Outline of Steel Production System

Tsutomu HAMADA*1

*1 Business Planning Section, Kakogawa Works, Iron & Steel Business

While taking place of upgrading such as consolidations and mergers in order to increase competitiveness in the steel industry, Kobe Steel aims to enhance competitiveness through the high added value of technology, products and services, and further differentiation by constructing unique business models. In order to provide competitive technologies and products, in 2017 Kobe Steel completed a new hot metal pretreatment plant at its Kakogawa Works and in order to enhance cost competitiveness, decided and implemented the consolidation of upstream (ironmaking and steelmaking) processes of Kobe Works with Kakogawa Works. After consolidation, Kakogawa Works has been transformed into the cost-competitive steelworks that manufactures a wide variety of steel products, such as steel sheets, thick plates and wire rods. Kobe Works could significantly improve the quality and cost competitiveness of special steel wire rods and bars using billets manufactured by Kakogawa's equipment introduced the latest technology, without reducing steel production. In the global supply system for products, Kobe Steel has established a three-pole supply system in Japan, US and China for special steel wire rods (steel wire) and high formable advanced high tensile strength steel sheet.

Introduction

Kobe Steel's iron and steel business has contributed to the development of society and industry by promoting "MONODZUKURI" (the art of design and manufacturing) in a wide range of fields and providing excellent products and technologies. The Iron and Steel Business comprises business units of iron and steel products, steel castings, titanium products and steel powders and is thoroughly strengthening the "Monodzukuri power" with an eye to improving quality, productivity, and cost competitiveness. Kobe Steel is also strengthening the global expansion of distinctive products and technologies and its response to the demand fields where future growth is anticipated, such as the field of transportation equipment represented by automobiles.

This paper describes a iron and steel production system capable of supplying highly efficient and high-quality products, which has been renewed by consolidating the upper processes at Kakogawa Works, as well as its global supply system of distinctive iron and steel products, in addition to recent capital investment in the application of state-of-the-art technology.

1. History of Kobe Steel's Iron and Steel Business

Kobe Steel's products at the time of the company's establishment in 1905 began with castings including anvils, anchors, and the wheels of coal mining vehicles. In 1924, the No. 1 wire rod mill was made available for operation in the Wakinohama area of Kobe, and high carbon steel wire material began to be produced domestically in Japan. Subsequently, new wire rod mills were added to expand the production volume in response to the increasing domestic demand. In 1959, the operation of Kobe Steel's first blast furnace began in the Nadahama area of Kobe; thus, Kobe Works was inaugurated as an integrated iron mill. In addition, the company undertook the construction of Kakogawa Works; and, following the completion of the steel plate plant in 1968, the No.1 blast furnace was blown-in in 1970. The main plants for steelmaking, hot rolling, cold rolling and wire rods were completed one after another, leading to the inauguration of Kakogawa Works, the second integrated iron mill. As a result, Kobe Steel was able to add steel plates and steel sheets to its menu, in addition to steel wire rod and bar.[1)]

Today, the company produces about 6 million tonnes/year of steel products at Kobe Works and Kakogawa Works and has developed multiple processing bases in North America, China and Asia to provide various steel products to customers inside and outside of Japan.

2. Steel manufacturing bases and merchandise category mix

Kobe Steel currently produces steel wire rods and bar products at Kobe Works, and steel wire rod products in addition to steel sheets and steel plates at Kakogawa Works.

Steel wire rods and bar products are mainly special steel for automobiles. The company ships a wide range of products, including steel wire rods for springs used especially for automotive engines and suspension parts,[2), 3)] steel bars for crank shafts and gears, and cold heading quality (CHQ) steel wire rods used for fasteners such as bolts and nuts, with

a focus on automotive manufacturers in Japan, but also in North America, Europe, China and Asia.

Steel sheets are mostly used in automobiles and home electronics and as building materials. In particular, the company is focusing on the development and production of high-tensile-strength (Hi-Ten) steel sheets, which have the world's highest level of strength and excellent workability,[4)-6)] to respond to societal needs, particularly those for the weight reduction of automobiles and reduction of the environmental burden through automotive fuel efficiency improvement. As for steel plate products, used mainly in the fields of buildings, bridges and ships, the company is developing new products that meet customer needs for high strength steel with excellent weldability, among others.

