cement plant;
- 2 Wastes are aerobically fermented in a “feedstock kiln” modified from a cement burning kiln;

3 Recycled into cement raw materials.

Verification testing of the municipal waste cement feedstock process using the AK system started in March 2001 and continued for one year at the Taiheiyo Cement's Saitama Plant in Hidaka. The plant started commercial operation in November 2002. Figure 9.8 shows a photograph of the entire AK system. For the City of Hidaka, it meant no more rebuilding of deteriorated incinerators, with all general combustible waste sent to Taiheiyo Cement for disposal. For the cement plant, this was a chance to reutilize kilns that were no longer used due to reduced demand and convert them to resource recycling kilns.

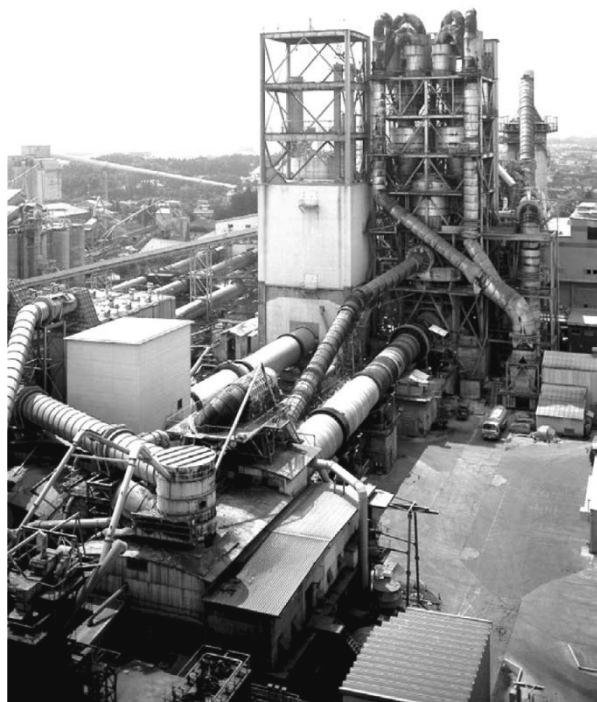


Fig. 9.8 AK System: Taiheiyo Cement Saitama Plant ⁹⁾
The rotary kiln on the left is the waste feedstock kiln; the rotary kiln on the right is the cement burning kiln.

Figure 9.9 shows the cement manufacturing process using the AK system. In the AK system, municipal waste brought directly into the cement plant is first transported to the feedstock kiln in the fermentation process. Inside the feedstock kiln, the garbage bags break down and the waste converts into odorless, easily-handled "feedstock matter" that is easily screened, magnetically separated and crushed. In the following crushing and separating process, any metals in the feedstock matter are removed by magnetic separator and the remainder crushed to a manageable size of 30-40mm. In the following burning process, the plastics and other combustible content in the feedstock matter is effectively utilized as alternative fuel for cement burning. Meanwhile, some of the incineration residue is burned in the rotary kiln and put into the clinker

(alternative feedstock). Since the cement burning kiln operates continuously at a high temperature of 1450°C, no dioxins or other harmful substances are generated by burning the municipal waste.

Thus, the AK system makes waste incinerators and final disposal sites unnecessary and also prevents the generation of dioxins from incineration. As a result, the system has attracted wide attention as a new waste disposal technology suited to a resource-recycling society.

9.2.6 Technology for Extracting Heavy Metals from Chlorides ²⁾

Until the 1990s, cement plants mainly accepted waste that was low in chlorides or heavy metal content. However, as the cement plant industry's resource recycling business expanded, the demand has grown for accepting waste matter that contains high chlorides or heavy metals, such as incineration ash. Accordingly, efforts have been made to develop technologies that focus on the heavy metals in chlorides as well as chloride-focused technologies such as the ash washing system and ecocement. The following is an outline of technology for extraction of heavy metals from chlorides, generated at ecocement plants.

In the ecocement manufacturing process, heavy metals contained in the feedstock of waste incineration ash undergo chloride volatilization in the rotary kiln during the burning process and are collected in the bag filter. An extraction system was developed in which lead, zinc and copper are extracted from the collected chlorides and recycled as raw materials for non-ferrous smelting, while calcium and other compounds are reutilized as cement feedstock. This Heavy Metal Extraction (HMX) system is made up of the following five processes.

- 1 Dealkalization process: The heavy-metal-containing chlorides collected in the bag filter are mixed with water to elute the soluble chlorides (NaCl, KCl), which account for around 80%. This reduces the solid content volume to around one-fifth, allowing the equipment for the following processes to be more compact.
- 2 Copper ion and zinc ion elution process: The solid-liquid separation residue from the dealkalization process has sulfuric acid added to it to elute the copper ions and zinc ions.
- 3 Lead ion elution process: The solid-liquid separation residue from process 2 has a sodium hydroxide aqueous solution added to it to elute the lead ions. Since the remaining residue is calcium hydroxide, it is returned into the cement feedstock.
- 4 Lead, copper and zinc compound separation process: The solid-liquid separated filtrates from processes 2 and 3 is pH adjusted to separate and remove the lead, copper and zinc compounds.

