The 50 Year History of Mold Powder at Shinagawa Refractories ～ Something New ～

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Abstract

Last year, Shinagawa Refractories Co., Ltd. celebrated its 50th anniversary as a supplier of technically advanced mold powder for the continuous casting of steel. Since its beginning in 1971, Shinagawa has conducted extensive development of this technology to become a technological leader. By providing a broad range of unique, high-quality products, Shinagawa has contributed significantly to improvements in continuous casting operations, helping to increase productivity and offer improved steel quality. At present, our products are widely used in many steel works around the world. This report will give a summary of the technological improvements made in Shinagawa's mold powders along with the technology trends in continuous casting over the last 50 years, and the products that have resulted.

1. Introduction

Shinagawa refractories Co., Ltd. (Shinagawa) started research and development of mold powder for continuous casting of steel in cooperation with NKK Corporation in 1971. Since then, along with the progress in continuous casting technology, Shinagawa has made significant technical developments in mold powders to enhance casting operations. The result is many unique products, providing excellent casting stability and achieving the highest possible quality of steel. Products are currently used in many Japanese steel mills as well as many other steel mills around the world with Shinagawa being widely recognized as a technological leader. Here we will introduce the technology that we have developed under the title of "The 50 years history of mold powder history at

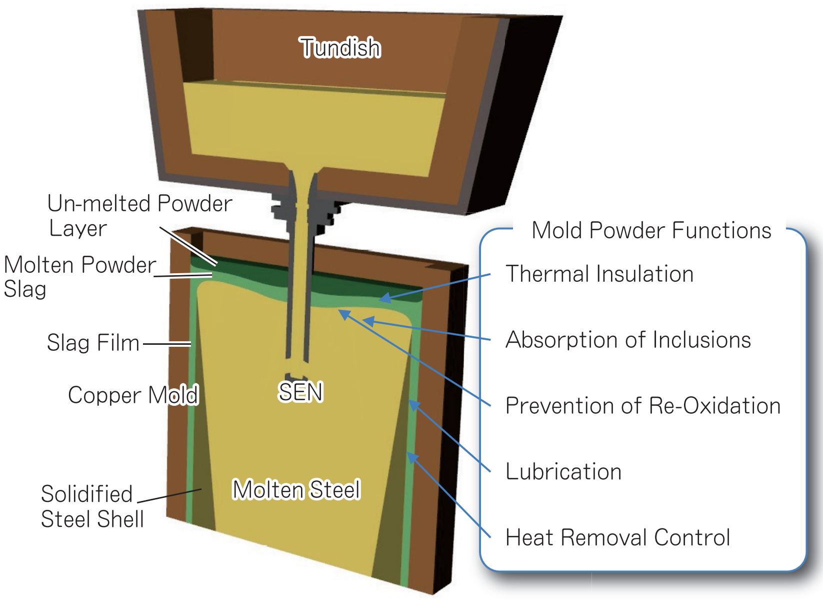

Fig. 1　Mold Powder Functions.

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Shinagawa Refractories".

The functions of mold powder are briefly described in Fig. 1. The mold powder is added into the mold in the form of either a fine powder or a granule. In either event the product is obtained by mixing raw materials such as oxides, fluorides, carbonates, carbons etc. The mold powder is heated by the molten steel, and melts to form a molten slag layer below the un-melted powder layer above the surface of the molten steel. The molten slag flows into the gap between the mold wall and the solidified steel shell and forms a solidified slag film. In this process, the five functions-thermal insulation of the molten steel surface, prevention of reoxidation of the molten steel, absorption and removal of inclusions from the molten steel by the molten slag layer, lubrication between the mold wall and the solidified steel shell, and control of heat removal from the solidified steel shell to the mold-are provided. Thus, mold powder is an indispensable functional material for the current continuous casting process to obtain stable operation and high-quality steel.

Continuous casting of steel was first tested in 1947 in former West Germany, and the first continuous casting in Japan was introduced by Sumitomo Metal Industry (Osaka) in 1955. The crude steel production in Japan increased drastically in the 1960s, exceeding 100 million tons in 1973 for the first time. However, the continuous casting share was less than 30 % at that time. In the 1970s, many continuous casters started commercial operation and by 1985 the continuous casting share of steel production exceeded 90 %. Today the share of continuous casting in Japan is over 98 %[1].

The first record of mold powder development was in 1959 on a billet continuous caster in Stavanger, Norway[2].

With the commissioning of many slab continuous casters in Japan in the early 1970s, mold powder casting combined with submersed entry nozzles became popular in order to improve steel quality and achieve stable casting.

Initially, the mold powders used in Japan were all imported products, but the steel industry strongly encouraged local steel consumables suppliers to develop domestically produced mold powders. In 1971, Shinagawa started developing mold powders for the local needs and started supplying test products in the following year. Three years later, in December 1974, Shinagawa started full-scale production from its manufacturing plant at Moriyama works. At that time, Shinagawa was a unique company in that it provided both mold powder and refractories.

Table 1 shows the mold powder chronology of the Shinagawa business alongside Japanese continuous casting technology trends.