3. Capital investment for strengthening competitiveness of steel business

3.1 New molten iron treatment plant at Kakogawa Works

Molten iron treatment is an indispensable process for producing high-quality steel that requires a high degree of cleanliness. Kakogawa Works has a new molten iron treatment plant (**Fig. 1**) that was put into operation in 2014, and established a system including two dephosphorization furnaces and two desulfurization apparatuses in 2017. Conventionally, the dephosphorization process had been performed in torpedo cars; however, the newly introduced dephosphorization furnace improved the dephosphorization ratio by approximately 50% and increased the crude steel production capacity. In addition, the introduction of desulfurization and dephosphorization technology with the highest efficiency in the industry has resulted in significant cost improvement. The new operation has increased the production capacity of products that require high cleanliness, such as special steel wire rods, high-tensile-strength steel sheets and steel plates for energy related applications.

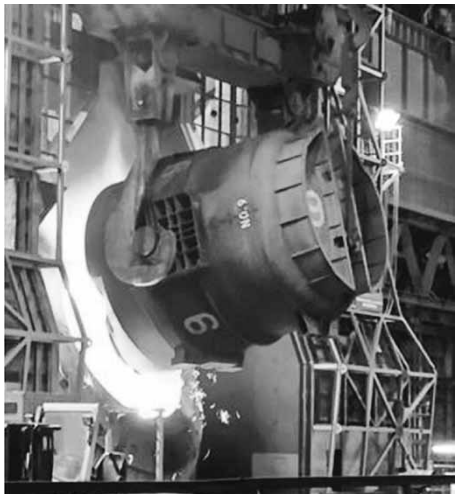

Fig. 1 New plant for molten iron treatment

3.2 Consolidation of upstream processes at Kakogawa Works

In view of the mid-to-long term business environment, both domestically and abroad, the environment surrounding the iron and steel business is becoming tough due to the decreased demand in Japan and an increased supply due to the expansion of iron & steel works outside Japan. The cost competitiveness of Kobe Works was inferior to that of Kakogawa Works due to structural factors, including the lack of in-house pretreatment facilities, such as coke plants and sintering plants, and its small production scale. Therefore, in 2017, the upstream process equipment (blast furnace to continuous casters, and some bloom mills) at Kobe Works was shut down and these processes were consolidated at Kakogawa Works. As mentioned in the preface of this issue, the upstream process utilization rate and steel quality were improved by addressing the process-specific issues through this consolidation. Moreover, the production cost has been improved, and a system has been established for reliable delivery on the dates desired by customers.

Conventionally, Kakogawa Works has been a large steelworks for producing large lot products of steel sheets and steel plates. However, as a result of the above-mentioned consolidation, special steel products such as steel wire rods and bars, which are produced in small lots and large variety, can be produced in large quantities with high quality at low cost. As such, Kakogawa Works was renewed and has become a steelworks that is unprecedented, both domestically and abroad.

3.3 Renovation of Kakogawa Works No. 3 blast furnace

The shutdown of the upstream process equipment at Kobe Works, including the blast furnace, and its consolidation into Kakogawa Works would make Kakogawa Works the only supply base for raw iron. For this reason, the No. 3 blast furnace of Kakogawa Works was renovated in 2016, prior to the consolidation. The renovation work adopted the continuous use of the steel outer shell of the blast furnace body, which was a first for any large

blast furnace in Japan. The renovation was finished in a short construction period of 90 days with the aim of shortening as much as possible the period of reduced crude steel production.

On the other hand, renovation aimed at anti-aging measures alone cannot attain the significance and effect of consolidation. In other words, a higher level and stable operation of the blast furnace is required to meet the responsibility of supplying raw iron. Hence, various sensors were installed in the blast furnace, and an AI system was introduced to support stable operation using the information obtained from the sensors.[7)]

4. Steel production system after consolidation

Fig. 2 shows the steel production system in both works after the equipment enhancement described in Section 3. As the blast furnace and steelmaking equipment at Kobe Works was shut down for consolidation, the semi-products produced at Kakogawa Works were supplied to the rolling plants at both Kakogawa Works and Kobe Works. The following is an overview of the advantages of each process in both of the steelworks:

4.1 Kakogawa Works

4.1.1 Raw material pretreatment process

Kakogawa Works has one line each of a sintering plant and pellet plant for pretreating raw materials (iron ore). Sintered ore produced by firing and sizing the raw ore fines in the sintering plant and smaller fines not suitable for the sintering raw material are mixed to be granulated and fired into ore pellets for use in the blast furnaces. The applicable range of iron ore is expanded in this way to reduce the cost. The sintering plant improves productivity by the appropriate designing of the raw material grain size, and the pellet plant is designed to further reduce cost by adopting a grate-kiln process,[8)] made in-house and one of the world's greatest, for firing.

