Melting, casting, and welding technology

Melting, Casting, and Welding Technologies Supporting the Art of Manufacturing in Materials Business

Dr. Hitoshi ISHIDA*[1]

*[1] Materials Research Laboratory, Technical Development Group

Abstract

Melting, casting, and welding are essential core technologies that support the art of manufacturing in the Kobelco Group's diverse materials businesses. Technological development has been promoted, considering the unique characteristics of each field: steel, aluminum, copper, cast & forged steel, titanium, and welding. In recent years, there has been a degradation in the quality of raw materials, leading to rapid demand for the expanded use of recycled materials from the perspective of CO_2 reduction and resource circulation. Numerous technologies are currently being developed with the aim of realizing carbon neutrality in the future. This article introduces the progress and future efforts related to melting, casting, and welding technologies in each materials business.

Introduction

The KOBELCO Group is a distinguished manufacturer of a wide variety of materials, including steel; nonferrous materials such as aluminum, copper, and titanium; and welding consumables. Our primary customers are in the automotive, aircraft, shipbuilding, railroad, food packaging, electronics, and architectural engineering industries. Our defining technologies, products, and services include special steel wire rods and high-tensile strength steel plate, aluminum body panels for vehicles, forged aluminum parts for vehicle suspensions, crankshafts, aluminum disk materials, lead frame materials for semiconductors, and non-copper-plated solid wire. These metal materials are used in transportation equipment as well as societal and industrial infrastructure and have supported safety and security in community development and manufacturing for many years. Recently, raw material prices and procurement risks have increased while quality has decreased. As such, achieving carbon neutrality requires a rapid reduction of CO_2 emissions and the expanded use of recycled materials in support of resource circulation. To this end, we are pursuing technological development from the perspectives of contributing to a green society and providing solutions for the future.

Melting and casting are the first processes in producing the metal materials related to these materials businesses. Hence, these processes constitute the starting point that determines the quality of the end product. Furthermore, as a process for joining structural materials, welding is an indispensable process that must be highly reliable in terms of safeguarding strength, ductility, and toughness. Kobe Steel's melting, casting, and welding technologies are defined as follows:

(1) Melting technology: This technology supports refining reactions based on high-temperature metallurgical phenomena to fine-tune results for the desired material composition. It also supports the removal of impurities such as unnecessary components, gases, and inclusions to achieve a high level cleanliness. (2) Casting technology: This technology supports the prevention of casting defects and cracking, refinement of crystalline grains, and control of the solidification structure of high-quality materials. (3) Welding technology: This technology supports the control of melting and casting to join materials, yielding excellent quality, efficiency, and workability. These are the core technologies that support Kobe Steel's competitiveness in the manufacturing operations of its diverse materials businesses. Since our founding, we have collaboratively developed and refined these technologies based on the parameters of the sectors we serve: steel, aluminum, copper, cast and forged steel, titanium, and welding. We are also working on innovations in melting, casting, and welding technologies to reduce CO_2 emissions throughout the company and supply chain and to use low-grade, high-impurity materials to their full potential.

This paper introduces the progress and future prospects related to the melting, casting, and welding technologies that support manufacturing in each materials business.

1. Melting, casting, and welding technologies in the materials business

Section 1 introduces the melting, casting, and welding technologies of steel, aluminum, copper, cast and forged steel, titanium, and welding. Although these technologies are based on common core technologies, they have been refined in various ways based on the nuances of each material's manufacturing processes.

1.1 Steel

Focusing first on the steel sector, Kobe Works (current Kobe Wire Rod & Bar Plant) has produced wire rod and bar, whereas Kakogawa Works has produced thick and thin steel plate in addition to wire rod and bar. We developed advanced melting and casting technologies in steelmaking to consolidate upstream processes, thereby enhancing productivity and cost competitiveness and creating high-value-added products that meet customers' quality requirements. The company started up a new hot-metal pretreatment plant in 2014, consolidated the upstream processes in 2017, and then installed two mechanical stirring desulfurization units (hereinafter, KR) and two converter-type dephosphorization furnaces. The secondary refining process makes use of a high-throughput molten steel ladle furnace (hereinafter, LF) and a degassing apparatus (hereinafter, RH). The continuous casting process makes use of a 5-strand continuous bloom caster (hereinafter, 6CC) to cast all types of steel with high throughput and quality. These refinements in our processes have enabled economical mass production of high-quality special-steel products such as wire rod and bar in small lots and with a high product mix.[1)]

We have refined numerous core technologies for melting and casting to yield high-quality, high-efficiency processing of molten steel in these steelmaking processes. One area of development comprises high-temperature metallurgical reaction control technology based on equilibrium theory and kinetics. Another area is that of chemical engineering experiments and analysis technologies such as water models and flow-solidification analysis.[2)] We are also working to improve the efficiency of reactions such as desulfurization and dephosphorization, and to control nitrogen and cleanliness. Following is a detailed description of how these core technologies have transformed the steelmaking process.

