セメント製造技術の系統化調査

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History of Cement Manufacturing Technology

下田　孝 *Takashi Shimoda*

■ 要旨

今日の日本のセメント産業は、セメントの品質はもとより、省エネルギー技術、労働生産性、廃棄物・副産物の原燃料への再資源化技術など、あらゆる面で世界のトップクラスにある。

本稿では、19 世紀初めに英国で発明されたセメント製造技術が、明治時代初期（19 世紀後半）に欧米から日本に導入されて以来、今日の世界トップレベルの技術水準に至るまでの技術の発展を、系統的に紹介する。

第 1 章では、セメント産業についての基本的な知識を紹介する。

第 2 章ではまず「古代のセメント」について略記し、続いて「近代のセメント」すなわち「ポルトランドセメント」が産業革命期の英国で誕生する過程を述べ、その技術が明治初期に導入されて、日本のセメント産業が始まった経緯を述べる。

第 3 章では、明治期から大正期にかけての日本のセメント製造技術の進歩について紹介する。この時期の画期的な技術進歩としては、①石膏添加の開始、②回転窯の導入、③セメント規格の制定、④余熱発電ボイラーの導入、などが挙げられるが、いずれも欧米技術の導入であった。

第 4 章では、昭和初期から太平洋戦争をはさんで昭和 30 年代までの技術進歩を述べている。この時期には、乾式法、湿式法、半湿式法など様々な焼成方式が欧米から導入され、それぞれが特長を競った。この時期の画期的な技術進歩としては、①セメント品種の多様化、②エアクエンチングクーラーの採用、③改良（生灰（きばい））焼成法の開発、④連続式ブレンディングサイロの導入、などがある。この中でも③は、明治草創期以来全てを導入技術に頼ってきた日本のセメント産業にとって、初めての「独自」の技術開発であり、これが後の日本発の大型技術・NSP キルン開発につながっていった点で重要である。

第 5 章では、昭和 40 年代以降、日本発のセメント製造技術が華と開いた状況を紹介している。昭和 30 年代末に「SP キルン」の技術がドイツから導入されるや、その優れた熱効率や、大型化・長期連続運転に適するという長所から、日本国内の新増設キルンはほとんどが SP 方式を採用するほどの勢いとなった。と同時に、日本では早速その SP キルンに「改良焼成法」の技術を加えた「NSP キルン」の開発競争が起こり、いろいろな型式の NSP キルンが成功裏に開発された。NSP キルンは SP キルンよりもさらに熱効率、大型化、長期連続運転に優れ、結果として、日本のセメント産業のエネルギー効率や品質を、世界のトップレベルに押し上げた。また、NSP 開発の成功が、日本のセメント業界に自信を与え、渦流型セパレーター、セメント粉砕用竪型ミルなど、省エネ指向の世界的に競争力のある日本発の新技術が次々と生み出されることにつながっていった。

第 6 章では、1970 年代に日本のセメント産業が直面した環境・公害問題の取組み、また 1990 年代以降課題になっている「気候変動問題」についての国際的なセメント業界の取組みを紹介している。

第 7 章の「セメント化学の進歩」では、製造上で重要な「焼成反応・セメント鉱物化学」の分野と、利用上で重要な「水和反応・セメント水和物の化学」の分野について、近代セメント誕生以来のセメント化学の進歩を説明する。この分野でも 1950 年代以降、日本人研究者の活躍が目立つようになってきた。クリンカー品質の顕微鏡判定法「小野メソッド」は、工場現場で役立つ技術として、世界的に高い評価を受けている。

第 8 章では、日本のセメント規格と、セメント品種の多様化の変遷について述べる。

第 9 章では、20 世紀を通じて培ってきたセメント製造の設備・技術やセメント化学の知識を基盤に、「建設基礎資材供給の基幹産業」から、「資源循環型社会構築を支える中核産業」へと発展しつつある日本のセメント産業の姿を紹介する。ここでも、塩素バイパス、灰水洗、エコセメントなど、廃棄物再資源化のための日本発の新しい技術が、次々と生み出されていることを紹介する。

■ 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 (NCL) Process." 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 NCL 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 NCL 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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1963年　東京大学工学部工業化学科卒
　小野田セメント㈱入社、中央研究所配属。
　以降、セメント製造工場、本社生産部、米国事業所などを転任。
　企業合併で社名も、小野田セメント㈱→秩父小野田㈱(1994)→太平洋セメント㈱(1998)と変更になる。
1996年　秩父小野田㈱　中央研究所長
2002年　太平洋セメント㈱　常務取締役、研究所・建材事業・セラミックス事業担当
2005年　セントラル硝子㈱　社外監査役
2006年　太平洋セメント㈱　取締役常務執行役員退任
2009年　セントラル硝子㈱　社外監査役退任

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石油化学技術の系統化調査

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A Systemized Exploration of Petrochemical Technology