2. Technological Trend of Mold Powders in Shinagawa

Shinagawa has expanded the commercial production of mold powder by emphasizing consistent supply and technical development. Mold powder technology is closely related to the development of continuous casting technology. When the history is roughly divided into 10-year increments, the trends and the important goals become clear. In this report, the mold powder technology developed in Shinagawa from the 1970s to the recent years is reviewed, together with the continuous casting technology trends. The latest technologies since 2010 are covered in detail in Section 2.2.

2. 1 From the 1970s to the 2000s

1) The 1970s ; Expanded application of continuous casting and mold powder.

In the 1970s, mold powder was commercialized, and its application became widespread. The number of continuous casters increased rapidly, and continuous casting of low carbon Al-killed (LCAK) steel grades became commonplace. At the same time, tests were being conducted on IF steels and other more quality sensitive steel grades. Attention focused on the improvement of steel productivity and the many curved type slab continuous casting machines used for normal carbon steel grades. The trend was to further increase productivity, and higher speed casting was adopted.

In LCAK casting, the main mold powder attributes needed for high quality, reliable production are good thermal insulation of the molten steel surface in the mold, prevention of steel reoxidation, adequate lubrication, good inclusion absorption, and prevention of carbon pickup.

Shinagawa first introduced mold powder as a product in the Shinagawa technical report in 1974[3]. At that time, the typical mold powder had a basicity CaO/SiO_2 of about 1.0 and a slag viscosity of 0.2–0.3 Pa·s at 1300 ℃. In some technical reports at Shinagawa in 1970s, the effects of Al_2O_3 pick-up on the powder slag characteristics for LCAK steel casting were emphasized. However, ranges in the type and properties of the mold powder products at that time were very limited compared to the extensive range of products now available.

2) The 1980s ; Time of further increases in productivity and higher steel quality demands in continuous casting and mold powder.

The two oil crises in the 1970s, increased the attractiveness of the more energy efficient continuous casting process. This helped drive the continuous casting share

Table 1 Mold Powder History in Shinagawa with Continuous Casting technology trend in Japan summarized in English.

<table>
<tr><th>Year</th><th>Main Event</th><th>Casting Technology Trend in Japan</th></tr>
<tr><td>1971</td><td>Shinagawa started research into mold powder with NKK</td><td rowspan="3">Low carbon Al killed in CC process
IF steel in CC process
Bending type slab caster (Increase Casing speed)</td></tr>
<tr><td>1974</td><td>Shinagaw started manufacturing of mold powder at Moriyama plant</td></tr>
<tr><td>1977</td><td>Shinagawa started providing granule products for low carbon Al killed steel</td></tr>
<tr><td>1984</td><td>World record the highest casting speed 2.2 mpm was achieved at NKK Fukuyama #5CCM with Shinagawa products</td><td rowspan="4">Energy efficiency
Direct rolling (HCR/DR)
High Speed Casting
Vertical bending type slab caster
Steel quality improvement</td></tr>
<tr><td>1987</td><td>Technical agreement with FMP Inc. (now Shinagawa Americas)</td></tr>
<tr><td>1988</td><td>Developed of an exothermic mold powder</td></tr>
<tr><td>1989</td><td>Thin slab caster at Nucor Crawfordsville started running with a Shinagawa/FMP product</td></tr>
<tr><td>1994</td><td>Shinagawa mold powder plant was moved to Hinase in Okayama (present location)</td><td rowspan="4">Near-net shape casting
High Speed casting
Increased production of Ultra low carbon Steel
Steel quality improvement
Mold Powder Granulation
Increase in heat number in sequence</td></tr>
<tr><td>1996</td><td>Shinagawa established a business alliance with KMC</td></tr>
<tr><td>1997</td><td>Established Shenyang Shinagawa Glorious Metallurgy Materials Co., Ltd. in China</td></tr>
<tr><td>1999</td><td>Development of ultra high viscosity products PRIOS series and exothermic carbon free type products</td></tr>
<tr><td>2005</td><td>High basicity products "REVIX" series has achieved high throughput casting</td><td rowspan="4">Increased productivity
Work environment improvement
CC of high strength steel and high Al electromagnetic steel
Development of Chinese steel industry</td></tr>
<tr><td>2006</td><td>Established Shinagawa Advanced Materials Americas Inc. in USA (Shinagawa Americas)
Developed mold powder for laminated can steel</td></tr>
<tr><td>2007</td><td>Development of mold powder for Al-TRIP
Expanded sales of high viscosity PRIOS in the USA</td></tr>
<tr><td>2008</td><td>Established Liaoning Shinagawa Hefeng Metallurgical Material Co.,Ltd. in China
Installed spray dry granulation system into Chinese plants
Development of exothermic spray dried granule mold powder</td></tr>
<tr><td>2010</td><td>Development of high viscosity exothermic mold powder with Shinagawa Americas</td><td rowspan="8">Yield improvement and quality improvement
Environmental improvement
SDGs</td></tr>
<tr><td>2011</td><td>Installed spray dry granulation system into Hinase plant</td></tr>
<tr><td>2015</td><td>Development of spray dried granule carbon free mold powder</td></tr>
<tr><td>2016</td><td>Development of low erosion SEN type mold powder</td></tr>
<tr><td>2017</td><td>Introduced a F free type product practical use for slab casting</td></tr>
<tr><td>2018</td><td>Established Shanghai office in Shenyang Shinagawa in China Development of high interfacial tension slag mold powder for ULC grades</td></tr>
<tr><td>2019</td><td>Marked total sales of 45000ton/year
Installed spray dry granulation system into Shinagawa Americas</td></tr>
<tr><td>2021</td><td>50th anniversary</td></tr>
</table>

of production above 90 % in the latter half[1]. This was enhanced with the introduction of the direct rolling process (Hot Charging Rolling and Direct Rolling) which connects a hot rolling mill with a continuous caster. Additionally, it was the era when the improvement of steel quality was ever more important. This led to the introduction of vertical bending type casters as well as remodeling of the existing casters to utilize this technology help with inclusion removal by floatation in the mold. The improvement of special steel for the automobile in bloom and billet casting was also needed. Thus, in the 1980s, further development of mold powder technology was needed to meet these increased demands for both productivity and quality improvements.