A KR and a converter-type dephosphorization furnace were installed in the new hot-metal pretreatment plant to share the functions of desilicification, desulfurization, dephosphorization, and decarburization to improve process efficiency and hot-metal pretreatment capacity (**Fig. 1**). This reduced the burden of desilicification and dephosphorization on the converter and improved crude steel production capacity by shortening the blowing time.

In researching desulfurization technology, we used water model experiments and 5-ton KR testing to determine the effects of impeller speed and immersion depth on desulfurizer dispersion, with the objective of improving reaction efficiency through intense stirring. As a result, we were able to use aluminum ash and inexpensive lime to yield highly efficient desulfurization (**Fig. 2**). In fine-tuning the dephosphorization technology, we used the rate equation and water model experiments to optimize the effects of bottom-blowing stirring and the parameters of the bottom-blowing tuyere to ensure a long service life even with high bottom-blowing flow rates, thereby achieving a highly efficient dephosphorization reaction.[3)]

Other KR activities include the optimization of slag preparation by arranging equipment for before-and-after slag separation in a space-saving manner. We have also established technologies for using residual arc furnace ash generated at Kobe Steel's Moka Works,[4), 5)] which is detailed in Section 2. Improvements related to the dephosphorization furnace include melting technology for skull adhered to the furnace, the acceleration of slag

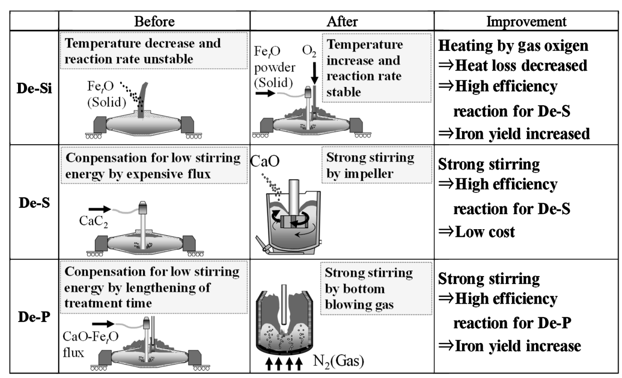

Fig. 1 Improvement by allotment of refining function in hot-metal pretreatment

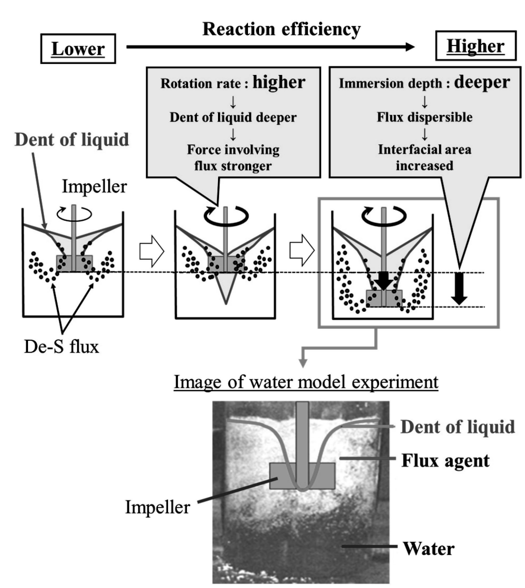

Fig. 2 Effect of impeller speed and immersion depth on dispersion of desulfurization agent

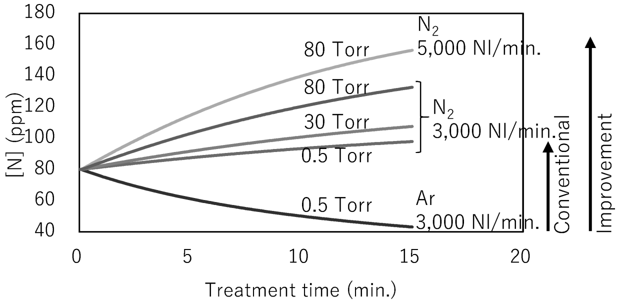

Fig. 3 Effect of RH treatment conditions on [N] content (calculation results)

cooling, and the optimization of logistics via simulation.[6]