田島 慶三 *Keizo Tajima*

■ 要旨

石油化学工業は、石油・天然ガスを原料に石油化学基礎製品、有機工業薬品、高分子を製造している。日本では、1950年代に誕生して以来、瞬く間に化学産業の中核を占め、医薬品、化粧品、合成洗剤、塗料、プラスチック成形加工、ゴム成形加工など、日本の化学産業の幅広い各部門に原材料を提供する基幹産業となって現在に至っている。1960年代には、プラスチック製品を大量に供給するようになったことから、高分子材料革命を起こして社会に大きなインパクトを与え、高度経済成長を支えた。また、石油化学臨海コンビナートという新しい化学工場群を誕生させた。

石油化学は米国で1920年代に始まった。しかし、1940年代前半までは米国だけに存在し、ごく一部の有機工業薬品を供給する程度の化学工業であった。石油化学よりも古くから繁栄している量産型化学工業としては、欧州でも、米国でも、日本でも、木材化学、油脂化学、発酵化学、石炭化学があった。米国の石油化学は、それらの化学工業と並存していた。1940年代にナフサの水蒸気分解技術が開発され、1950年代に石油化学の欧州移転が実現したことによって、石油化学技術は大きく変わった。伝統ある欧州化学技術との融合が進み、石油化学の技術革新が一挙に花開いた。これによって、石油化学の誕生以前に存在していた多くの量産型化学工業を石油化学は一挙に飲み込み、化学産業の基幹的な地位に就いた。

日本は、そのような時代に石油化学を始めた。しかも、石油化学以前に量産型化学工業が存在したことから、石油化学技術を受け身で導入するだけでなく、積極的に技術革新の一端を担った。この経験によって、早くも1960年代後半には石油化学技術を吸収し、自社開発技術が続出している。1970年代後半には、石油化学の激しい技術革新が一段落し、発展途上国への石油化学の普及が始まった。この時代には石油化学の負の側面が顕在化した。環境問題、化学物質汚染問題などである。しかも、2度にわたる石油危機によって、石油化学製品のコストが上昇した。このため、低公害型技術や省エネルギー技術が求められるようになった。日本の石油化学工業は、もはや技術導入にのみ依存することなく、自社開発技術で対応できるようになった。1980年代からは、炭素数2のエチレン系製品よりも、炭素数3以上のオレフィン製品の技術開発が課題となった。日本の石油化学はこの分野で大いに活躍した。石油化学は、多数の製品を抱える厚みのある化学工業に変わっていった。

一方、1980年代には中東石油化学が登場し、世界の石油化学の産業地図が大きく変わり始めた。この動きは、2000年代以後、中国での石油化学の開始、大増産によって加速している。2010年代には、石油化学工業の中心が欧米から中東を含むアジアに大きくシフトしつつある。このため、1990年代以後は、石油化学事業から撤退する欧米化学会社が相次いだ。しかし、日本の石油化学会社は欧米とは違う道を選んだ。石油化学内での機能化を図るばかりでなく、従来の石油化学の範囲を超えた高分子成形加工技術までも取り込んだ機能化学を展開している。

一方、従来の範囲の石油化学においても、エチレン需要に比べてプロピレン需要が大きく伸びるなどの変化が起きた。こういう事業環境の変化に対応して、1990年代以後、石油化学技術に新しい潮流が見え始めている。石油化学は、次の10年～20年で大きく変わるかも知れない。

このように世界の石油化学の歴史の中で、石油化学技術の流れを捉え、技術の系統化を考えてみた。その中で日本の石油化学技術の位置づけを明らかにした。

■ Abstract

The petrochemical industry involves the production of basic petrochemical products, organic industrial chemicals and polymers using petroleum or natural gas as the raw material. The industry took hold in Japan in the 1950s and almost immediately dominated the chemical industry; to this day, the petrochemical industry still remains a key industry, providing raw materials to a wide range of sectors in the Japanese chemical industry, including pharmaceuticals, cosmetics, synthetic detergents, paints, plastic molding, and rubber molding. By the 1960s, a mass supply of plastic products had dramatically impacted society, triggering a polymer revolution and undergirding Japan's rapid economic growth. New chemical factory conglomerates sprang up along the coastlines, known as petrochemical industrial complexes or kombinats.

The petrochemical industry originated in the 1920s in the United States. However, up until the early 1940s, it was little more than a chemical industry supplying a few organic industrial chemicals. Wood chemistry, oleochemistry, fermentation chemistry, and coal chemistry had all long flourished prior to the advent of petrochemistry. Petrochemistry co-existed with these in the U.S. as yet another type of chemical industry. The development of naphtha steam-cracking technology in the 1940s and the European migration of the petrochemical industry in the 1950s had a major impact on petrochemical technology. Innovations in petrochemical technology suddenly began to proliferate as the technology began to be combined with conventional European chemical technology. The petrochemical industry swallowed up the existing mass-producing chemical industries and quickly assumed a leading role among the other chemical industries.