For example, prevention of mold powder entrainment was needed to improve steel quality for direct rolling without surface treatment. At the same time, better lubricating products were needed for high-speed casting. To meet these needs Shinagawa developed its LMP series that utilized Li_2O to provide excellent lubrication properties. In the Shinagawa Technical Report 1985, the successful case study of casting at a maximum rate of 2.5 m/min was reported[4]. In addition, defects based on the entrainment of mold powder slag at higher casting speeds became more apparent. Shinagawa responded by developing high viscosity type mold powders. Since then, research and development for prevention of mold powder entrapment has becomes an essential countermeasure for inclusion defects.

In the Shinagawa Technical Report 1988 and 1989, the emphasis was on crack sensitive, medium carbon steel grades (including the peritectic grades where C：0.08–0.20 %). To prevent cracking on the steel strand surface, softer heat removal of the steel shell is needed. Cuspidine crystal layer formation in the mold powder slag film using high crystallization temperature mold powder was investigated[5,6]. Research to gain an understanding of the mechanisms, etc. of softer heat removal were also conducted.

Fig. 2 shows the comparison of viscosity and basicity of mold powder products during the 1980s and 2021. As shown in Fig. 2, the typical basicity (CaO/SiO_2) of the mold powder until then was around 1.0. The newly developed product was revolutionary with a high basicity of 1.2. Using these newly developed products, the surface cracking could be reduced dramatically, and in fact similar mold powders are still used in many continuous casters today.

Fig. 3 shows the relationship between casting speed and powder slag viscosity used in slab casting at today. The plots in the Fig. 2 show the applied maximum speed, and the lines show the applied speed range. The viscosity of low carbon (LC) and ultra-low carbon steel grades (ULC) has been increased as much as possible in order to reduce mold powder entrainment and still have sufficient lubrication. At the same time, high speed casting has been achieved even in medium carbon steel (MC&P) while reducing surface cracking by the utilizing high basicity technology.

Furthermore, utilizing this advanced mold powder technology, Shinagawa saw a significant development of the overseas business. In 1987, Shinagawa started providing technology to FMP Inc. (Now Shinagawa Advanced Materials Americas Inc.) in Ohio, U.S.A.

3) The 1990s；Higher steel quality requirement and mold powder.

The 1990s saw the development of molten steel flow control in the mold and the practical application of high frequency mold oscillation, as well as further progress of high-speed casting technology. In particular, production increases and steel quality improvements were needed on ULC steel grades.

For example, to improve the quality of ULC steels, Shinagawa developed carbon free mold powders where metal additions replaced the role of carbon. This was reported in the Shinagawa Technical Report 1991[7]. An experimental study for the generation of inclusion defects by iron particle phenomena was presented in the Shinagawa Technical Report 1997[8]. Development of better high viscosity and high surface tension products for reduction of mold powder entrainment defects was achieved.

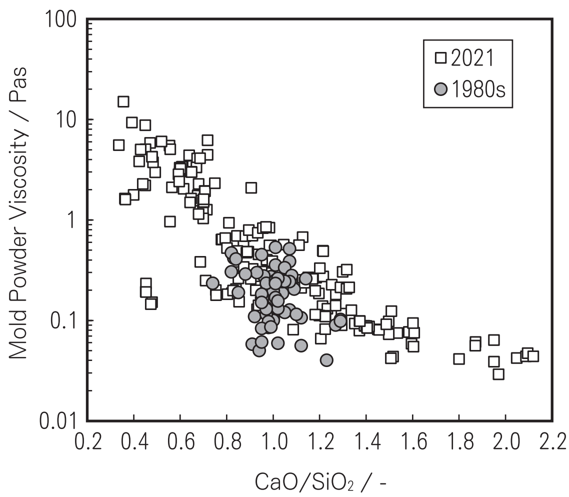


Fig. 2 Basicity vs Viscosity on 1980s and 2021.

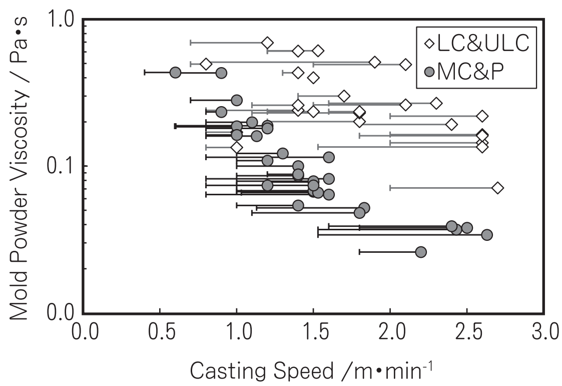


Fig. 3 Casting Speed vs Viscosity in conventional slab casters.