We have devised a unique system to calculate the nitrogen concentration in the secondary refining process to maintain the nitrogen concentration of the RH within a predetermined range. The system accounts for the effects of parameters such as the treatment gas type, gas flow rate, tank vacuum, and molten steel composition (**Fig. 3**).[7] In response to concerns about deteriorating cleanliness due to slag entrainment, we optimized slag treatment in conjunction with stirring conditions in the LF to control cleanliness, inclusions, and sulfur concentration. These molten steel processing technologies using LF, RH, etc. enable the production of high-quality steels such as inclusion-controlled steels[8)~10)], and ultra-clean steels.[11] After the molten steel has been treated, the 6CC (No.6 continuous caster) can be used to produce various types of high-quality, high-function special steels. Its large tundish enables stable flow control and small-lot production. An easy-to-maintain tertiary cooling system combines uniform cooling with variable cooling rates.

We will use these advanced melting and casting technologies in the steelmaking sector and enhance existing technology, including by using advanced AI technology, to yield high-value-added products that meet customers' quality requirements. Furthermore, in support of carbon neutrality, we will promote the distribution of our industry-leading low-CO_2 blast furnace steel (Kobenable Steel). For this same objective, we will also promote the development of melting and casting technologies that enable electric furnaces to produce high-grade steel from diverse raw materials, including low-grade raw materials and scrap.

1.2 Aluminum

Moka Works manufactures profile and sheet products for the aluminum sector, producing materials for beverage cans, magnetic disk substrates, and vehicle panels. This plant is equipped with a melting furnace, holding furnace, DC (direct chill) casting machine, and one of the largest wide rolling mills in Japan. Daian Works has casting and forging technology cultivated in the manufacture of aircraft parts and has established an integrated production system for hydraulic forging, sand casting, and forged aluminum vehicle suspension parts. Chofu Works manufactures aluminum extrusions using world-class technological capabilities.

The aluminum melting process generally involves melting the raw material, fine-tuning its composition and temperature, and purifying it. These processes employ a melting furnace, a holding furnace, degassing equipment, and filtration equipment. Fast, economical melting and purification of alloys requires advanced refining technology, especially in the molten metal treatment process for removing impurities. Removing impurities such as alkali metals, hydrogen, and inclusions requires techniques such as flux refining in a holding furnace, hydrogen gas removal via degassing equipment, and the filtration of inclusions.[12] DC casting is used as the continuous casting method for aluminum after melting and refining. The basic principle was invented in 1935 and has become the main process for drawing materials in Japan. The casting process requires certain technologies to ensure the proper ingot shape and solidification structure and, in particular, to prevent cracks and casting defects, refine the crystalline structure, and ensure precise shape and dimensioning.[13]

To address these melting and casting challenges and produce high-value-added products that meet customers' quality requirements, we have developed advanced melting and casting technologies such as high-temperature metallurgical reaction control technology for cleanliness of molten metal and thermal stress analysis technology to prevent DC casting cracks. Most casting cracks in large rectangular DC ingots are surface cracks that start at the surface of the ingot. The crack prevention technology Kobe Steel has refined over many years is an exemplary component of our portfolio of casting technologies. Because surface cracks originate in the solid-liquid coexistence region, the heat transfer and solidification processes are used to hypothesize the mechanism of ingot cracking starting at the surface in this temperature range. The points at which alloy composition can inhibit casting cracks are investigated to initiate the proper countermeasures.[14)~17)]

Specifically, it is hypothesized that the shrinkage of dendrites in the semi-solidified region generates strain and that cracking is caused by the disparity between the magnitude of strain and the strain rate within a given solid-phase rate region. The crack propagation parameter ΔT_{II}, which represents the magnitude of shrinkage strain, and the temperature gradient with respect to the change in solid-phase rate were used to calculate the crack initiation parameter, $\Delta R_{II}/\Delta T_{II}$, which represents crack susceptibility.

Cracking of several alloy compositions was evaluated at three casting rates (60 mm/min, 80 mm/min, and 100 mm/min). Results, indicated by the symbols ◎○△×, showed that cracking was more likely to occur in regions where the crack propagation parameter ΔT_{II} and the crack initiation parameter $\Delta R_{II}/\Delta T_{II}$ were high for any given casting rate (**Fig. 4**).

By quantitatively expressing crack susceptibility in this way, the approach to crack suppression can be clarified even for alloys with different crack initiation modes.

Technological development is underway to secure the quality of the melting and casting processes and thereby meet increasingly stringent quality requirements. Alongside these requirements, customers have intensified demands for CO_2 curtailment in the aluminum sector. As such, the trends toward using internal and external scrap and recycling by-products have been accelerating. Kobe Steel is actively engaged in the technological development necessary for aluminum scrap recycling in support of a carbon-neutral society, and we will continue refining our unique melting and casting technologies.