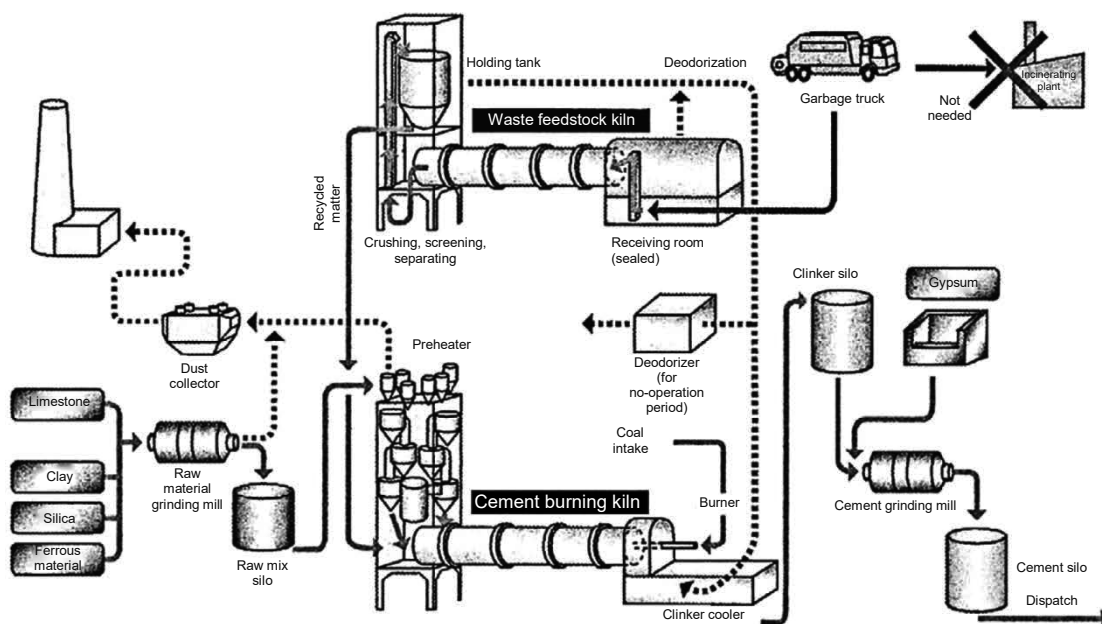


Fig. 9.9 Cement Manufacturing Process using the AK System ⁹⁾

5 Wastewater treatment process: The wastewater from process 4 is treated to meet the effluent water standards.

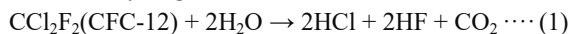
Since the residue from process 2 contains calcium, calcium sulfate is produced by reacting it with an aqueous sulfuric acid solution. As a result, the main compound in the residue obtained by solid-liquid separation in process 2 is calcium sulfate containing small amounts of lead sulfate. The sodium hydroxide aqueous solution added in process 3 not only elutes the lead ions, but also acts to transform the calcium sulfate into calcium hydroxide. While it is still a calcium compound, calcium hydroxide is preferable to calcium sulfate in cement. This method of allowing residues to be recycled into cement feed is a major advantage to the HMX system. A mini plant was established while the technology was gathered to scale it up. The Tokyo Tama Ecocement Facility adopted the system in 2006.

9.2.7 Decomposition of Fluorocarbons: The World's First Decomposition Technology Using a Cement Kiln ²⁾

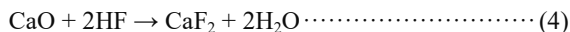
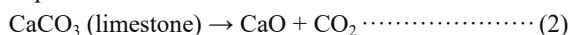
Since the 1990s, many countries including Japan have placed strict legal regulations on fluorocarbons as substances that destroy the ozone layer. A major issue has been the establishment of technology that will decompose fluorocarbons safely and reliably. Chichibu Onoda Cement (now Taiheiyo Cement) started joint research with the Tokyo Metropolis in 1994 with the aim of creating such technology using a cement kiln. This resulted in the world's first successful use of a cement kiln to decompose fluorocarbons. The cement kiln method was one of the technologies accepted at a Meeting of the Parties to the Montreal Protocol on

Substances that Deplete the Ozone Layer. The treatment method is outlined below.

Since fluorocarbons decompose at 900°C or higher, inserting them into a cement kiln with a burning zone temperature of around 1500°C causes the breakdown reaction shown in formula (1), generating hydrogen chloride and hydrogen fluoride.



The acidic gas of the generated hydrogen chloride and hydrogen fluoride passes through the cement kiln and is absorbed into the bases in the cement raw materials and dust. Reactions (3) and (4) take place, generating calcium chloride and calcium fluoride, which are eventually incorporated into the cement.



This process has significant advantages. It has an extremely high decomposition efficiency of 99.99% or higher. Also, since the harmful gases mentioned above (hydrogen chloride and hydrogen fluoride) generated by the decomposition of the fluorocarbons are incorporated into the cement, there is no need to treat the exhaust gas.

The technology was put into operation at Taiheiyo Cement's Chichibu No. 2 plant, but fluorocarbon disposal had to stop when the plant discontinued cement production (September 2010) due to reduced demand for cement.

9.3 Cement Plants Active in Waste Processing from the Great East Japan Earthquake ¹²⁾

In the Great East Japan Earthquake of March 2011, the major earthquake and accompanying tsunami caused

unprecedented major damage across a vast area of the Pacific coast. The disaster left behind all kinds of earthquake and tsunami waste and deposits in 239 cities, towns and villages in 13 prefectures (excluding the evacuation area in Fukushima). Earthquake waste amounted to 20.188 million tons, while tsunami deposits amounted to 11.016 million tons across 36 cities, towns and villages in six prefectures. The waste matter was contaminated with salt from the tsunami, which was a major obstacle in the subsequent reconstruction process.

In Iwate Prefecture, the disaster waste disposal plan centered on “processing of disaster waste at cement plants in and out of the prefecture as cement feedstock”. There were three reasons for this:

- 1 It is possible to process large volumes of disaster waste rapidly and in a short period of time using existing facilities.
- 2 It reduces the amount of disposal sites needed for disaster waste incineration ash.
- 3 The cement manufactured at the waste processing stage can be supplied as a rebuilding material.

Taiheiyo Cement’s Ōfunato plant in Ōfunato, Iwate Prefecture, sustained substantial damage from the tsunami and was unable to operate. However, efforts were made to start rebuilding the plant at the same time as the processing of disaster waste. A “disaster waste desalination system” was developed that made it possible to use salt-contaminated disaster waste as cement raw materials. Working facilities (Figure 9.10) were established and started operation. By March 2014, at the end of the contract period agreed with the prefectural government, the plant had received and processed more than 950,000 tons of disaster waste.

This system produced four types of desalinated disaster waste: soil, sand, combustible material and incombustible material. The soil and sand were improved to conform to the Iwate Prefecture disaster waste recycling manual. A new project was commenced for processing disaster waste into earthworks material for the rebuilding of the prefecture. This initiative and the cement feedstock initiative made it possible to increase the amount of disaster waste processed.