In addition, it was recognized that the ability to cast long periods was limited by the amount of erosion on slag line in the submersed entry nozzle. To counter this, Shinagawa developed low erosion type mold powders where the amount of F was reduced and ZrO_2 was added. This study was reported in the Shinagawa Technical Report 1993[9].

This time period also saw granular type mold powder become popular for the improvement of working environment (low dust). Improved granulation was reported in the Shinagawa Technical Report 1995[10].

The U.S.A. was at the forefront in the introduction of thin slab continuous casting machines, with the first commercial caster being commissioned in 1989. As the 90s progressed the operation became even more popular. As reported in the Shinagawa Technical Report 1994, Shinagawa, in cooperation with FMP Inc. in the U.S.A. succeeded in developing mold powder for thin slab casting by applying the technology that had been developed for conventional slab super high speed casting in Japan[11].

At the same time, the steel industry in China also grew dramatically and so in 1997 Shenyang Shinagawa Glorious Metallurgy Materials Co., Ltd. (Now Shenyang Shinagawa Metallurgy Materials Co., Ltd.) was established in Shenyang City and started to manufacture mold powders in China[12].

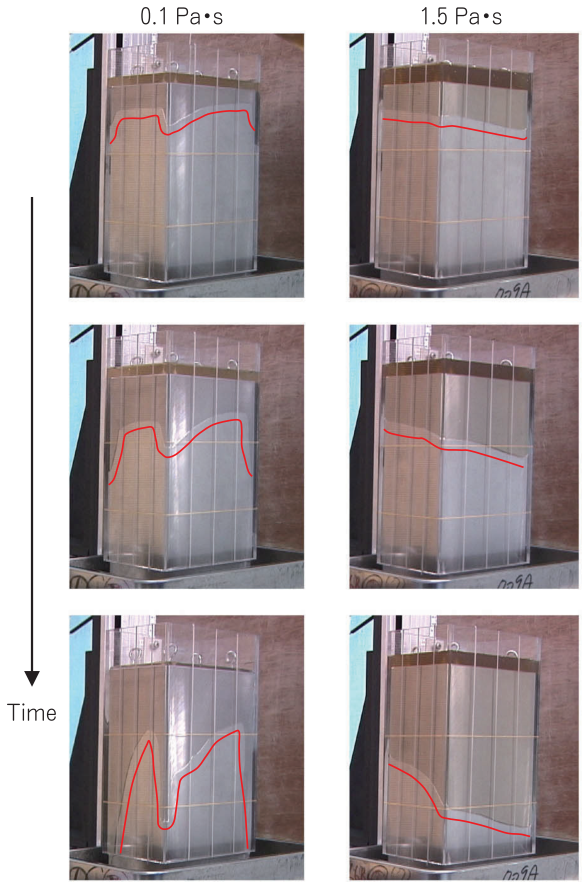
4) The 2000s；Further drastic improvement in productivity and mold powder

In the 2000s, the productivity of casting process was further improved. High Al steels casting such as electrical steel and advanced high strength steels were required, so powder development on these steels was carried out in earnest. In addition, the improvement of working environment and the effects of steelmaking to the external environment were begun to focus on.

Innovative mold powders with special chemistries were developed based on the previous technologies and these products contributed significantly to improved productivity.

For example, as reported in the Shinagawa Technical Report 2001 and 2002, PRIOS series powders with high viscosity slag properties that are 1.0 to 10.0 Pa·s were developed. These succeeded in achieving commercial use by showing superior performance in small size mold casting such as blooms and beam blanks[13, 14]. The newly developed products created a new paradigm by offering various technical advantages such as reducing mold powder entrapment, improved lubrication to prevent sticking problems, reduction of oscillation mark depth, reduction of erosion of submersed entry nozzle as well as a reduction of mold powder consumption without any casting issues. Consequently, this technology became widely adopted.

A further notable feature of the PRIOS series is that it allows a F free composition. F was previously considered essential for obtaining the slag fluidity and crystallization in the slag films. However, the high viscosity product PRIOS series creates a uniform slag inflow, providing uniform heat removal in the mold. A crystal layer in the slag film is not required to achieve softer heat removal with this technology. This made possible to make F free mold powders. Fig. 4 shows the results of simulation of the uniform inflow of high viscosity slag with using oil. 1.5 Pa·s high viscosity oil showed a small inflow rate differences between each position around the mold. In addition, environmental improvement, reducing corrosion of continuous casting facilities, expanding submersed entry nozzle life, reduced secondary cooling water treatment cost, etc. can be obtained from F free mold powders.



Slag Flow Test
Imitation Slag：Oil
Acrylic Mold Size：100 × 150 mm
Oscillation Condition：8 mm × 85 cpm

Fig. 4　Slag Flow Test result.