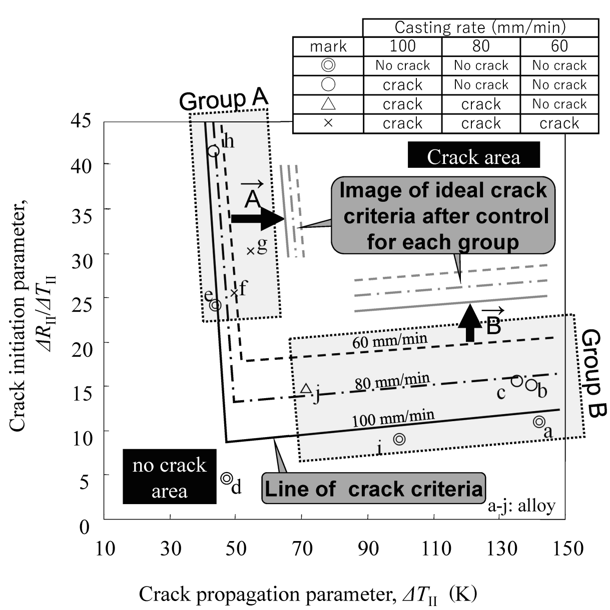

Fig. 4 Crack susceptibility evaluation of each alloy by crack susceptibility parameter and crack prevention concept for each group

1.3 Copper

Chofu Works has two types of copper melting furnaces: shaft furnaces and coreless induction furnaces. Shaft furnaces are the main melting furnace for mass production because of their large melting capacity. This type of furnace can melt raw materials efficiently but cannot change their composition, so raw materials are adjusted to specification in an electric holding furnace before casting. Chofu Works use this type of furnace to produce pure-copper-based alloys, mainly KFC® [Note 1)] (highly conductive heat-resistant alloy). Coreless induction furnaces use induction heating to melt raw materials. Coreless induction furnaces do not require a seed bath and can melt raw materials from room temperature. These furnaces are generally best for melting a wide variety of products in small quantities. Taking advantage of their ability to melt metals with high melting points, such as Ni and Fe, they are used to melt alloys in the KLF® [Note 2)] (high-strength, high-conductivity copper alloy) and CAC® [Note 3)] (high-strength, high-formability copper alloy) series.

We have made multiple contributions toward achieving high cleanliness and ingot quality within the field of copper melting and casting. For instance, we have developed high-temperature metallurgical reaction control technology based on equilibrium theory and kinetics as well as experimental analysis technology such as simulation programs.

Clean molten metal with minimal gases and inclusions during melting and casting is required for a sound ingot. H_2 gas, water vapor, and CO_2 gas lead to inferior product quality. As such, we eliminate these to the extent possible by controlling raw materials, equipment parameters, and the furnace atmosphere. Continuous casting produces slabs with a rectangular cross-section and a length of four to six meters, with the intention that they will be hot rolled. In the past, mold design and casting conditions related to ingot quality were largely based on experience and trial and error, but recent advances in solidification and thermal stress analysis technology have made it possible to determine ideal mold shapes and casting conditions through simulation.[18), 19)] This makes it possible to produce alloy systems that are susceptible to cracking at the

Note 1) KFC® is a trademark of Kobe Steel.
Note 2) KLF® is a trademark of Kobe Steel.
Note 3) CAC® is a trademark of Kobe Steel.

ingot stage due to medium-to-high-temperature brittleness, reduce defects inside the ingot, and improve surface quality, resulting in a system that can produce a wide variety of products. Recent advances in simulation technology have enabled a more detailed analysis of the casting process. In terms of experimental technology, we have also been conducting in-situ observation of microscopic solidification phenomena using synchrotron radiation from SPring-8. Moreover, progress has been made in defining the theory behind the effects of microsegregation on casting cracks. We will continue to provide the copper sector with high-quality materials backed by advanced analytical and experimental technologies to increase value to the customer in the areas of vehicle electrification, the expanding demand for semiconductors, and necessities to achieve carbon neutrality.

1.4 Cast and forged steel

Kobe Steel launched its cast and forged steel business, starting with the production of castings, when the company was founded. Marine products were added later, with the company eventually becoming Japan's sole provider of a full range of marine products. Within this division, large cast and forged steel products comprising solid type and built-up type crankshafts are our main products. The crankshaft is a key component of the engine. It requires high overall and fatigue strength, making technology that supports exceptional cleanliness in the melting and casting process essential. Kobe Steel has applied its advanced melting and casting technologies and inclusion control technologies to reduce impurities and suppress the entrainment and formation of inclusions. This is how we have earned the unwavering confidence of customers all over the world.