Fig. 9.10 Disaster Waste Desalination System at Taiheiyo Cement’s Ōfunato Plant (photographed by the author)

To cover vast disaster areas, other cement plants in the

Tōhoku region, Mitsubishi Materials’ Iwate plant (Ichinoseki) and Hachinohe Cement (Hachinohe, Aomori Prefecture), assisted in the processing of a variety of disaster waste. Taiheiyo Cement’s Kumagaya and Saitama plants and Mitsubishi Materials’ Yokoze plant (Chichibu, Saitama) and Aomori plant (Hachinohe) assisted from afar with the processing of wood chips. Thus, cement plants in the Tōhoku and Kantō areas contributed to the processing of disaster waste.

In the spring of 2013, Their Majesties the Emperor and Empress came to inspect the rebuilding of the disaster-affected area in the Tōhoku region. The tour included a visit to Taiheiyo Cement’s Ōfunato plant and observation of disaster waste processing in operation. This imperial visit was regarded as an honor for the whole cement industry, a major event carried out because the nation, the prefecture and the local community highly regarded the contribution of cement plants to disaster waste disposal.

Note 1: Industrial waste and byproducts

“Alternative fuel and raw materials purchased for a price” by cement plants are termed “byproducts”, while “alternative fuel and raw materials received with a processing fee” are termed “waste”. Examples of byproducts include blast-furnace slag and byproduct gypsum.

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10 | Summary: Systematization of Cement Manufacturing Technology

The major course of cement manufacturing technology development discussed in the above chapters through to Chapter 9 is summarized in the appended diagram “Systematization Diagram of Cement Manufacturing Technology in Japan”. To keep it simple, the diagram focuses on Japanese cement manufacturing technology. Western cement manufacturing technology inventions and developments, from the invention of Portland cement in the United Kingdom at the start of the 19th century through to the mid-20th century, are adequately understood by examining the development of the Japanese technologies based on them. Japan had drawn even with the West by the mid-20th century and then from the 1980s onwards led the world. The appended table “Chronology of Cement Manufacturing Technology” is provided at the end of the report to help readers understand this course of events.

From the invention of Portland cement to the present day, the greatest driving factors for advances in cement manufacturing technology have always been the pursuit of energy-saving and ensuring a consistently high-quality product. Accordingly, this systematization of the technology is also taken mainly from these two angles.

10.1 Burning Process: Technology Development Goals of Saving Energy and Producing High-Quality Clinker

When Portland cement was first invented, it was batch-produced in shaft kilns. Even Japan’s first cement plant, the Fukagawa Cement Works, produced inconsistent quality during the shaft kiln era, with the higher quality product having to be screened from the clinker coming out of the kiln. The development of the rotary kiln at the end of the 19th century enabled continuous burning of clinker. The rolling movement of the raw materials within the kiln also improved the burning reaction and made it possible to mass produce high-quality cement. However, the rotary kiln had the significant drawback of poor thermal efficiency. The main causes of heat loss were heat escaping with the exhaust gas and heat escaping with the clinker. Technology developments to improve the thermal efficiency of rotary kilns focused on these two points.

(1) Exhaust gas residual heat (kiln exhaust gas thermal loss)

At the start of the 20th century, waste heat power generation technology using waste heat recovery boilers

was developed and spread in use. In Japan, the introduction of waste heat power generation facilitated the transition from steam to electricity as the source of power for cement plants. This led to improved efficiency of machinery.

However, as it became easier to purchase electricity externally, or as more efficient in-house power generation facilities were developed, cement plants began utilizing exhaust gas to preheat raw materials directly rather than for kiln waste heat power generation, as the maintenance of the boilers and generators took time and labor.

In the 1930s, the first Lepol kiln was invented in Germany, which had an attached preheater that transferred heat directly from the exhaust gas to the raw materials. This was widely adopted in Japan up until the 1960s.

In the 1950s, the suspension preheater (SP) kiln was developed in Germany, which had even better heat recovery, made the kiln larger and offered longer operation. The SP kiln and the Japanese-developed new suspension preheater (NSP) kiln, with improved thermal efficiency, long-term operation and upscaling capability, have been the world’s dominant cement burning devices ever since.

Meanwhile, in 1907, soon after the emergence of the rotary kiln, Asano Cement patented a “calcined lime burning process” to decarbonize the limestone in advance in a thermally-efficient shaft kiln in order to improve the thermal efficiency of the rotary kiln. The company adopted the method for its rotary kilns. However, the method was discontinued in the 1940s as it was difficult to increase the size of the limekiln. The later development of a large-scale limekiln by Onoda Cement, among other factors, led to the revival of the calcined lime burning process in the mid-1950s in the form of the “New Calcined Lime Burning Process (NCB)”. Production volumes were successfully quadrupled for a dry-process kiln with a boiler attached. When the SP kiln was introduced to Japan, Japanese cement companies noted its superiority and also its limitations for upscaling. They came up with the idea of incorporating the advantages of the NCB into the SP kiln and competed to develop the New Suspension Preheater (NSP), an SP kiln with attached precalciner. Several formats were in operation by the early 1970s. The NSP system had a number of advantages, such as saving energy, long-run operation, reduced NO_x emissions and use of alternative feedstock. It is world-class cement manufacturing technology developed in Japan.

(2) Clinker residual (sensible) heat (cooler exhaust heat loss)

When rotary kilns were first developed, there was no recovery of heat from the clinker coming out of the kiln. In the 1910s, a “rotary cylinder cooler” was invented, which allowed heat to be recovered as secondary air for blowing fuel into the kiln. In the 1920s, a “multi-cylinder cooler” was invented in Denmark, which further improved the heat recovery. These were widely adopted in Japan for rotary kilns until the 1940s. At around the same time, a number of device manufacturers in the West were developing air-quenching coolers (AQC). While these began to be introduced to Japan before the war, they did not grow widely in popularity until the 1950s, after the Second World War. Although AQC systems offered slightly poorer thermal efficiency than the multi-cylinder system, they gained popularity due to greater ease of maintenance and better cement quality. The Fuller system was adapted for upscaling and was the only cooler system installed from the 1970s onwards. Under the NSP system, the technology was further developed, with the remaining cooler exhaust heat in the secondary air utilized as precalciner combustion air or for drying coal. The residual cooler heat has been thoroughly utilized.