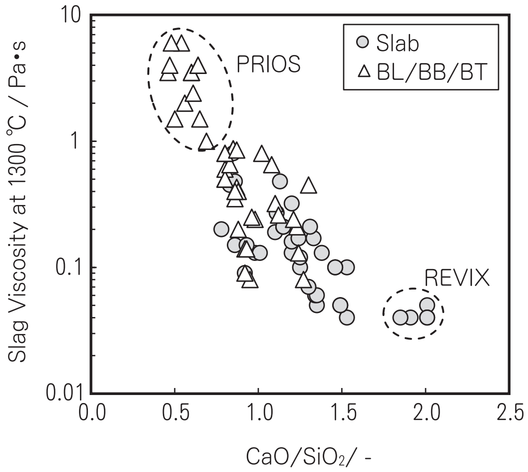


Fig. 5　Characteristics of product Basicity and Viscosity.

Shinagawa believed that the acceleration of crystallization was effective in maintaining steel quality in the high speed slab casting of medium carbon steel grades, and developed REVIX series in which the crystallization in the slag film was remarkably improved by combining the high basicity composition range (CaO/SiO_2 = 1.8 and more) and appropriate flux components[15]. High speed casting requires more heat removal, but when medium carbon steel is cooled rapidly, the phase transition accompanied by volume shrinkage tends to cause slab surface cracking. REVIX is characterized by allowing softer heat removal from the initial solidification stage, where the cracking of the cast strand occurs. The use of REVIX enabled high throughput operation/high speed casting operation exceeding the maximum 9 ton per minute while keeping surface cracks to a minimum.

SIPS series was developed for the high Al content electrical steel, and was reported in Shinagawa Technical Report 2007[16]. The SIPS can prevent the formation of high liquidus temperature crystals and provide the sufficient lubrication even if a large amount of Al_2O_3 pick up occurs from the molten steel in the mold.

Fig. 5 shows the matrix of mold powder basicity and viscosity at present. The basicity ranges from 0.3 to 2.1 and the viscosity ranges from 0.04 to 8.0 Pa·s. Further shown in Fig. 6 is a cross sectional micrograph of each characteristic mold powder slag film taken from actual casting. High viscosity PRIOS sample has no crystal formation i.e. it is only glass phase, whereas a high density crystallization can be observed in the high basicity product REVIX sample.

In the 2000s, Shinagawa also focused efforts on developing environmental friendly products. Development of GEMINI series, a low dustiness fine powder with surface treatment was reported in the Shinagawa Technical Report 2000[17]. Also expansion of the application of F free mold powders, and the development of white powder by use of a special carbon application was described in the Shinagawa Technical Report 2005[18].

Shinagawa also expanded its overseas mold powder business during this decade. FMP was acquired by Shinagawa in the U.S.A. which up until then had been

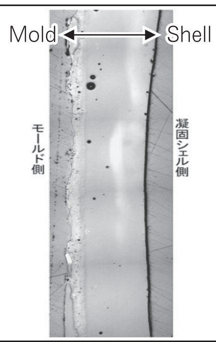
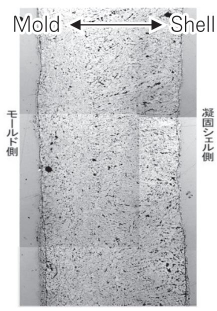
Brand	PRIOS	Low Crystallization Type (LMP)	High Crystallization Type	REVIX
Characterestics	High Viscosity Glassy	Thin Crystal layer Low Basicity	Thicker Crystal Layer Medium Basicity	High density crystal layer High Basicity
Apprication	Bloom Beam Blank Billet	Slab(LC,ULC,MC,HC) Thin Slab High Speed Casting	Slab(MC,Peritectic) Bloom	Slab (MC,Peritectic) High Speed Casting
Slag Film Cross Section				

Fig. 6　Comparison of Slag Film.

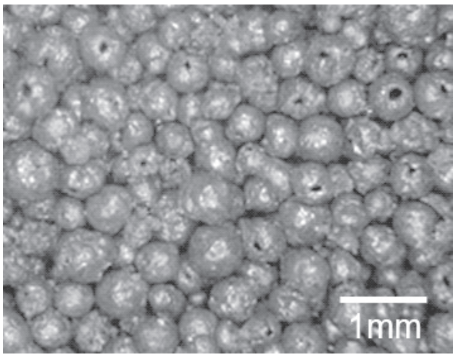


Fig. 7　Appearance of exothermic spray dried Granule.

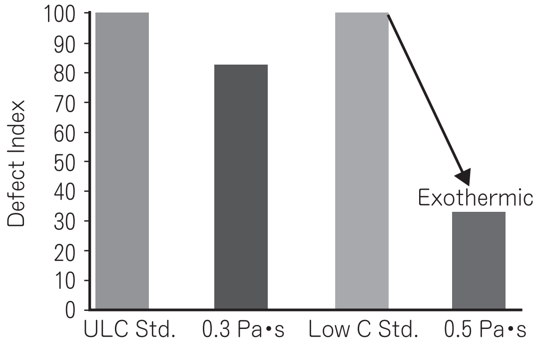


Fig. 8　Defect Result[21].

licensing technology. Hence Shinagawa Advanced Materials Americas Inc. (abbreviated as Shinagawa Americas) was established in 2006[19]. In addition, in 2008, Liaoning Shinagawa Hefeng Metallurgical Materials Co., Ltd. was created in Anshan City, Liaoning Province, China as the second manufacturing and sales base in China[20].

2. 2　Latest mold powder technical reviews since 2010

In the 2010s, the demand for high strength steels increased significantly, and with it the need for a suitable mold powder. Steel grades such as high Al steel, by virtue of the activity of the Al, are known to be difficult to cast. Other new high alloy (Mn, Cr, etc.) grades are being tested on casters.