The reductant coke has been processed by Kansai Coke and Chemicals Company Limited in Kakogawa Works since 1970, and coke gas is supplied together with coke. There are 4 coke furnaces, a total of 248 gates, in operation, which will become a 50-year-old furnace in 2020. For that reason, the renewal of these coke furnaces is being planned.

4.1.2 Ironmaking process

Prior to the consolidation of the upstream processes, Kobe Steel operated three blast furnaces; namely the No. 3 blast furnace of Kobe Works and No. 2 and No. 3 blast furnaces of Kakogawa Works. As mentioned above, the No. 2 blast furnace was renovated in 2007 and the No. 3 blast furnace was renovated in 2016. After the consolidation, these two blast furnaces of Kakogawa Works are currently in full operation discharging molten pig iron.

Kakogawa Works has been purchasing a part of coke from the outside, which has increased the cost. Therefore, with the purpose of reducing the energy costs, technologies are being developed, aiming at operation with a high pulverized coal ratio and low coke ratio.[9)] As a result, operation continues with a high pulverized coal ratio and low coke ratio, which

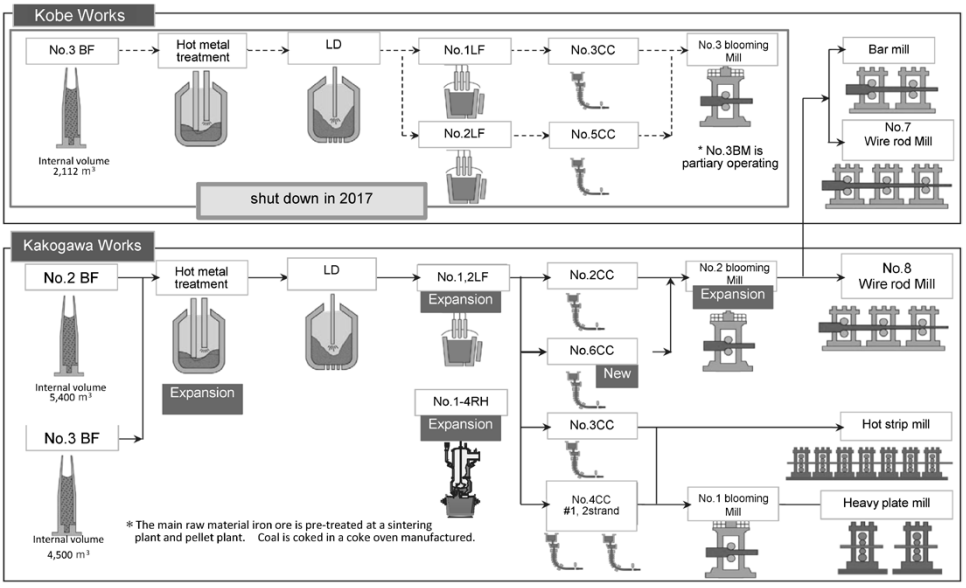

Fig. 2 Steel production system

is top level in Japan.

4.1.3 Steelmaking process

The steelmaking plant of Kakogawa Works features the supplying of crude steel for use in a wide variety of steel sheets, steel plates and wire rods. In other words, molten iron is dephosphorized and desulfurized and processed by three top-blowing converters to create a wide range of steel compositions. After the blowing, the molten steel is subjected to molten steel treatments using a ladle furnace (LF), Ruhrstahl-Heraeus (RH) degassing apparatus and so on, enabling the production of high-quality steel such as inclusion-controlled steel[10)-12)] and ultra-clean steel.[13)]

After the molten steel treatment, various special steels with high quality and high function are produced by continuous slab casting equipment and continuous bloom casting equipment.