It was at this time that Japan entered the petrochemicals arena. Since it already had mass-producing chemical industries in place, it was in a position to do more than simply adopt the new petrochemical technology being introduced; it could take an active role in new technological innovations. Japan's prior experience meant that by the late 1960s it was absorbing petrochemical technologies and successively developing its own. By the late 1970s, the intensive developments in petrochemical technology had eased, and petrochemistry began to spread across the developing nations. It was during this time that the negative aspects of petrochemistry began to emerge, such as environmental issues and chemical pollution issues. On top of this, the two oil crises in the 1970s escalated the cost of petrochemical products, resulting in a demand for low-emission technology and energy-conserving technology. By this time the Japanese petrochemical industry was no longer simply relying on technology imports and was developing its own technology. From the 1980s, the challenge was to develop olefin products with at least three carbons, rather than ethylene products with two carbons. The Japanese petrochemical industry was very active in this field. Petrochemistry became a substantial chemical industry with a wide range of products in its arsenal.

Meanwhile, significant changes started taking place on the petrochemical world map with the emergence of the Middle Eastern petrochemical industry in the 1980s. This trend has accelerated since the 2000s with China entering the industry and huge increases in production. In the 2010s, the core of the petrochemical industry is taking a dramatic shift away from the West and towards Asia and the Middle East. Accordingly, Western companies have been successively dropping out of the industry since the 1990s. However, unlike its counterparts in the West, the Japanese petrochemical industry took a different path. Japan is now not only planning for greater functionalization within the petrochemical industry, but also developing fields of functional chemistry outside of the conventional scope of petrochemistry, even incorporating polymer molding technology.

There have also been changes within the conventional scope of petrochemistry, such as significant growth in the demand for propylene in contrast to ethylene. In response to these changes in business environment, new trends have been observed in petrochemical technology since the 1990s. Petrochemistry may change significantly in the next decade or two. This survey report aims to identify the trends in petrochemical technology throughout the history of the petrochemical industry worldwide and pinpoint Japan's contribution to petrochemical technology.

■ Profile

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昭和42年　都立上野高校卒業
昭和47年　東京大学工学部合成化学科卒業
昭和49年　東京大学大学院工学系研究科修士課程修了
同　年　通商産業省入省（行政職）
昭和62年　三井東圧化学㈱入社
平成９年　合併により三井化学㈱に転籍
平成20年　三井化学㈱を定年退職
以後、著作、編集、翻訳、講演活動に従事
平成27年　国立科学博物館産業技術史資料情報センター主任調査員

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反転鋤込み耕 (ボトムプラウ耕) 技術の系統化調査

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History of Reversal Tillage (bottom plow tillage) Technology

田辺 義男 *Yoshio Tanabe*

反転耕 (ボトムプラウ耕) は一般の人にとっては馴染みが薄く、その説明に苦慮するところである。農耕が始まって以来、農作物を栽培するうえで耕すという行為は大昔より棒→石斧→鍬→鋤→洋犂と時代と共に変遷してきたが土を掘る、反転する、砕土することには基本的に変わりはないのではないかと思われる。人々は鍬や犂により田畑の土を少しでも深く耕し、柔らかな土を求めて圃場を作ってきた。そのことが豊かな稔りを得るために必要であることを長い経験の中で学んできた。農具をけん引する動力源の進歩と同時に農機具自体が改良されて、大型化、堅牢化、精密化が図られてきているが原理は同じである。

望ましい土の条件は、播種した種子の発芽と、その後の生育に良好な環境を与え、その環境が毎年維持されることである。このことは土壌構造と密接な関連を有する。

作物が生育するには、根から養分を吸収しなければならず、そのために根は自由に伸びなければならない。土の養分は広い範囲にバランスよく位置していること、有機物が豊富にあり、その腐食を助けるに必要な水と空気、地温が充分であること、それを分解して根に吸収しやすくする微生物も豊富にあることが肝要である。水と空気が適当であれば地温も高まるのである。腐食した有機物は土の単粒構造を結びつけて団粒にする糊のような役目を果たし、土壌の団粒構造化を促進する。

化学肥料を与えすぎない、表土に雑草や害虫がなく作物の生育に支障を与えないことも大事である。根は養分を求めて自由に伸びる。したがって土は広い範囲にわたって適度の柔らかさに保たれていなければならない。これを実現するために硬盤（不透水層）を破砕し、さらに深く耕し、広い範囲を膨軟にし、作土層を広げなければならない。また、条件に応じて排水を良くすることも必要である。サブソイラやプラソイラで心土を破砕しても不足の場合は、暗渠を施工して作物の生育環境を良好にすることもしなければならない。

土の中の養分は作物に吸収されて、減少してゆく。したがって、有機物を入れなければ地力は低下していくことになる。残った養分の維持は当然として、作物により吸収されたよりも多くの有機物を土に返さなければならない。この循環農法こそ作物にとって、望ましい土づくりの条件であり、持続型農業の基本である。