By this time high-speed casting was routine, but yield improvement and environmental improvement were still needed. This remains the general direction for mold powder development.

To help improve both environmental issues (dust) and to maintain technical performance, Shinagawa invested in spray drying granulation facilities. Products that result offer both improved working environment and offer better flowability in the mold.

The latest mold powder technologies that have benefited our customers since 2010 are reviewed in the following sections.

1) Exothermic spray dried granule

Previously, the main application for exothermic type mold powder had been for the start of casting and in carbon free powders for stainless steel or enameled steel etc. where carbon pick up can cause serious defects. The exothermic reaction, achieved by the oxidation of an addition of metal, has enhanced the effective thermal insulation property of the mold powder. Three advantages are realized, namely, 1) prevention of inclusion defects by reducing the excessive solidification of the steel shell (called solidification hook) that can trap those inclusions, 2) prevention of surface cracking by virtue of a more uniform solidified shell formation and by reducing the thickness of slag roping and so offering better heat supply to the meniscus area, and 3) Prevention of solidification of the molten steel surface in the mold.

However, exothermic type mold powder had not been used widely for steady state casting stage of common steel grades. This was in part because it was difficult to produce exothermic mold powders in granular form.

Shinagawa has succeeded in developing manufacturing technology for producing exothermic granulated products that have low dustiness. Available in both agglomerated fine granule and spray dried granule form, these exothermic type granule products can now be applied even on common steel grades for the purpose of the quality improvement. Fig. 7 shows an appearance photograph of the exothermic spray dried granule mold powder. As an example, the application of exothermic granule product improved the quality of low carbon tin plate steel grades in United States Steel Corporation, as was reported in the Shinagawa Technical Report 2013[21]. Fig. 8 shows an example of quality improvement result.

The features and benefits of exothermic spray dried granule were introduced in detail with experimental data in the Shinagawa Technical Report 2021[22]. Fig. 9 shows the effect of different types of mold powder on the temperature of molten iron in a high frequency induction furnace series of experiments. When exothermic spray dried granule mold powder which has 644 J/g exothermic reaction was applied onto molten iron in a high frequency induction furnace, a temperature increase of about 5 ℃ was observed compared with a non-exothermic granule type. Fig. 10 shows the effect of exothermic property on the temperature fluctuation measured by thermocouples in mold copper plates in actual casting. The thermocouple temperatures were stabilized by the application of exothermic spray dried granule mold powder.

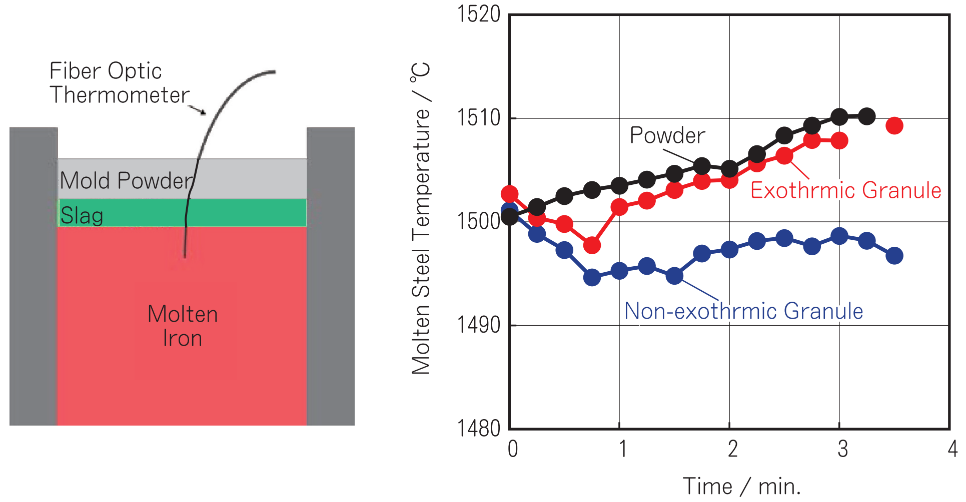


Fig. 9 Test Result of Insulation[22].

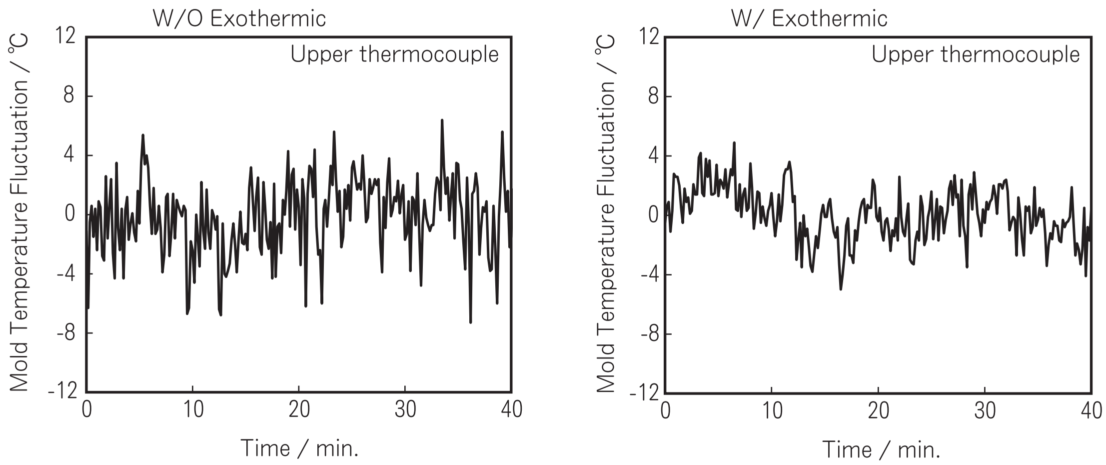


Fig. 10 Comparison of mold temperature fluctuation (O = Normalized Temperature).