In 2017, Kakogawa Works completed a new molten iron treatment plant equipped with two Kanbara reactor (KR) desulfurization apparatuses and two converter-type dephosphorization furnaces. With this completion of facilities, the molten iron treatment time was significantly shortened, while improving efficiency in the production, among others, of special steel wire rods /steel bars that require a high degree of cleanliness, high-tensile-strength steel plates, and of steel plate for energy related applications.

In addition, the upstream process consolidation accompanied the new installations of continuous casting equipment and molten steel processing equipment incorporating advanced technologies, such as surface quality technology, which have been cultivated over many years at Kobe Works. As a result, Kakogawa Works has established a system for supplying the 150,000 tonnes/month of crude steel required to produce steel wire rods and bars at Kobe Works.

4.1.4 Blooming mill process and logistics for semifinished products

Since the upstream process consolidation, Kakogawa Works has been supplying 130,000 tonnes/month of steel billets, produced at its No. 2 blooming mill plant, to Kobe Works for use in the production of steel wire rods and bars there. The conventional blooming capacity of the No. 2 blooming mill plant was 150,000 tonnes/month. Therefore, production capacity enhancement was carried out in the upstream process consolidation work, such as newly installing a heating furnace and reinforcing the continuous rolling mill for steel billets (**Fig. 3**). As a single unit, the blooming mill secured a rolling capacity of 300,000 tonnes per month, which is unparalleled in the world. In addition, two new roll-on/roll-off (RORO) ships were built to deal with the transportation of steel billets from Kakogawa to Kobe, which has increased dramatically from approximately 30,000 tonnes per month to 130,000 tonnes per month. Previously, these steel billets were loaded on the ships by a slinging operation. Now the steel billets are loaded onto pallets to be moved, establishing a transportation system that is safe, efficient and low-cost. These and other efforts have helped maintain a stable supply to the rolling process at Kobe Works. In addition, steel billet yards were constructed at both Kakogawa Works and Kobe Works with a total inventory capacity of 160,000 tonnes. This allows the inventory to be increased, establishing a system to meet the customer's desired delivery date for small quantity, large variety orders, which are unique to special steel.

Fig. 3 Rolling mill in No. 2 blooming mill factory at Kakogawa Works

4.1.5 Steel sheet process

The hot-rolling plant with a nominal monthly capacity of 360,000 tonnes produces hot-rolled products (steel plate) and titanium materials that are shipped after hot rolling. It also supplies the cold-rolling plant with stock materials for, among other things, high-tensile-strength steel sheets for automobiles and highly functional steel sheets for home electronics.[14), 15)]

In the cold-rolling plant, hot-rolled coils are used as the stock material to be cold-rolled into cold-rolled products (steel sheet) and as stock material for plated steel sheets. A continuous annealing line (CAL), continuous galvanizing line (CGL), and electro galvanizing line (EGL) are used to make a

large assortment of products, including high-tensile-strength steel sheet and highly functional, surface-treated steel sheet.[16]

4.1.6 Steel plate process

Steel plates are produced in a steel plate finishing mill (**Fig. 4**) with a nominal monthly capacity of 140,000 tonnes, and are used in the fields of construction, bridges and shipbuilding. Thermo-mechanical control process (TMCP) technology,[17] based on controlled rolling and accelerated cooling, is used to produce steel with excellent strength and toughness while having favorable welding workability, providing a large assortment of products, including high-heat-input steel[18), 19] for building construction and steels for low temperature service in shipbuilding.[20] Recent applications include circular steel pipes used in Tokyo Skytree and Roppongi Hills.

4.1.7 Wire rod process

The No. 8 wire rod mill with a nominal monthly capacity of 115,000 tonnes produces steel wire rods, each with a diameter of 5-18 mm. Being a 4-strand mill plant for mass production, the No. 8 wire rod mill is suitable for the mass production of high carbon steel wires, such as tire steel cords and wire ropes, adopting controlled cooling with a Stelmor conveyor after the winding of steel wire rods.

In recent years, with the improvement of the production process, the rolling quantity of highly functional products for automobiles, such as steel wire rods for cold heading and spring steel, has been increased to meet the strong demand from customers. In addition, in response to the recent increase in demand for special steel wire rods for automobiles, a production technology to improve the surface quality has been developed and introduced into this mill, despite its mass production type, which has increased the production volume of the steel wire rods for cold heading that have stringent surface quality requirements.