農作業体系を一般的に説明すると、①排水対策（サブソイラ、プラソイラ、溝掘り機）②施肥、堆肥散布（ブロードキャスター、マニアスプレッダ）③耕起（ボトムプラウ、ロータリティラー、駆動型デスクプラウ、スタブルカルチ）④砕土・整地（ロータリハロー、バーチカルハロー、デスクハロー、レーザーレベラー）⑤播種・移植（ドリル、田植え機、プランター）⑥防除（スプレイヤー）⑦追肥　⑧収穫（コンバイン、ハーベスタ）⑨乾燥・調整（乾燥機、もみすり機、選別機）と多工程になる。

農作業体系の中の③耕起方法は大きく分けてⓐ反転耕（ボトムプラウ耕）、ⓑ撹土耕（ロータリティラー）、ⓒ簡易耕（スタブルカルチ、駆動型デスクプラウ）に分類される。

本系統化のテーマである反転耕（ボトムプラウ耕）は農業にとって基本となる土の物理性の改善と維持のため有効な手段である。深耕によって根圏域の拡大、有機物の鋤き込み、表層土壌の再生、土壌の均質化、潜在地力の活用と保全、作業の高能率化をもたらし、播種作業前に最適な土壌環境を作ることを可能とする。

北海道農業は、明治開拓以来ケプロンをはじめ多くの西欧の技術者の指導により、畑作畜産を主体とし、西欧型畜力機械化農業が行われてきたが、その西欧では既に戦前にトラクタによる農業の機械化が広く実施されていた。

これに対し、北海道農業の機械化が進みだしたのは、戦後になってからの昭和 30 年ころからであった。しかし、誰もが考えられないハイスピードで、明治開拓以来続いていた畜力機械体系から一挙にトラクタ機械体系に移行し、現在の様な北海道の農業に進展したのである。

農業の機械化の急速な進展の背景には、戦後の混乱した世相を安定させるために、食糧を確保しようとする社会経済政策があった。一刻も早く不足する食糧を増産し、アメリカによる全面的な食糧支配から脱することに加え、機械化の結果余剰となった農村の労働力を、他の産業の振興のために振り向けようという思惑もあった。

また占領政策にとって封建的な農村機構の体制は不都合であり、これを変革して農業の近代化を急ぐ必要もあった。その基本政策として農地法、農協法、更には農業基本法を制定した。北海道は広大なる農地と未墾地を有している。これらを改良・開発し、食料増産基地として早期に整備することは当時の諸々の時代背景として喫緊の課題であったのである。このためにも大型機械化の普及が急務であった。

第１章では農耕の始まりを紹介する。田畑の耕しは、棒によって土を突く、掘ることに始まった。このため、持ちやすく、刺さりやすくする形態のものが多い。それが進化して打込みやすいように角度が付き、鍬の原型のようになった。さらに進歩して人力で引っ張る鋤のような形になった。これは現在のプラウの原型のように思える。4000 年前から土の耕起・反転の原理は同じである。

第２章では、韓国・中国から伝わり、日本で江戸時代に盛んに改良が進んだ和犂について説明する。増収のための深耕の始まりである。この流れは、明治時代後半からの松山原造、高北新治郎を始めとする諸人の研究につながり、近代短床犂が完成した。

第３章では、洋犂（プラウ）の起源と、現在のプラウの基となった洋犂の発達を紹介する。

第４章では、洋犂（プラウ）の北海道への導入と農業機械化の変遷について述べる。1869（明治２）年にプロシア商人ガルトネルが七重村に 3 頭曳きプラウを持込んだのが最初といわれる。北海道開拓庁は 1874（明治７）年に基幹農機具としてプラウを米国から輸入している。ケプロンは技術普及のために農業現術生制度を設け、洋式農業の普及に努めた。当時導入された洋式農具についても説明する。また北海道農業機械の進展についての経緯を説明する。

第 5 章ではトラクタ用プラウの変遷と畑地の耕起について述べる。欧米の製品をそのまま、日本の土に適用できるほど農耕は単純ではない。物真似の時代を経て、日本独自のプラウ曲面、土壌付着問題の解決などに到った国産化の過程について説明する。

第 6 章では、畑地の土層・土壌改良とその器具であるプラソイラおよび沖縄用プラウについて述べる。北海道は火山灰土、泥炭など不良土が多く土層改良が必須の課題であった。開発された畑地の土層改良について、利用した機械とその効果について説明する。また、心土を活用する新しい考えで開発されたプラソイラについての効果も説明する。さらに、沖縄の重粘土に取組んだ土耕機メーカーの開発経緯を紹介する。

第 7 章では、水田の耕起、砕土、整地（レーザーレベラー）について述べている。日本の水田面積は約 245 万 ha で耕地面積の約半分を占める。コメ余り現象の中でこれをどのように活用するかが長年の課題であるが、農業技術は確実に進んでおり、本章では新しいレーザーレベラーを使用した耕法について説明する。

第 8 章では、作物にとり望ましい土の構造はどうあるべきか、何故プラウ耕が必要なのか、といったことを含め、畑地の易耕性について説明する。

第 9 章では、プラウ耕とトラクタドラフトコンントロール機能について説明する。耕起作業の仕上がり状態は後作業に大きな影響を与える。圃場の変化に合った耕起作業が出来るようにドラフトコンントロール機能が設定されている。この装置について説明する。