2) F free mold powder for slab casting (SDGs for mold powder)

F can play a significant role in mold powder by decreasing the melting temperature, decreasing the slag viscosity to provide better lubrication, and being a component element of Cuspidine, the crystal generated in the slag film for control of heat removal. However, there are disadvantages associated with its use. Problems such as corrosion of continuous casting facilities, increased processing cost of the secondary cooling water, the working environment, as well as the accelerated slag line erosion of the submersed entry nozzle, all give reason for concern. Since the latter half of the 1990s, Shinagawa has introduced the F free PRIOS series of high slag viscosity products aimed at uniform heat removal provided by control of the viscosity instead of crystal formation in the slag film. This is now widely applied in bloom and beam blank casting as described in 2.1. However, in the slab casting with a large mold aspect ratio, and where the molten steel flow is more complicated. This requires softer heat removal by crystallization in the slag film in order to achieve stability of the mold copper plate temperatures. Shinagawa recognized this and developed a brand-new F free mold powder, in which the crystallization and viscosity properties are controlled by the addition of B_2O_3. It has been successfully used on low carbon steel slab casting. This technology was reported in Shinagawa Technical Report 2019[23]. Table 2 shows the typical property of the newly developed F free mold powders.

On the other hand, F free mold powders for use on medium carbon steel grades casting remains an area for future work. As these grades require softer heat removal property for prevention of strand surface cracking, not easily done without the formation of Cuspidine.

3) Mold powder for high Al medium carbon steel

The need for high strength steels is increasing as they

Table 2　Typical property of fluorine free mold powder [23)]

	Mold Powder A	PRIOS Type
Chemical Composition (%) SiO₂ CaO F Na₂O B₂O₃ CaO/SiO	 34 32 0 10 4 0.9	 39 27 0 2 0 0.7
Softening Temperature (℃)	1065	1120
Viscosity at 1300 ℃ (Pa•s)	0.4	1120
Crystallization Temperature (℃)	1060	-
Application	Slab Low Carbon Steel	Bloom

offer not only workability and formability but also collision safety and car body weight reduction. These steels are ideal for the purpose of fuel efficiency improvements for automotive steels. Some of the high strength steels are medium carbon steels in which high Al is added such as Al-TRIP steel. Because the Al in the molten steel and the SiO_2 in the mold powder slag reacts during the casting, the powder composition changes significantly on high Al steels. The chemistry changes can result in quality and/or operation problems due to the lack of lubrication and insufficient heat removal property due to the creation of a very crystalline mold slag. For this reason, providing a stable softer heat removal property is required of the mold powder even when a large amount of Al_2O_3 is absorbed into the slag. Shinagawa has developed a mold powder with suitable crystallization properties that avoids the generation of high liquidus temperature crystals even when the Al_2O_3 increases to high levels. Table 3 shows the chemical composition and properties of newly developed mold powders for high Al medium carbon steel grades, as reported in the Shinagawa Technical Report 2020 [24)]. The new mold powder has appropriate crystallization characteristics even after composition change, and therefore helps prevent strand surface cracking on these problematic grades.

4) Mold Powder for Thin Slab Casting

The main grades produced on thin slab continuous casters have been common steel grades such as LCAK (C : 0.01–0.08 %) and medium carbon steel (C : 0.16–0.25 %). Recently there have been demands for mold powder which achieves improved quality. Additionally, production of other grades such as peritectic steel (C : 0.08–0.15 %) and ULC (C : < 0.01 %) is now required. Soon it is expected that further quality improvements will be

Table 3　Chemical compositions and properties of mold powder for High Al medium carbon steel [24)]

		Conventional A	Conventional B	Developed C
Original	Chemical Composition / % SiO₂ Al₂O₃ CaO CaO/SiO	 40 2 31 0.8	 39 2 39 1.0	 36 2 43 1.2
In casting	Chemical Composition/% SiO₂ Al₂O₃ CaO CaO/SiO	 22 22 31 1.4	 19 22 39 2.1	 16 22 43 2.7
	Crystallization Temp. / ℃	950	1180	1110
	Appearance of Quenched Slag			
	Crystalline in Quenched Slag Gehlenite Fluorite Mayenite Cuspidine	 － － － － (Glass)	 ○ ○ － －	 － － ○ ○

needed, possibly even higher than for conventional slab casting. Shinagawa has developed proprietary technology based on high-speed casting knowledge in conventional slab casting. For example, in the Shinagawa Technical Report 2020, a high surface tension powder with excellent ability to peel off the slab surface for LCAK and ULC steels was introduced as well as a high basicity type mold powder with softer heat removal type for prevention of cracking on medium carbon steel[25].