4.2 Kobe Works

About 70% of the total shipping volume of steel wire rods and bars produced at Kobe Works is highly functional special steel for automotive applications.

4.2.1 Wire rod mill

The No. 7 wire rod mill (**Fig. 5**) has a nominal monthly capacity of 55,000 tonnes and produces steel wire rods, each with diameters of 5.5 to 22 mm. The finish rolling line has the world's highest level of controlled rolling and controlled cooling capabilities.[21] The company supplies steel wire rod products with high dimensional accuracy, and they are softened by a thermomechanical control process,[22] which can reduce the cost of auto parts by simplifying the secondary processing.

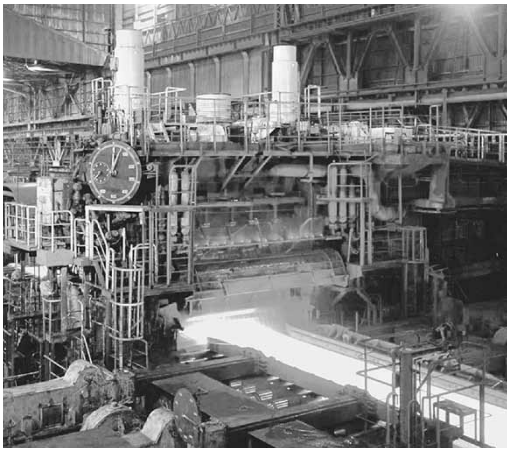

Fig. 4 Finishing mill for steel plate at Kakogawa Works

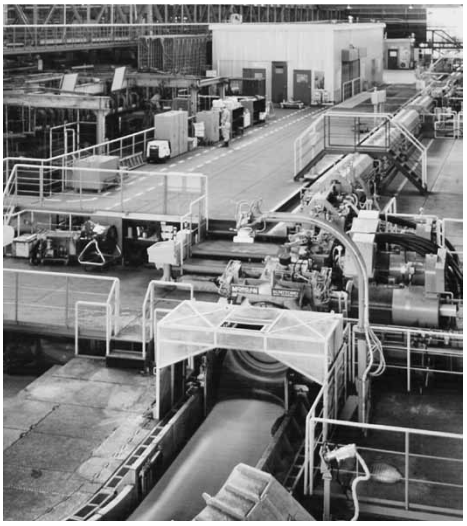

Fig. 5 Laying head of No. 7 wire rod and bar mill at Kobe Works

4.2.2 Steel bar mill

The steel bar mill has a nominal monthly capacity of 68,000 tonnes and produces ϕ17-108 mm steel bars and large diameter ϕ17-60 mm steel rods. The finish rolling line has a finish rolling mill capable of rolling with one of the highest product dimension accuracies ($\pm$0.1 mm) in the industry, which meets the needs of many customers. In the steel bar processing plant, steel bars are subjected to non-destructive testing to guarantee the quality of all surfaces and all cross-sections.

Table 1 Processing bases for steel products outside Japan

Category	Company name	Start up	Investment ratio (%)	Business content	Location
Wire Rod and Bar	Grand Blanc Processing, LLC	*2003- 4	20	Manufacture and sales of CHQ wire	Michigan, USA
	Kobe CH Wire (Thailand) Co., Ltd.	1997- 8	30	Ditto	Thailand Bangkok
	Mahajak Kyodo Co., Ltd.	*2002- 5	30	Manufacture and sale of grinding bars	Thailand Bangkok
	Kobelco Millcon Steel Co., Ltd.	2016- 2	50	Rolling and sales of special steels and ordinary steel wire materials	Thailand Rayong Rayong County
	Kobe Wire Products (Foshan) Co., Ltd	2004-11	60	Manufacture and sale of steel bars and CHQ wires	Foshan, Guangdong, China
	Kobelco Spring Wire (Foshan) Co., Ltd.	2012- 1	50	Manufacture and sale of high-grade spring steel wire	Foshan, Guangdong, China
	Jiangyin Sugita Fasten Spring Wire Co., Ltd.	2005- 8	60	Manufacture and sales of wire for automobile suspension springs	Jiangyin, Jiangsu Province, China
	Kobe Special Steel Wire Products (Pinghu) Co., Ltd.	2007-11	50	Manufacture and sales of CHQ wire and bearing steel wire	Pinghu, Zhejiang Province, China
	Kobelco CH Wire Mexicana, S.A. de C.V.	2014- 9	10	Manufacture and sales of CHQ wire	Mexico Guanajuato
Sheet	PRO-TEC Coating Company	1990- 3	50	Manufacture and sale of hot dipped galvanized steel sheet and cold rolled high tensile steel	Leepsic, Ohio, USA
	Kobelco Angang Auto Steel Co., Ltd.	2014- 8	50	Ditto	Anshan City, Liaoning Province, China
Other	Kobe Steel Asia Pte. Ltd.	1990- 1	100	Steel-related market research and technical services	Singapore