第 10 章では、ボトムプラウの種類と機能について基本的なことを説明する。

第 11 章では、プラウ耕の技術を応用した工事について説明する。土を起こす、反転する、破砕するといった機能を持つプラウは農耕以外に利用されることが多いので、その例を紹介する。火山噴火による降灰への対策、湖底に水道管を敷設する湖底プラウ、プラウ耕を利用した基盤整備、汚染土壌のゼロ排土埋却等、代表的なものについて説明する。

第 12 章では軽量で耐久性のあるプラウの生産についての一部を紹介する。プラウの生産は農業大国のヨーロッパ、アメリカが主流である。日本では 20〜200PS の幅広い範囲のトラクタを使用して、小規模から大規模までの農業が行われている。対応する製品も少量多品種になっている。このようなニーズに対応したプラウについて述べる。

日本農業も TPP 大筋合意で専業農家と兼業農家の進むべき方向が明確になってくるものと考えられる。農業製品分野では米国、カナダ、ブラジル、豪州、ニュージーランドが主な参加国で、わが国は経営規模的には対等に戦えず、品質、安全性等の面での競争になると考える。本技術系統化が、農業経営の後継者が反転耕（プラウ耕）による持続性ある土つくりを不断に行い、魅力ある農業を実践していく上での参考になることを期待する。

■ Abstract

Reversal tillage (bottom plow tillage) is not a familiar term for the general public, and it can be a struggle to explain. Since the start of agriculture, tilling has been a part of cultivating crops. Though the tools have changed with the times, from sticks to stone axes to hoes to spades to Western plows, the basic act of digging, turning, and harrowing the soil appears to have remained the same since the earliest of times. Humans have used hoes and plows to till the soil as deep as they could, making fields in pursuit of soft soil. They have learned through experience over a long period of time that tilling is necessary to achieve a bountiful harvest. Agricultural equipment has been improved along with the advancement in sources of power to pull agricultural implements. Equipment has been made larger, more durable, and more precise, but the principle is the same.

The best soil condition is one that provides a good environment for sown seeds to germinate, then grow—and preserves that environment every year. This is closely related to soil structure.

For crops to grow, they must absorb nutrients with their roots, and for that, the roots must be able to grow freely. The keys are for the soil to have its nutrients distributed in a balanced way over a wide area; have ample organic matter; have enough water, air, and soil temperature to help it decay; and have ample microorganisms which break it down and make it easier for the roots to absorb nutrients. If the water and air are appropriate, the soil temperature also rises. Decomposed organic matter acts like glue to bind together the single particles in the structure of soil into aggregates, promoting the formation of aggregate structures in the soil.

It is also important that not too much chemical fertilizer is used, and that the soil surface is free of weeds and harmful insects so that they do not inhibit crop growth.

Roots grow freely as they seek nutrients. Accordingly, soil must be kept reasonably soft over a wide area. To bring this about, the hardpan (impermeable layer) must be broken up, the soil tilled even deeper, and a wider area loosened to spread the plowed layer. It is also necessary to improve drainage according to the circumstances. If breaking up the subsurface soil with a subsoiler or plowsoiler is not enough, ditches may need to be constructed to make the growing environment good for the crop.

The nutrients inside soil decrease as they are absorbed by the crop. Therefore, soil productivity decreases unless organic matter is added. In addition to retaining the remaining nutrients, more organic matter than was absorbed by the crop must be returned to the soil. This cyclical farming method is a condition for creating the ideal soil for crops and is the basis for sustainable farming.

A general explanation of the system of agricultural operations involves many stages: (1) draining (subsoiler, plowsoiler, trench excavators); (2) fertilization and compost-spreading (broadcaster, manure spreader); (3) plowing (bottom plow, rotary tiller, driven disk plow, stubble cultivator); (4) harrowing and soil preparation (rotary harrow, vertical harrow, disk harrow, laser level); (5) sowing and transplanting (drill, rice transplanter, planter); (6) pest control (sprayer), (7) fertilizer addition; (8) harvesting (combine, harvester); and (9) drying and preparation (dryer, huller, sorter).

The methods for Item (3) plowing in the system of agricultural operations can be loosely classified into (a) reversal tillage (bottom plow tillage); (b) tillage by stirring (rotary tiller), and (c) minimum tillage (stubble cultivator, driven disk plow).

Reversal tillage (bottom plow tillage), the theme of this systemization, is an effective method of improving and maintaining the physical condition of soil, a basis for farming. Deep tilling brings about the expansion of the rhizosphere, the plowing in of organic matter, the renewal of surface soil, the homogenization of soil, the use and conservation of potential soil productivity, and the enhancement of work efficiency. It also makes possible the preparation of a suitable soil environment before the sowing process.