10.2 Raw Materials Grinding: Technology Development Goals of Saving Energy and Producing Raw Materials of Good Burnability

At the time of the invention of Portland cement to the late 19th century, when Japan began manufacturing cement, adequate grinding machinery was not developed yet. It was very difficult to grind limestone and other hard materials finely. Instead, a method was used of calcining the limestone to form quicklime and then mixing it with water to form slaked lime powder (the wet process).

In 1891, the tube mill was invented in Germany, which improved the grinding performance as well as the grinding efficiency. This was introduced to Japan and by the end of the 19th century, the grinding of shaft kiln raw materials had shifted to the dry process.

Up until the 1940s, it was not easy to adjust the powder fineness nor to achieve good homogeneity of raw materials by using the tube mill dry process. On the other hand, in response to consumer demand in the 1930s to develop concrete technology, cement companies had to begin producing high quality cement, such as high-early-strength cement and moderate-heat cement. They chose to use wet process grinding in order to obtain finely-ground, well-homogenized raw materials. However, raw materials ground using the wet process required more heat during the burning process than dry process materials to evaporate the moisture content. Companies in the West developed wet process kilns attached with both a boiler and filters to filter out the moisture content. Also, the long wet kiln was developed. This elongated kiln used waste heat for drying raw feed. Japan introduced the former in 1932 and the latter in 1954.

In the 1950s, improvements in separators meant improved adjusting of powder fineness during dry process

grinding of raw materials. The introduction of the blending silo, developed in Germany in the 1960s, further improved the homogeneity of the raw materials as well. In the 1970s, technology was developed that incorporated online X-ray fluorescence analysis and computerized control of raw mix proportioning. The dry process then surpassed the wet process in terms of proportioning accuracy, powder fineness and homogeneity. The wet process, which required more heat consumption, was no longer necessary. As the dry process SP kiln rose to dominance, the wet process disappeared from cement plants altogether.

In the 1930s, vertical (roller) mill technology was developed for grinding raw materials. Since it required less energy than the tube mill, it began to be widely adopted around the 1960s, as better structural materials were developed for the grinding rollers and table. The vertical mill used kiln exhaust gas to dry the raw materials at the same time. It was also capable of upscaling. Combined with the SP kiln, it formed an energy-efficient integrated process from raw materials to burning.

10.3 Finishing Process: Technology Development Goals of Saving Energy and Producing High-Quality Cement

Powdered cement in the shaft (bottle) kiln era was weathered to prevent rapid hardening and to prevent expansion of the concrete due to free lime. The issue of rapid hardening was solved by the addition of gypsum, introduced in 1888. The introduction of the rotary kiln also reduced the amount of free lime. The weathering process was discontinued as shaft kilns fell out of use.

At the end of the 19th century, tube mills were introduced into the finishing process as well, improving the grinding efficiency (energy efficiency) as well as improving the quality of the cement by improving the particle size distribution. In 1973, the addition of grinding aids was approved under the JIS, further improving the grinding efficiency.

As the facilities for the burning process increased in size due to the adoption of SP and NSP systems, the facilities for the finishing process also increased in size. This resulted in the development of new Japanese technologies and devices, such as eddy current separators, clinker (finishing) grinding vertical mills and finishing mill pre-crushers. These were exported to the world, along with the NSP system.

10.4 Shipping Process: Technology Development Goal of Reducing Distribution Cost

In the late 19th century and early 20th century, cement was transported in barrels. Jute sacks were used from the 1910s, followed by paper sacks from the late 1920s. In

the 1950s, it became more common for concrete to be mixed at the ready-mixed concrete plant and transported by mixer truck to construction sites rather than mixing concrete on site. Accordingly, bulk shipping became the predominant method of shipping cement from cement plants to storage silos in markets. The shift to bulk shipping of cement resulted in a dramatic change in cement distribution, or a “distribution revolution”. This and the upscaling of cement plants made possible by the SP and NSP systems were the primary factors enabling the cement industry’s integration of production in large-scale cement plants in coastal areas.

10.5 JIS Standards and Cement Diversification

As the first industrial standard in Japan, the Japanese test method for Portland cement was enacted in 1905. This kept being revised to reflect advances in technology and consumer demand. In the 1970s, cement products diversified through advances in cement chemistry, with corresponding standards established. In the 1990s, JIS standards for alkalis and chlorine ion content in cement were set in order to ensure concrete durability. Also in the 1990s, concrete additives were developed to become the main means of determining concrete performance. Accordingly, very few further attempts were made to

produce new types of cement after that.

10.6 Evolving to a Core Industry Supporting a Resource-Recycling Society in the 21st Century

From around the 1970s, the cement industry began to use large volumes of industrial waste and byproducts as alternative fuel and raw materials (AFR). The use of industrial waste was initially a means of reducing fuel and raw material costs. From the 1990s, the industry expanded in scope from recycling industrial waste to including general municipal waste. In the 21st century, the cement industry has evolved from a “key industry providing construction materials” to a “core industry supporting a sustainable resource-recycling society”. Throughout this process, Japan has continued to develop new technologies, such as the chlorine bypass system, ecocement, ash washing and the AK system. Technology development by cement companies continues to focus on recycling even more waste as cement feed.

Following the Great East Japan Earthquake of March 2011, Taiheiyo Cement’s Ōfunato plant and other cement plants in the Tōhoku and Kantō areas made a significant contribution to disaster waste disposal.

11 | Conclusion and Acknowledgements

In 1899, with the 20th century looming, master inventor Thomas Edison proclaimed that the 20th century would be the century of concrete. He began constructing a cement plant with an output capacity of 1600 tons per day, an unprecedented volume for the time. Edison's prediction was correct: as the provider of the key ingredient for concrete, the cement industry has indeed made a significant contribution to society throughout the 20th century as a key industry providing an essential material to social infrastructure, including homes, high-rise buildings, roads, railroads, harbors, rivers and watercourses. The latter half of the 20th century in particular saw huge advances in cement manufacturing technology. Systems were created that made it possible to produce and supply mass volumes of inexpensive yet high quality cement. Cement types became more diverse in response to demand for greater concrete performance and functionality. The supply of this high quality cement in mass volumes, consistent quality and low prices has indeed undergirded the "concrete civilization" of the 20th century.