In the melting process, the removal of phosphorus and sulfur and degassing are especially important for minimizing impurities in the crankshaft. Until around 1988, Kobe Steel used a steelmaking process known as tap degassing. In 1993, however, the company installed a ladle refining furnace (vacuum holding furnace). The company then transitioned to a process in which the molten steel is refined outside the furnace, after transfer from the electric furnace into the ladle. Unlike processes involving refining inside the electric furnace, this process enables the substantial removal of impurities such as sulfur and gases such as oxygen. This contributes to the high quality of large cast and forged steel products such as crankshafts.[20)~22)] Other papers within this report detail our inclusion control technologies. These technologies are important for reducing inclusions, which are the origin of fatigue failure. Accordingly, we have developed technology that supports high cleanliness by reducing impurities, optimizing refining conditions, and improving ingot production conditions.[23)] The fatigue strength of super-clean steel is more than 20% greater than that of current clean steel and up to nearly 40% greater than that of conventional steel. The k-factor used in the calculation of design fatigue strength recognized by all ship classification societies is k = 1.15. This means that Kobe Steel's material is recognized as having a design fatigue strength margin 15% greater than the standard value (1.00). Engines using these materials should be able to achieve higher output and greater compactness (**Fig. 5**).[24)]

Kobe Steel's technology also enables the use of by-products in support of resource circulation. Additionally, it can reduce CO_2 emissions by expanding the applications of electric furnace scrap, furthering the objective of carbon neutrality. We will continue to promote the use of low-grade raw materials alongside high cleanliness. These conditions will improve productivity, ensure quality for the safe and secure manufacture of products designed for vessels, and meet society's changing needs in the transportation equipment sector.

1.5 Titanium

Kobe Steel's titanium business has enabled mass production through stable melting and coil rolling technologies for scrap titanium. And as the first company in Japan to put titanium to practical use, Kobe Steel has led Japan's titanium industry, developing strong relationships with our customers as well as an extensive track record of delivered products. Titanium is a reactive metal that readily reacts with elements such as oxygen. This is why

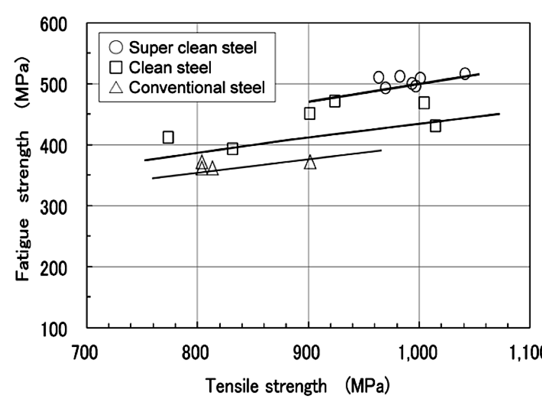

Fig. 5 Fatigue strength of super clean steel for solid type crankshaft

special melting and casting technologies such as vacuum arc remelting (hereinafter, VAR) and cold crucible induction melting (hereinafter, CCIM), detailed in Section 2, have been developed. We have also developed high-temperature metallurgical reaction control technology and segregation control technology under special melting environments to yield high-value-added products that meet customers' quality requirements.

In the VAR method, titanium sponge is pressed and formed with alloying materials into briquettes, which are then welded to form rod-shaped consumable electrodes. In a water-cooled copper crucible that is under vacuum or has an atmosphere of inert gas, an arc is generated between the consumable electrode and the surface of the molten metal. The heat melts the consumable electrode, which falls as a molten droplet. While the molten metal pool is close to unidirectional solidification, a static magnetic field is introduced to stir the molten metal pool by rotation to improve the surface quality of the ingot. Melting once is not sufficient to homogenize the ingot's alloy composition. Double melting is therefore commonly practiced, wherein the ingot from the initial melting is remelted as a consumable electrode. Triple melting is also sometimes performed for aerospace materials, which require particularly high quality.