Farming in Hokkaido since its development in the Meiji era had been mainly of crops and livestock by way of animal-powered mechanized farming in the Western style under the guidance of many Western experts such as Capron. In the Western world, mechanized farming using tractors was already widely in use before World War II.

In contrast, the mechanization of farming in Hokkaido started to progress only after the war, in the mid-1950's. However, the speed of adoption was higher than anyone would guess. The animal-powered mechanical system which had been in use since its development in the Meiji era was at once abandoned for the system of mechanized tractors, advancing to the current state of farming in Hokkaido today.

Behind the rapid advancement of the mechanization of farming was a socioeconomic policy seeking to secure food to stabilize the social conditions of postwar confusion. One goal was to increase the then the insufficient production of food as soon as possible to get away from complete reliance on the U.S for food. There was the additional anticipation of using the labor of farming villages made redundant by mechanization to further other industries.

Furthermore, a system with a feudalistic farming-village structure was not suitable for the occupation policy, and there was a need to reform this and expedite the modernization of farming. The Agricultural Land Act, the Agricultural Cooperatives Act, and the Agricultural Basic Act were enacted as basic policies. Hokkaido has a vast amount of agricultural and uncultivated land. In the varying context of the times, improving and developing these and expediting their preparation as a base for increased production of food was a pressing issue. For this reason, also, the adoption of large-scale mechanization was an urgent matter.

Chapter 1 presents the start of agriculture. Tilling of the field began with jabbing and digging soil with sticks. For this reason, most utensils are shaped for easy holding and piercing. It evolved to form an angle for easier driving and became a primitive hoe. It progressed further and became shaped like a spade to be pulled by human force. This appears to be the primitive form of the modern plow. The principle of soil plowing and overturning has been the same since 4,000 years ago.

Chapter 2 explains the wari, a plow introduced from Korea and China that underwent extensive improvement in Japan during the Edo period. It was the beginning of deep tilling for increased yield. The course of events led to the research of many such as Genzo Matsuyama and Shinjiro Takakita starting in the latter half of the Meiji period, culminating in the completion of the modern tanshori (short-heel plow).

Chapter 3 presents the origins of the Western plow and the development which became the basis for the plow of today.

Chapter 4 describes the introduction of the Western plow to Hokkaido and the changes of the mechanization of farming. A plow pulled by three animals brought by the Prussian merchant Gaertner to the village of Nanae in 1869 is

said to be the first. The Hokkaido Development Agency imported plows from the U.S. in 1874 as key farming equipment. Capron established the farming internship program to spread technology and made efforts to popularize the Western way of farming. The Western style farming equipment introduced at that time is also explained, as well as the sequence of events regarding the advancement of Hokkaido farming equipment.

Chapter 5 describes the changes in plows for tractors and the tilling of farmland. Agriculture is not so simple that European and American products can be applied as-is to Japanese soil. The process leading to a domestic plow is explained, from the period of imitation to the development of a Japanese original curve on the plow and a solution for the problem of soil attachment.

Chapter 6 describes the improvement of the soil layer and soil of farmland, the tools used—the plowsoiler and the plow for Okinawa. Hokkaido has much volcanic ash soil, peat, and other undesirable soil, making soil layer improvement a necessary challenge. Equipment used in improving soil of developed farmland is explained, along with its effects. The effect of a plowsoiler is also explained—a product of a new idea to make use of subsurface soil. Also presented is the history of development by a soil tilling machinery manufacturer who took on the heavy clay soil of Okinawa.

Chapter 7 describes the tilling of paddy fields, harrowing, and soil preparation (laser level). Paddy fields in Japan total 2,450,000 hectares (9,459 square miles), taking up about half of cultivated land. Making use of this has been a long-term issue with the phenomenon of excess rice, but farming technology has certainly progressed. This chapter explains a new method of tilling using new laser levels.

Chapter 8 explains the tilth of farmland, including what the ideal soil structure for crops should be and why plow tilling is necessary.

Chapter 9 explains plow tilling and the tractor draft control system. The condition at the completion of tilling greatly affects the procedures that follow. The draft control system is set so that tilling can be done, adapting to the variations of the field. This system is explained.

Chapter 10 explains the basics of the types and functions of bottom plows.

Chapter 11 explains how plow tilling technology is applied to construction. Plows which bring up soil, overturn it, and crush it are often used outside of agriculture. Some examples are presented. Some typical uses are explained, such as measures against ash from volcano eruptions, lake-bottom plows for laying water pipes on lake floors, laying of foundations using plow tilling, zero-soil removal burial of contaminated soil.

Chapter 12 presents an aspect of the production of lightweight and durable plows. Plows are mainly manufactured in the great farming countries of Europe and the U.S. A wide range of tractors from 20 to 200 PS are used in Japan for farming, from small-scale to large-scale. A wide variety of applicable products are also becoming available in smaller lots. Plows filling such needs are described.