Chapters 1 to 8 of this report discussed the history of technology in the cement industry. The Japanese cement industry originated with the government-managed cement plant of the late 19th century. Equipment was purchased from the West and the technology was studied and developed. In the 1970s, Japan was producing ground-breaking new technologies, such as the NSP system. By the end of the 20th century, Japan had risen to worldwide preeminence in product quality and energy conservation. Leading-edge Japanese cement manufacturing technology is now being exported to the entire world. Japanese cement companies have been expanding overseas (mainly into Asia and the Pacific) in earnest since the 1990s and this technology gives them the competitive edge.

Meanwhile, the domestic demand for cement in Japan reached full maturity in the 1990s and unfortunately no further quantitative expansion of domestic demand is expected. Given these severe economic conditions, the Japanese cement industry used its cement manufacturing technology to advance into a new area of waste recycling, thus contributing to a sustainable resource-recycling society and setting itself up for new growth in the 21st century.

The Japanese cement industry began utilizing waste in the 1970s. Since the dawn of the cement industry in the late 19th century, it has been developing manufacturing facilities and technology, as well as building up a wealth of knowledge in cement chemistry. By actively utilizing these assets and also developing new technologies, the

industry has pioneered ambitious new areas, allowing it to increase the variety, quality and volume of waste it can process. Chapter 9 discussed the innovations in the cement industry over the past two decades. The trailblazing waste recycling technology of the Japanese cement industry is gaining international attention with the growing awareness of global environmental issues.

In order for cement companies to contribute to a sustainable resource-recycling society, it is essential that they sell cement. There needs to be a cement industry for there to be waste recycling. Consequently, those in the cement industry must never forget their time-honored role of producing the valuable commodity that is cement, while also taking pride in their position as a core industry in a sustainable resource-recycling society. Meanwhile, wider society needs to be aware that cement is more than just an ingredient in concrete; it is an essential ingredient in the building of a sustainable resource-recycling society. These closing comments are from the author as a member of the cement industry for half a century.

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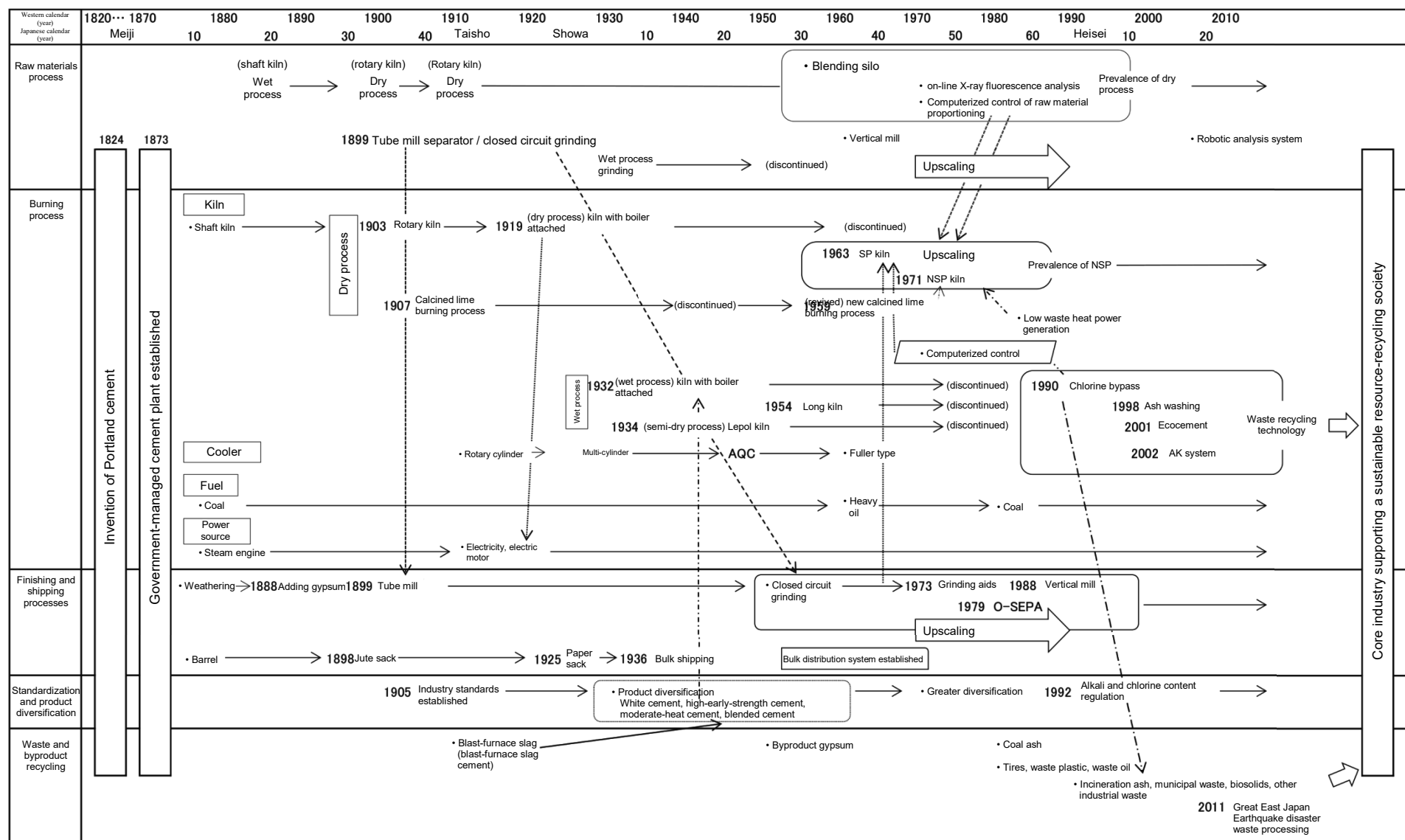
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Systematization Diagram of Cement Manufacturing Technology in Japan



Cement Manufacturing Technology Historical Resources Confirmed Location

(cited from the National Museum of Science and Technology Center of the History of Japanese Industrial Technology database)