This melting method is characterized by low radiation heat loss and low power consumption because the surfaces of the consumable electrode and the molten metal pool are close and oriented toward each other. However, it is challenging to use the scrap as raw material. To overcome this challenge, Kobe Steel has developed a proprietary technique (the Kobe Method) that continuously introduces scrap fragments and other materials into the space between the consumable electrode and the wall of the copper crucible (about 100 mm) during initial melting. This results in highly efficient and homogeneous melting, thereby reducing melting time by 50% and electricity consumption by about 60%.[25] We have also developed a model to predict segregation in VAR ingots. Specifically, the model evaluates concentration changes in moving areas of the VAR ingot to predict the distribution of constituents throughout the entire ingot and thereby improve ingot quality.[26]

1.6 Welding

Kobe Steel's welding business is the only one in Japan with a comprehensive portfolio of welding consumables, robot systems, power sources, and construction methods, offering a variety of welding solutions by combining materials, systems, and processes. Since its inception in 1940, the company has led the charge in developing welding technology, a key technology for industry, and has responded to the changing needs of its customers in line with the progress of various industries. "Development and Practical Applications of Welding Core Technologies" on pages 123-130 of this issue contains details regarding the broad scope of welding core technologies we have refined over the years. This section describes examples of technologies to reduce solidification cracking in weld metals for safety and security in manufacturing.

One local welding phenomenon is that of simultaneous melting and solidification in the molten pool at the joint. Core technologies can be used here to control high-temperature metallurgical reactions and solidification behavior in steel and other materials. TiO_2-based FCW (flux-cored wire) is widely used in shipbuilding and bridge construction because it exhibits good weldability in any position. However, it is susceptible to solidification cracking in the first layer of single-sided butt welds. As such, we have developed technology to inhibit solidification cracking.[27] We started by developing a new equation to evaluate solidification cracking that accounts for the presence of deoxidizing elements. To evaluate solidification cracking susceptibility more accurately, we determined the effects of strong deoxidizing elements that tend to form compounds by accounting for microsegregation as well as oxides in the weld metal. Various models that account for microsegregation in evaluating the solidification cracking susceptibility of steel and aluminum have been proposed. We have devised a solidification cracking evaluation equation that accounts for not only microsegregation, but also the state of oxides from strong deoxidizing elements in the weld metal formed by TiO_2-based FCW.[27] Furthermore, based on knowledge related to refining the solidification structure by heterogeneous nucleation in steel and aluminum, we focused on controlling the solidification structure of weld metal by using non-metallic inclusions. From this, we demonstrated that equiaxed crystallization of carbon steel weld metal is possible not only with TiN but also with Ti_2O_3, which serves as a guideline for inhibiting solidification cracking.

Also underway is the development of various types of welding consumables that are suitable for use in a variety of applications and environments. These new developments advance welding technology by building upon Kobe Steel's expertise within its many materials businesses and its core technologies in melting and casting.

2. Recent examples of melting, casting, and welding technologies for the future

This section introduces the developments necessary to reduce CO_2 emissions in support of carbon neutrality as well as the latest examples of melting, casting, and welding technology developments that promote resource circulation in production. Pertinent core technologies include safety and security in community development and manufacturing, contributing to a green society, and providing solutions for the future.

2.1 Development of hot-metal desulfurization technology using arc furnace ash

As an example of resource circulation unique to Kobe Steel, which has multiple materials businesses, this section will describe the collaboration between the steel and aluminum businesses in the use of by-products generated in the melting process. Desulfurization is promoted in the steelmaking process at Kakogawa Works by mechanically stirring aluminum ash (metallic aluminum and alumina) and lime into the molten metal. Conversely, the Moka Aluminum Plant uses a rotary arc furnace to efficiently recover metallic aluminum from aluminum dross (a mixture of metallic aluminum and oxides) generated in the melting process. The rotary arc furnace also deactivates harmful constituents within the residual ash after recovery and recycles this ash.[28] Compared with typical aluminum ash, arc furnace ash generated as residue has less metallic aluminum that can be used for desulfurization and more aluminum nitride (AlN) instead. However, we determined the conditions necessary to use arc furnace ash as a desulfurization agent, thus enabling the recycling of by-products between facilities.[29]

The desulfurization efficiency of arc furnace ash was determined in a 300-kg laboratory test. Although the desulfurization rate was initially inferior to that of aluminum ash, it was confirmed that a sulfur concentration of less than 0.005 %wt could be achieved with a 10-minute treatment time by using lime/50% arc furnace ash. We also examined the mechanism by which arc furnace ash contributes to desulfurization, confirming that AlN dissolves in molten iron, thereby increasing the concentration of Al that can be used for desulfurization. This tendency is more pronounced at higher temperatures. Based on these findings, we established a method blending arc furnace ash with desulfurization agent for a mechanically stirred desulfurization process at Kakogawa Works.

This achievement is an example of collaboration among Kobe Steel's multiple materials businesses, and it is an idea made possible by the company's expertise in steel and aluminum melting and casting technologies. We also have the advantage of being able to mass-produce and demonstrate new technologies within the KOBELCO Group before deploying them outside the company. Our goal is to leverage Kobe Steel's technological capabilities to solve our customers' challenges in resource circulation.