5) Mold powder quality control technology

Since mold powder properties has a significant effect on steel quality and on the casting operation, consistent product quality is essential. The Shinagawa quality control system includes acceptance inspection of all raw materials, high frequency process inspection of each manufacturing batch, product inspection including unique test methods, trend control method, etc. The result is the highest degree of product consistency and with it a trust from our users.

3. Towards The Next 50 Years

At the UN sustainable development summit held at UN Headquarters in September 2015, 17 Sustainable Development Goals, (SDGs) were adopted to realize a sustainable world. Global companies and organizations are formulating and promoting specific measures to achieve those goals, and the characteristics of steel products that are oriented to achieve those goals were highlighted. For example, by using a steel sheet which is lightweight, high in strength, and easy to be processed, it is possible to reduce the total weight of the automobile. This results in saving the energy required for driving the automobile. Further, it is also possible to reduce the energy used for steel production by improving the yield. Since the mold powder is closely related to improvement of the steel quality and reducing the defect rate in continuous casting, technical development of mold powder will be a contributor to the achievement of SDGs.

Technical development of mold powder is carried out not only by Shinagawa but also by many other organizations, and at the same time, theoretical analysis and experiments are also being carried out. However, direct observation condition of mold powder in use (such as inflow mechanism of the slag, etc.) is impossible due to the casting situation. The suppliers can only estimate the mechanism from various pieces of operational data. Despite evidence that significant progress has been made, development has not been sufficient. New steel grades have been introduced to casting, and the technology of continuous casting facilities have also been enhanced. Therefore, the mold powder technology development is never complete. In other words, there is still room for research of the mold powder, and it is not difficult to imagine that further technological innovation will be required in the future.

Here is a anecdote that we experienced in a customer's

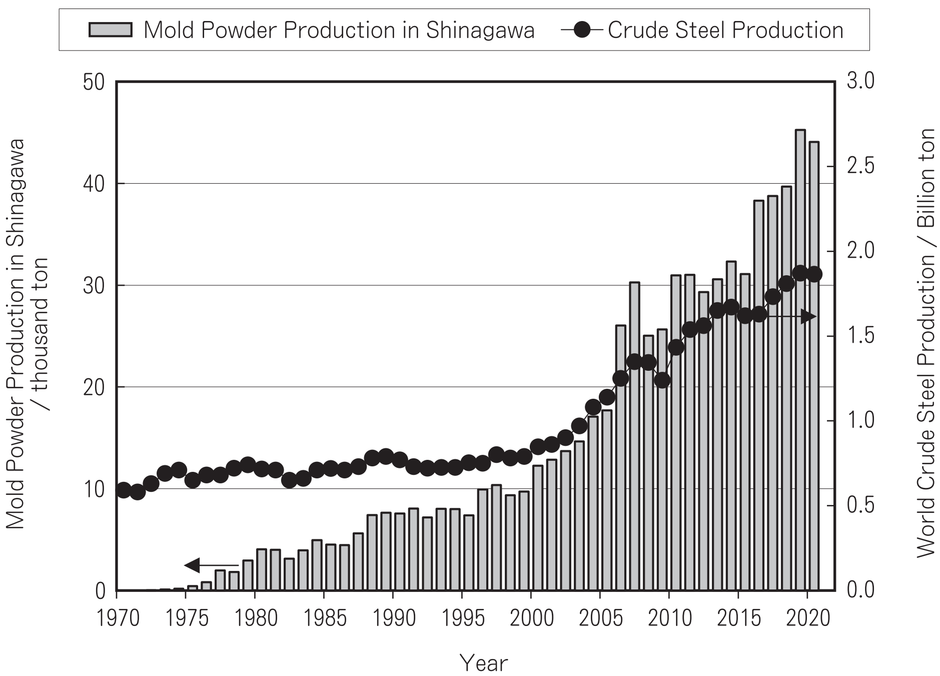


Fig. 11 Trend of mold powder production in Shinagawa and world crude steel production.

meeting room[26]. One day, when our mold powder engineer visited the customer, to start the meeting, the customer wrote in large letters "Something New" on a black board and said "I'm not interested in techniques that well known and obvious!". This was the moment it became clear the direction our mold powder division needed to take, and also for the overall development of our company. Since this event, "Something New" has been taken over as a guiding principle of Shinagawa's mold powder representatives.

As presented in this paper, Shinagawa has introduced newly developed products to the steel industry in a timely and continuous manner as technological improvements in casting were made over the years.

In fact, Shinagawa has been providing "Something New" for 50 years. Fig. 11 shows the world crude steel production and Shinagawa group's total mold powder production. The production of mold powder has continued to increase since it was first commercialized. In addition, the requests for mold powder proposals for new steel grades and steel grades that are difficult to cast from steel mills are as numerous as ever. This will require new mold powder technology from Shinagawa, and we are pleased to continue to partner with our valuable customers to develop these products.

Shinagawa will contribute to the improvements in technologies in the steel industry and continuous casting for the next 50 years and more using the "Something new" approach.

4. Acknowledgment

Shinagawa has been developing the mold powder business for 50 years, and have become one of main mold powder supplier with considerable support and guidance from our customers, as well as from raw material suppliers and equipment manufacturers. Shinagawa would like to thank everyone related to our business. Shinagawa is looking forward to your continued cooperation in the future.

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