With broad agreement having been reached by the Japanese government regarding TPP, the paths to be taken by those who farm as their main or subsidiary business are expected to become clearer. In the category of agricultural products, the major players are the U.S., Canada, Brazil, Australia, and New Zealand. Japan cannot compete in terms of size of operations, but is expected to be able to compete in terms of quality and security. It is hoped that this systemization of technology will become a reference point as successors to agricultural management continue to use reversal tillage (plow tilling) to prepare sustainable soil to put attractive farming into practice.

■ Profile

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■ Contents

アーク溶接技術発展の系統化調査

4

A Systemized Exploration of the Development of Arc Welding Technology

三田 常夫 *Tsuneo Mita*

■ 要旨

金属を接合する溶接は、今日の工業製品にとって欠くことのできない重要な加工技術となっている。その溶接では、接合部を局部的な高温に高めるために、電気的なエネルギーを利用した種々な手法が開発されているが、とりわけ、アーク熱を利用して母材を溶融するアーク溶接があらゆる産業分野で大きな役割を果たしている。アーク溶接に用いられるアークは 1807 年に発見され、発電機が出現した 1860 年頃以降アークを用いる溶接法の適用が本格化し、現在の主要なアーク溶接法のほとんどは 1950 年前後に開発された。1914（大正 3）年にアーク溶接が導入されたわが国では、その後の 100 年間でアーク溶接技術は大きく発展し、近年では、世界の溶接界をリードする主要国としての立場を確立している。

本報告は、このようなアーク溶接技術のわが国における発展経過を中心にまとめたもので、その構成は次のようである。第 1 章では、本報告のテーマである溶接技術の概要と加工技術としての位置付けを述べるとともに、その中でアーク溶接法の占める役割を説明した。第 2 章では、アーク溶接法の概要を説明するために、溶接アークの性質ならびに主なアーク溶接法の原理と特徴を述べた。

第 3 章からは本報告の本題であり、第 3 章ではアーク溶接プロセスの発展経過をアーク溶接法ごとにまとめた。取り上げたアーク溶接法は、被覆アーク溶接、サブマージアーク溶接、ティグ溶接、ミグ溶接、マグ溶接、パルスマグ・ミグ溶接およびその他のアーク溶接である。その他のアーク溶接としては、プラズマアーク溶接、セルフシールドアーク溶接、エレクトロガスアーク溶接、アークスタッド溶接ならびに狭開先溶接を取り上げている。第 4 章ではアーク溶接に用いられる溶接機・溶接電源の発展経過について、時期を 1900 年代前期の萌芽期、1900 年代中期の開拓期、1900 年代後期の発展期および近代 (1969 年以降) に分け、それぞれの時期ごとにアーク溶接機および電源の発展経過を記述した。第 5 章では、溶接棒、溶接ワイヤなどのアーク溶接材料と、アーク溶接に用いられるシールドガスの発展経過について述べた。

第 6 章は本報告のまとめであり、第 3 章～第 5 章で述べたアーク溶接技術の発展経過を整理し、溶接プロセス、溶接電源および溶接材料それぞれの発展経過の概要をフロー図としてまとめた。また、アーク溶接技術の今後の課題についても概説した。

■ Abstract

Welding, the fusing together of metals, has become a processing technology indispensable for the industrial products of today. Many methods using electric energy have been developed to raise the localized temperature at the joint for welding. Arc welding, in particular—using heat from an electric arc to fuse the base material—plays a major role in various industrial fields. The electric arc used in arc welding was discovered in 1807. The application of welding methods using this arc became full-fledged since electricity generators appeared in 1860, and most major arc welding methods in use today were developed around 1950. Arc welding was introduced to Japan in 1914. In the 100 years since, its arc welding technology has developed greatly, and Japan has established itself in recent years as a major country leading the welding world globally.

This report outlines such arc welding technology, focusing on the course of its development in Japan, and is organized as described below. Chapter 1 gives an overview of the theme of the report—welding technology—and where it stands as processing technology, as well as the role played in it by arc welding. Chapter 2 is an overview of the arc welding method, describing the characteristics of the welding arc and the principles and features of the major methods.

The main subject of this report starts in Chapter 3, laying out the course of development of processes in arc welding, categorized by arc welding method. The arc welding methods featured include shielded metal arc welding, submerged arc welding, Tungsten Inert Gas (TIG) welding, Metal Inert Gas (MIG) welding, Metal Active Gas (MAG) welding, and pulsed MAG/MIG welding. Other arc welding featured are plasma arc welding, self-shielded arc welding, electrogas arc welding, arc stud welding, as well as narrow-gap welding. Chapter 4 documents the course of development of welding equipment and welding power supply used in arc welding, classified by period: the embryonic phase of the early 1900's, the pioneering phase of the mid-1900's, the progressive phase of the late 1900's, and the modern phase (since 1969). Chapter 5 describes the course of development of arc welding materials such as welding rods and welding wire, and shield gases used in arc welding.

Chapter 6 is the conclusion of this report, and reiterates the course of development of arc welding technology described in Chapters 3 to 5. The course of development of welding processes, welding power supplies, and welding materials are each summarized in a flow chart. Issues currently facing arc welding technology are also outlined.