2.2 Development of CCIM melting and casting technology

Alloys based on the titanium aluminide intermetallic compound (TiAl) have excellent high-temperature strength and are lightweight, with a density roughly half that of Ni-based alloys. This is why they are increasingly being used in low-pressure turbine blades of jet engines for commercial aircraft, as this supports the recent need to reduce fuel consumption and curb CO_2 emissions in pursuit of carbon neutrality. TiAl is a highly reactive alloy with a high melting point that is easily oxidized at its melting temperature. Various melting technologies are used for melting TiAl. This section introduces recent technological developments in the cold crucible induction melting method (hereinafter, CCIM).[30]

CCIM is a melting method in which a crucible consisting of many water-cooled copper segments replaces the refractory crucible of the vacuum induction melting method commonly used for melting steels. Unlike VAR and other methods, CCIM melts all raw materials at once. This enables easy adjustment of molten metal composition, making CCIM suitable for melting alloys. The challenge in melting TiAl via CCIM was to develop a melting and casting process that achieves both compositional homogeneity and high yield as well as a foundational technology for a scrap treatment process to reduce costs and CO_2 emissions.

As an advancement of our composition control technology, we subsequently developed a rapid analysis technique for use during melting to narrowly control the variation in Al concentration. We also proved that controlling the casting rate could enable the production of ingots free of casting defects, thereby improving casting yield. Another challenge is that, when recycling scrap and other materials to promote resource circulation as part of the SDGs, it is particularly important to remove oxygen (an impurity) from titanium (a reactive metal). This is why we developed a new deoxidization technique using the intermetallic compound of TiAl. From a thermodynamics viewpoint, we have focused on the fact that in the Ti-Al-O ternary phase diagram, the oxygen solubility of the intermetallic compound decreases markedly with an aluminum content of at least 30 to 40 mass percent. We have demonstrated the effectiveness of a deoxidation process in which a high aluminum concentration is added when melting TiAl via CCIM or PAM (plasma arc melting), with the additional variable of adding flux (**Fig. 6**).

This finding adds new value by enabling maximum scrap recycling as well as the advanced special melting technology of melting TiAl via CCIM. Moreover, the technique developed can also be used for other titanium alloys. As the demand for titanium expands into fields such as aerospace, we can expect increasing instances of practical application for this metal. Also to be anticipated are the promotion of resource circulation as part of the SDGs as well as efforts to reduce CO_2 emissions in support of carbon neutrality, which is becoming increasingly necessary.

2.3 Development of new electroslag welding method

Electroslag welding (hereinafter, ESW) is anticipated to expand as a method for automatic vertical welding; a new ESW method (SESLA[TM, Note 4)]) is in development.[31)] This method improves weldability and quality and reduces the burden of welding work via automation and reduced technological needs. We also discovered through our development efforts that this method can be applied to 9% Ni steel.[32)]

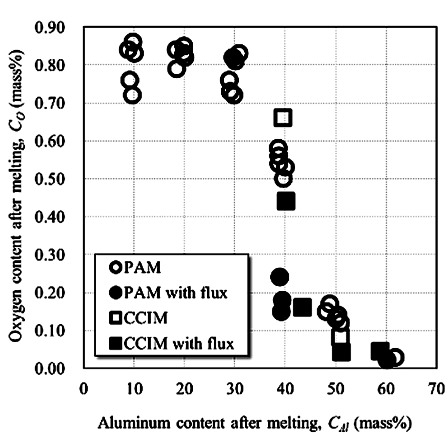

Fig. 6 Effect of aluminum concentration on deoxidation behavior in molten TiAl with flux addition

Note 4) SESLA™ is a trademark of Kobe Steel.

The new ESW method maintains the advantages of traditional ESW (less spatter and fumes, good wind resistance) while overcoming its disadvantages (limited weld length). Additionally, long weld lengths are possible with water-cooled sliding copper plates for slag bath control.

With an expanded torch oscillating range and a new maximum plate thickness of 80 mm for single-pass welding, good penetration and weldability when welding extra-thick plate are guaranteed. ESW testing of 30-mm-thick 9% Ni steel plate with 12% Ni welding consumables exhibited good bead appearance and improvements in the weld metal's tensile strength and low-temperature toughness.

Carbon-neutral LNG has recently been introduced as a new approach to offsetting CO_2 emissions from natural gas. Carbon capture and storage is expected to be one of the supportive technologies in the related developments. Although 9% Ni steel is the planned standard for liquid CO_2 storage tanks, there is an increasing possibility of using steels designed for cryogenic applications. Application is also anticipated in the highly efficient welding of extra-thick plate in renewable energy applications such as offshore wind power generation equipment. We will continue developing infrastructure that supports the carbon cycle as well as high-quality, high-efficiency welding solutions for the energy sector.