No.	Name	Year manufactured	Manufacturer	Type of resource	Status of resource	Location	Reason for selection
1	Shaft kiln of the former Onoda Cement Company	1883	Taiheiyo Cement Corporation	Structure	Open to the public	Taiheiyo Cement Corporation Onoda Office Sanyo-Onoda, Yamaguchi	As the only complete cement burning shaft kiln in Japan, this kiln is a very valuable piece of the history of the modern ceramics industry. It has importance as the central facility of the former Onoda Cement Company, which undergirded the modernization of the construction industry in Western Japan. Designated as an important cultural asset in December 2004. See Section 2.3.3.
2	Roller from a fret grinding mill	c. 1875-1882	Unknown	Device	Open to the public	Asano Concrete Corporation Koto, Tokyo	Cement manufacturing equipment from the days of the Ministry of Industry Fukagawa Works Sub-Bureau, Japan's first cement plant. The plant was later sold to Asano Cement Company in 1883. See Section 3.2.3.
3	Steam engine	1881	Osaka Army Arsenal	Device	Open to the public	Taiheiyo Cement Corporation Onoda Office Sanyo-Onoda, Yamaguchi	A steam engine used to drive the cement manufacturing machinery from when Onoda Cement, Japan's first private cement company, started operating. It is the earliest extant steam engine used in a domestic plant. It is the only extant engine manufactured by the Osaka Army Arsenal for a private plant. See Section 3.5.
4	Japan's first bulk cement tanker, Kiyotada Maru	1936	Mitsubishi Heavy Industries, Ltd. Kobe Shipyard	Model photograph	Open to the public	Ube Shipping & Logistics, Ltd. Ube, Yamaguchi	Kiyotada Maru is Japan's first bulk cement tanker, commissioned in April 1967. With a total tonnage 3,079 (deadweight tonnage 3,648), this single-helix diesel vessel had a propulsion of 1,650 hp. Loading was done by a more rational air-blown method rather than a Western-style conveyor system. Combined with the establishment of stock points nationwide, this achieved remarkable streamlining of transportation. See Section 4.12.3.
5	The world's largest SP kiln, Isa No. 1 Kiln	1972	Ube Industries, Ltd.	Photograph	Open to the public	Ube Industries, Ltd. Ube Construction Materials Co., Ltd. Mine, Yamaguchi	The Isa No. 1 Kiln is a suspension preheater (SP) kiln 6.2m in diameter and 125m in length. Its fire lighting ceremony was held on September 29, 1972. It has an annual output capacity of 1.86 million tons, the highest in the world at the time. It is also the largest existing SP kiln in the world. See Section 5.1.
6	Japan's first fly-ash cement (pozzolan cement)	1956	Ube Industries, Ltd.	Literature	Open to the public	Ube Industries, Ltd. Ube Construction Materials Co., Ltd. Research & Development Center Ube, Yamaguchi	Japan's first pozzolan cement blended with fly ash emitted from a coal-fired power plant was released on the market in February 1987. Compared to ordinary Portland cement, pozzolan cement blended with fly ash has greater long-term strength, better finishing, less free lime, better water resistance, better chemical resistance and less shrinkage. It was later standardized under JIS R 5213 (fly-ash cement). See Section 8.3.2 (3).

Chronology of Cement Manufacturing Technology

Western calendar	Japanese calendar	Japan	World	Related major events (Japan, world)
BC			<p>7000 BC Archaeological site in Israel containing concrete-like material</p> <p>3000 BC Dadiwan archaeological site in China containing concrete-like material</p> <p>2600 BC Egyptian pyramids containing inorganic adhesive material</p> <p>1000 BC Greece, volcanic ash mixed with slaked lime</p> <p>200 BC Rome, "kiln" built to manufacture quicklime and hemihydrate gypsum</p>	
1750			<p>The age of "ancient cement" in Greece, Rome and the Middle Ages (technical stagnation)</p> <p>1756 Smeaton (UK) Invention of "hydraulic mortar" (beginning of modern cement)</p>	<p>1770s Industrial Revolution in England</p> <p>1776 American War of Independence</p> <p>1789 French Revolution</p> <p>1820s Industrial Revolution in Germany</p>
1790			<p>1796 Parker (UK) Invention of Roman cement</p>	
1810			<p>1815 John (Germany), 1818 Vicat (France) Invention of a method of manufacturing "hydraulic mortar" by burning a mix of limestone and clay</p>	
1820			<p>1824 Aspdin (UK) Patented "Portland cement"</p>	
1830			<p>1830 Fuchs (Germany) "hydraulic properties due to chemical bonding between silicic acid and lime"</p>	
1840			<p>1844 Johnson (UK) Established the basic principles of Portland cement manufacturing</p> <p>1848 (France) Portland cement manufacturing begins</p>	
1850			<p>1850 (Germany) Portland cement manufacturing begins mid-1800s</p> <p>(UK) Regulating of setting by weathering</p>	
1860				
1861	Bunkyo 1	Portland cement first imported (construction of Nagasaki ironworks)	<p>1862 Langen (Germany) Discovery of the latent hydraulic properties of granulated blast-furnace slag</p> <p>1867 Monier (France) Invention of reinforced concrete</p>	
1870	Meiji 3		<p>1870 Michaelis (Germany) Discovery of the delayed setting effect of gypsum</p> <p>1871 Discovery of the basic principle of blended cement (USA) Portland cement manufacturing begins</p>	1868 Meiji Reformation
1873	Meiji 6	First manufacture and shipping of cement by Fukagawa government-managed cement plant		1872 Great Fire of Tokyo/Ginza
1875	Meiji 8	Fukagawa government-managed cement plant starts manufacturing cement rivaling the quality of imported product		
1880	Meiji 13		<p>1878 (Germany) World's first cement standard</p> <p>1882 Le Chatelier (France) Uses polarization microscopy of clinker thin flakes to identify the most commonly occurring phase in clinker as 3CaO·SiO₂</p> <p>Prussing (Germany) Invention of blast-furnace slag cement</p> <p>(Germany) Addition of gypsum approved</p>	1877 Satsuma Rebellion
1883	Meiji 16	Onoda Cement plant (Yamaguchi) starts operation (privately managed) Shipping in barrels, net weight per barrel of 400 pounds (181 kg)		
1884	Meiji 17	Fukagawa government-managed cement plant sold to Sōchirō Asano	<p>1885 Michaelis (Germany) Proposal of "hydraulic modulus"</p> <p>Ransome (UK) Patented the use of rotary kilns for cement burning</p> <p>Jackson (USA) Published on pre-stressed concrete</p> <p>1880s (Germany) White cement manufacturing begins</p>	
1888	Meiji 21	Asano starts adding gypsum to regulate setting Onoda starts manufacturing using the shaft kiln dry process		
1890	Meiji 23		<p>1890s Atlas (USA) Successful burning of cement in a rotary kiln</p> <p>1892 Davidsen (Denmark) Invention of the tube mill</p> <p>Michaelis (Germany) Discovery of hydrate "cement bacillus"</p>	1891 Mino-Owari Earthquake (proof of the earthquake-resistance of concrete)
1893	Meiji 26	8 cement companies request the Minister of Agriculture and Commerce for standardized cement test methods		
1895	Meiji 28	Reinforced concrete technology imported		1894-95 First Sino-Japanese War 1895 Roentgen (Germany) Discovery of X-rays
1896			<p>1896 Atlas Cement Company (USA) Successful burning in a rotary kiln with cooling cylinder attached</p>	
1897	Meiji 30	Onoda changes the net weight per barrel to 380 pounds (172 kg)	<p>1897 Törnebohm (Sweden) Naming and heavy media separation of clinker minerals</p>	
1898	Meiji 31	Onoda starts using jute sacks holding 190 pounds (86 kg) "Japanese Imperial Portland Cement Test Methods" proposed by cement industry members		
1899	Meiji 32	Asano installs a tube mill (raw materials grinding, Moji plant)		
1900	Meiji 33	Japan Portland Cement Association established Onoda manufactures Japan's first blended cement	<p>1900 Polysius (Germany) Invention of the compound tube mill</p>	