■ Profile

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■ Contents

History of Cement Manufacturing Technology

1

Takashi Shimoda

■ 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

Takashi Shimoda

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1963:	Graduated from the University of Tokyo Faculty of Engineering, Department of Industrial Chemistry Started working for Onoda Cement Co., Ltd. assigned to the Central Research Laboratory Later assigned to other departments, including a cement production plant, the head office production department and a concrete subsidiary in the U.S. Company name changed through mergers from Onoda Cement Co., Ltd. to Chichibu Onoda Co., Ltd. (1994), then to Taiheiyo Cement Co., Ltd. (1998)
1996:	Appointed as the general manager of the Chichibu Onoda Central Research Laboratory
2002:	Appointed as managing director of Taiheiyo Cement, overseeing the Laboratory, Construction Materials Business Department and Ceramics Business Department
2005:	Appointed as an outside company auditor for Central Glass Co., Ltd.
2006:	Retired from Taiheiyo Cement as director and managing executive officer
2009:	Retired from Central Glass as outside company auditor

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Systematic Survey on Petrochemical Technology 2

Keizo Tajima

■ Abstract

The petrochemical industry involves the production of basic petrochemicals, industrial organic chemicals and polymers using petroleum or natural gas as the raw material. The industry took hold in Japan in the 1950s and almost immediately dominated the chemical industry; to this day, the petrochemical industry still remains a key industry, providing raw materials to a wide range of sectors in the Japanese chemical industry, including pharmaceuticals, cosmetics, synthetic detergents, paints, plastic molding and rubber molding. By the 1960s, a mass supply of plastic products had dramatically impacted society, triggering a polymer revolution and undergirding Japan’s rapid economic growth. New chemical factory conglomerates sprang up along the coastlines, known as petrochemical industrial complexes or *kombinats*.

The petrochemical industry originated in the 1920s in the United States. However, up until the early 1940s, it was little more than a chemical industry that existed only in the United States, supplying a few industrial organic chemicals. Wood chemistry, oleochemistry, fermentation chemistry and coal chemistry had all long flourished to the point of mass production prior to the advent of petrochemistry, in Europe, the United States and Japan alike. Petrochemistry co-existed with these in the United States as yet another type of chemical industry. The development of naphtha steam-cracking technology in the 1940s and the European migration of the petrochemical industry in the 1950s had a major impact on petrochemical technology. Innovations in petrochemical technology suddenly began to proliferate as the technology began to be combined with conventional European chemical technology. The petrochemical industry swallowed up many of the existing mass-producing chemical industries and quickly assumed a key role among the other chemical industries.

It was at this time that Japan entered the petrochemicals arena. Since it already had mass-producing chemical industries in place, it was in a position to do more than simply adopt the new petrochemical technology being introduced; it took an active role in new technological innovations. Japan’s prior experience meant that by the late 1960s it was absorbing petrochemical technologies and successively developing its own. By the late 1970s, the intensive developments in petrochemical technology had eased, and petrochemistry began to spread across the developing nations. It was during this time that the negative aspects of petrochemistry began to emerge, such as environmental issues and chemical pollution issues. On top of this, the two oil crises in the 1970s escalated the cost of petrochemical products, resulting in a demand for low-emission technology and energy-conserving technology. By this time the Japanese petrochemical industry was no longer simply relying on technology imports and was developing its own technology. From the 1980s, the challenge was to develop olefins-based products with at least three carbon atoms, rather than ethylene products with two carbon atoms. The Japanese petrochemical industry was very active in this field. Petrochemistry became a substantial chemical industry with a wide range of products in its arsenal.

Meanwhile, significant changes started taking place on the petrochemical industrial world map with the emergence of the Middle Eastern petrochemical industry in the 1980s. This trend has accelerated since the 2000s with China entering the industry and huge increases in production. In the 2010s, the core of the petrochemical industry is taking a dramatic shift away from the West and towards Asia and the Middle East. Accordingly, Western companies have been successively dropping out of the industry since the 1990s. However, unlike their counterparts in the West, Japanese petrochemical companies took a different path. Japan is now not only planning for greater functionalization within the petrochemical industry, but also developing fields of functional chemistry outside of the conventional scope of petrochemistry, even incorporating polymer molding technology.

There have also been changes within the conventional scope of petrochemistry, such as significant growth in the demand for propylene in contrast to ethylene. In response to these changes in business environment, new trends have been observed in petrochemical technology since the 1990s. Petrochemistry may change significantly in the next decade or two.

■ Profile

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1967: Graduated from Tokyo Metropolitan Ueno High School
1972: Graduated from the Department of Synthetic Chemistry, Faculty of Engineering, The University of Tokyo
1974: Completed Master's degree at the Graduate School of Engineering, The University of Tokyo
Joined the Ministry of International Trade and Industry (administrative post)
1987: Joined Mitsui Toatsu Chemicals Co., Ltd.
1997: Transferred to Mitsui Chemicals, Inc. by merger
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