Conclusions

We have developed melting, casting, and welding technologies to support the manufacture of a wide range of materials within the KOBELCO Group, with developments always being based on the specific needs of a given sector. The general vision for the future is a sustainable world, made a reality through carbon neutrality and resource recycling. Our aspiration is to support both CO_2 reduction and resource circulation by integrating the diverse technological capabilities of our materials businesses in the development of melting, casting, and welding technologies.

References

1) T. Hamada. R&D Kobe Steel Engineering Reports. 2019, Vol.69, No.2, pp.3-8.
2) K. Nakayama et al. R&D Kobe Steel Engineering Reports. 2001, Vol.51, No.3, pp.2-8.
3) K. Saito et al. R&D Kobe Steel Engineering Reports. 2019, Vol.69, No.2, pp.32-36.
4) D. Watanabe et al. Iron Steel Technology. 2018, Vol.15, p.74.
5) T. Nishimura et al. R&D Kobe Steel Engineering Reports. 1997, Vol.47, No.3, pp.31-34.

6) T. Iwatani. R&D Kobe Steel Engineering Reports. 2018, Vol.68, No.2, pp.29-35.
7) Y. Yoshida et al. R&D Kobe Steel Engineering Reports. 2019, Vol.69, No.2, pp.26-31.
8) S. Kimura et al. R&D Kobe Steel Engineering Reports. 2004, Vol.54, No.3, pp.25-28.
9) S. Kimura et al. Iron and Steel. 2002, Vol.88, No.11, p.53.
10) T. Sugimura et al. ISIJ International. 2011, Vol.51, No.12, p.1982.
11) H. Ohta et al. R&D Kobe Steel Engineering Reports. 2011, Vol.61, No.1, pp.98-101.
12) K. Takahashi. Keikinzoku. 2015, Vol.65, No.10, pp.518-522.
13) K. Takahashi. Keikinzoku. 2015, Vol.65, No.11, pp.599-603.
14) M. Morishita et al. R&D Kobe Steel Engineering Reports. 2008, Vol.58, No.3, pp.23-28.
15) M. Morishita et al. Keikinzoku. 2009, Vol.59, No.8, pp.417-423.
16) M. Morishita et al. Mat. Trans. 2011, Vol.52, No.2, pp.166-172.
17) M. Morishita et al. R&D Kobe Steel Engineering Reports. 2012, Vol.62, No.2, pp.18-23.
18) K. Takeuchi et al. Journal of the Japan Copper and Brass Research Association. 1998, Vol.37, pp.182-188.
19) H. Ishitobi et al. Journal of the Japan Copper and Brass Research Association. 1998, Vol.37, pp.189-194.
20) H. Mori et al. R&D Kobe Steel Engineering Reports. 2000, Vol.50, No.3, pp.41-45.
21) M. Okamura et al. R&D Kobe Steel Engineering Reports. 1983, Vol.33, No.3, pp.3-7.
22) A. Suzuki. 10th International Forging Conference Sheffield. 1985.
23) T. Shinozaki et al. R&D Kobe Steel Engineering Reports. 2009, Vol.59, No.1, pp.94-97.
24) N. Fujitsuna. R&D Kobe Steel Engineering Reports. 2016, Vol.66, No.1, p.2-6.
25) T. Kusamichi et al. R&D Kobe Steel Engineering Reports. 1999, Vol.49, No.3, pp.13-14.
26) H. Yokoyama et al. R&D Kobe Steel Engineering Reports. 2005, Vol.55, No.3, pp.57-60.
27) M. Shimamoto et al. R&D Kobe Steel Engineering Reports. 2013, Vol.63, No.1, pp.32-36.
28) K. Tokuda. Keikinzoku. 2009, Vol.59, No.11, pp.652-653.
29) Takero Adachi et al. "Utilization of low-grade aluminum ash for mechanical stirring desulfurization process." 7th International Congress on Science and Technology of Steelmaking. Venice. 13-15 June 2018. Organized by ASSOCIAZIONE ITALIANA DI METALLURGIA. ICS081.
30) D. Matsuwaka et al. R&D Kobe Steel Engineering Reports. 2020, Vol.70, No.2, pp.27-31.
31) T. Kakizaki. Bodayori. 2020, Vol.507, p.2-6.
32) T. Kakizaki et al. Journal of the Japan Welding Society. 2021, Vol.90, No.6, pp.18-23.