Western calendar	Japanese calendar	Japan	World	Related major events (Japan, world)
1901	Meiji 34	Cement barrel unified across the industry at 380 pounds (172 kg)	1901 (USA) Construction completed on master inventor Thomas Edison's cement plant	1904-05 Russo-Japanese War 1906 (USA) Cottrell precipitator patented (successfully used on a working machine at practical use at a lead smelting works)
1903	Meiji 36	Asano installs the first rotary kiln in Japan (Fukagawa plant) The first concrete bridge (Lake Biwa Canal)		
1904	Meiji 37	The first reinforced concrete construction (Sasebo)		
1905	Meiji 38	The first cement standard created Ministry of Agriculture and Commerce Notice No. 35 "Japanese Portland Cement Testing Methods"	1905 (UK) Cement standard created	
			1906 (USA) Cement standard created (USA) Bates packer patented	
1907	Meiji 40	Asano patents the calcined lime burning process		
1909	Meiji 42	Onoda starts operation at its Dalian plant (the first overseas plant)		
1910	Meiji 43	Asano installs an air separator		
1911	Meiji 44	Onoda and Asano's Moji plant start using electricity as a power source		
1912	Taisho 1	Jute sacks start being used instead of barrels		
1913	Taisho 2	Yawata Iron Works starts producing "blast-furnace slag cement"	1913 Kuhl (Germany) Proposal of silica modulus and iron modulus Spindel (Austria) Successful manufacturing of high-early-strength cement	1912 Laue (Germany) Discovery of X-ray diffraction phenomenon 1913 Bragg father and son (USA) X-ray analysis of crystal structure
1914				1914-18 First World War 1920 (Japan) Recession following the First World War worsens
1915			1915 Rankin (USA) & Wright (USA) C-S-A 3-way phase equilibrium diagram completed (USA) Successful implementation of waste heat boiler (using forced draft) Emley (USA) Proposal of a method of free lime quantitative analysis (*) (* This method later spread after being improved upon by Lerch (USA) & Bogue (USA) in 1930)	
1916	Taisho 5	Onoda starts manufacturing white cement		
1917	Taisho 6	Asano installs a Cottrell electrostatic precipitator at its Fukagawa plant		
1920	Taisho 9	Onoda installs a waste heat power generation boiler (Onoda plant)		
1921	Taisho 10	The industry establishes two types of jute sacks, 127 pounds (58 kg) and 95 pounds (43 kg)		
1922	Taisho 11	Asano installs a Bates packer		
1923			1923 FL Smith (Denmark) Development of a multi-cylinder Unax cooler	
1924	Taisho 13	The industry adopts the metric system and standardizes shipping weight at 50 kg for sacks and 170 kg for barrels		
1925	Taisho 14	Chichibu uses paper sacks for cement packaging	1925 (USA) Continuous slurry filter installed on a wet process kiln	
1926	Taisho 15	Blast-furnace slag cement standardized	1926 Hansen (USA) & Bogue (USA) Use of X-ray diffraction to identify clinker minerals	1927 (Japan) Financial crisis 1929 Worldwide Great Depression 1937 Second Sino-Japanese War 1941 Pacific War 1945 (Japan) Potsdam Declaration accepted 1950 Korean War 1955-56 (Japan) Economic boom 1959 (Japan) Economic boom 1961 (Japan) Trade liberalization begins
1927	Showa 2	Asano adopts a multi-cylinder cooler (Fukagawa plant)		
1928	Showa 3	Tokuyama installs an air-quenching cooler	1928 Freyssinet (France) Established the basic principles of pre-stressed concrete	
1929	Showa 4	Asano installs a wet process kiln (Nishitama plant) Asano starts manufacturing high-early-strength cement	1929 Bogue (USA) Proposal of the Bogue method for calculating clinker mineral composition	
			1930 (Germany) Invention of the Lepol kiln	
1932	Showa 7	Onoda installs a kiln with a wet process filter attached (Fujiwara plant)	1932 (USA) Grinding aid RDA goes on the market (USA) Large volumes of low-heat cement used in dam construction	
1934	Showa 9	Mikawa installs a Lepol kiln (Tahara plant, Aichi) Asano starts manufacturing moderate-heat cement	1934 Polysius (Germany) Development of the air blending silo (Germany) First use of a Loesche vertical mill at a cement plant	
1935	Showa 10	A number of companies start manufacturing silica cement		
1936	Showa 11	Ube commissions bulk cement tanker Kiyotada Maru (3600 tons) Domestic cement bulk cement shipping		
1937	Showa 12	Onoda adopts a Smith grate cooler (Ofunato plant)		
1938	Showa 13	Early-high-strength cement standardized	1938 Musssnug (Germany), Hagerman (Germany) Publication on the optimum amount of added gypsum	1941 Pacific War 1945 (Japan) Potsdam Declaration accepted 1950 Korean War 1955-56 (Japan) Economic boom 1959 (Japan) Economic boom 1961 (Japan) Trade liberalization begins
1939	Showa 14	Pre-stressed concrete technology introduced		
1941	Showa 16	Mortar strength testing method: hard method → soft method		
1942	Showa 17	Non-construction cement standardized		
1945	Showa 20			
1946	Showa 21	Cement Technology Association founded		
1947	Showa 22	Cement exports resume		
1949	Showa 24	The first ready-mixed concrete plant, Iwaki Narihira-bashi (Tokyo) Pre-stressed concrete put to practical use		
1950	Showa 25	JIS for cement established in place of the JES for ceramics Cement free trade system resumed	1950 Humboldt (Germany) Development of the SP kiln	
1951	Showa 26	Nihon Cement installs the first Fuller cooler (Nishitama plant) Ube starts burning with heavy oil Onoda installs an electron microscope		
1953	Showa 28	Moderate-heat cement standardized under JIS		1955-56 (Japan) Economic boom 1959 (Japan) Economic boom 1961 (Japan) Trade liberalization begins
1954	Showa 29	Tokuyama installs the first wet process long kiln		
1955	Showa 30	<Advances in bulk shipping from around this time>		
1956	Showa 31	Ube starts marketing fly-ash cement		
1957	Showa 32	Aso introduces a blending silo (batch-type)		
1959	Showa 34	Onoda starts transitioning to new calcined lime burning process Onoda introduces a continuous blending silo Ube installs the first raw material vertical mill (Loesche)	1959 Riverside (USA), Ideal (USA) and others Start of computerized control	
1960	Showa 35	Fly-ash cement standardized under the JIS Transition to heavy oil advances rapidly from this year Trial computerized process control begins around this year EPMA is applied to cement chemistry research from around this time		

Western calendar	Japanese calendar	Japan	World	Related major events (Japan, world)
1962	Showa 37	Chichibu installs computerized control at its Kumagaya plant	1962 Wedag (Germany) Development of cyclone separator	1962 (Japan) Smoke and Soot Regulation Law
1963	Showa 38	Daiichi installs the first SP kiln Mitsubishi installs the first double rotator mill (Higashitani plant)	1964 CPC (USA) Trial computerized control of raw materials and burning processes	1964 (Japan) Tokyo Olympic Games Tokaido Shinkansen opens 1965-70 (Japan) Izanagi economic boom
1965				
1966	Showa 41	Chichibu adopts the first cyclone separator The Cement Technology Association is reorganized into the Research and Development Laboratory The Ono Method of microscopy mostly complete from around this time	1967 Magotteaux (Belgium) Development of high Cr wear-resistant balls (allowing a smaller diameter)	1968 (Japan) Air Pollution Control Act
1967				
1968	Showa 43	5 th International Symposium on the Chemistry of Cement held in Tokyo		1971 Dollar shock
1971	Showa 46	Mitsubishi installs the world's first NSP kiln (Higashitani plant, Fukuoka) SF and RSP developed within one year Cement sacks lightened from 50kg to 40kg		1973 Oil crisis
1973	Showa 48	JIS revised to enable the use of grinding aids		
1974	Showa 49	Chichibu/Hi export SF technology to Fuller (USA) (first cement technology export)		
1976	Showa 51	Onoda establishes Onoda Engineering (first engineering subsidiary of a cement company)		
1977	Showa 52	Regulation of cement kiln NOx begins Ube implements a 1-kiln 1-mill system using a Loesche mill		
1978	Showa 53	Sulphate-resistant cement standardized under the JIS Nihon Cement develops technology for feeding waste tires into kilns	1978 (USA, Germany) Development of high-belite cement begins around this time	1978 Oil crisis
1979	Showa 54	Onoda develops the O-SEPA, the world's first eddy current separator Addition of up to 5% additives permitted by JIS for ordinary cement		
1980	Showa 55	<Waste heat power generation starts spreading to the NSP system around this time> <Concrete damage from alkali and chloride content becomes an issue> <Research and development of high belite cement becomes more active>		
1986	Showa 61	Alkali content of cement standardized under the JIS		
1987	Showa 62	Chichibu develops the CKP finishing mill pre-grinder		
1988	Showa 63	Onoda develops the OK mill, the world's first vertical cement grinding mill		1988 (Japan) Construction of the Akashi Kaikyō Bridge begins
1990	Heisei 2	Chichibu invents the chlorine bypass system		1990 (Japan) Bubble economy begins to burst 1991 USSR dissolves
1992	Heisei 4	Chlorine ion content of cement standardized under the JIS (0.02%) Alkali content of all types of Portland cement is regulated to be 0.75% at maximum Chichibu commercializes high belite cement Tokuyama develops technology for using waste plastic as kiln feed		
1994	Heisei 6	Onoda and Chichibu merge to form Chichibu Onoda Sumitomo and Osaka merge to form Sumitomo Osaka Cement		
1995				1995 (Japan) Great Hanshin Earthquake
1996	Heisei 8	Domestic cement production of 99.27 million tons (declining trend after that) Cement sacks lightened 40kg to 25kg		
1998	Heisei 10	Chichibu Onoda merges with Nihon to form Taiheiyo Cement Ube and Mitsubishi form a joint venture Ube-Mitsubishi Cement Taiheiyo starts operating the first incinerator ash washing system		
1999	Heisei 11	The WBCSD launches the Cement Sustainability Initiative (CSI) for international cooperation on environmental issues		
2001	Heisei 13	Taiheiyo and its partner companies start operating the Ichihara Ecocement Plant		
2002	Heisei 14	Taiheiyo starts commercial operation of the AK system		
2003	Heisei 15	Chlorine ion content of cement eased to 0.035%		
2005	Heisei 17	Taiheiyo changes from a Cottrell to a bag filter at the Kumagaya plant		
2006	Heisei 18	Tokyo Tama Ecocement Facility commences operation		
2011	Heisei 23			2011 (Japan) Great East Japan Earthquake