*Date of investment

Fig. 6 Kobelco Millcon Steel in Thailand

Fig. 7 PRO-TEC Coating Company in USA

4.2.3 Secondary processing of steel wire rods and bars

The bases for the secondary processing of steel wire rods and bars are located in-house. These bases provide customers with higher added value by conducting the pickling, heat treatment, and surface lubrication treatment of cold heading steel, bearing steel, spring steel, and the like.

5. Global supply system of special steel wire rods and high-tensile-strength steel sheets

5.1 Wire rod rolling base

In the Asian region centering on Thailand, demand for special-steel wire rods for automobiles is expected to increase in the future. Hence, Kobe Steel established "Kobelco Millcon Steel Co., Ltd. (hereinafter referred to as "KMS", **Fig. 6**)" in Rayong, Thailand in 2016, and began production in 2017. This is the only Kobe Steel wire rod mill base outside Japan.

5.2 Bases for secondary processing of steel wire rods and bars, and for processing parts

As a secondary processing base for wire-rods in Japan, Shinko Wire Company, Ltd., a group company of Kobe Steel, manufactures secondary processed products such as high strength springs and wire ropes for buildings and bridges. Shinko Bolt, Ltd. produces high-strength bolts for buildings, civil engineering and bridges, while Nippon Koshuha Steel Co., Ltd. manufactures secondary processed products such as steel wire rods for bearing steel.

Table 1 contains a list of steel processing bases outside Japan. They are located in North America, China, and Southeast Asia for the timely supply of steel wire rods and bars, which are stock materials for the production of automobile parts, among other parts. The main customers are Japanese parts manufacturers that have entered each local market.

In 2016, the company established "Kobelco CH Wire Mexicana, S.A. de C.V. (KCHM)" in Mexico, its 9th base outside Japan, to produce and sell steel wires for cold heading.

5.3 Bases for steel sheets and highly formable high-tensile-strength steel sheets

In North America, the PRO-TEC Coating Company (hereinafter referred to as "PRO-TEC Co." (**Fig. 7**)), established by a splitting investment of Kobe Steel and United States Steel Corporation, started operations in 1993. This company serves as a production base for thin-gauge steel sheet and

highly formable high-tensile-strength steel sheet and produces hot-dip galvanized thin-gauge steel sheets and cold-rolled high-tensile-strength steel products.

In China, Kobelco Angang Auto Steel Co., Ltd. was established as a joint venture with Angang Steel Co., Ltd. (hereinafter referred to as "Angang Steel"), a subsidiary of Anshan Iron and Steel Group Corporation., in 2015. A continuous annealing line (CAL) with an annual production capacity of 600,000 tonnes was built in Anshan Steelworks, Angang Steel, and inaugurated in 2016 as a production base for cold-rolled high-tensile-strength steel sheet.

With the opening of these bases, Kobe Steel has established a trilateral global production system for high-tensile-strength steel sheets in Japan, the US, and China.

6. Future plans

During the upstream process consolidation, continuous casting equipment and molten iron treatment equipment with advanced technologies were newly installed to improve the quality of special steel wire rods and bars. KMS, which has started rolling special-steel wire rods in Thailand, is currently being evaluated by local Japanese automobile manufacturers with a view to acquiring approval for special steel wire rods. The plan is for it to meet the demand for special-steel wire rods in the ASEAN region as Kobe Steel's No. 9 wire rod mill.

The automobile manufacturers inside and outside Japan are promoting "automotive weight reduction" vigorously, and to meet this demand, there are plans to increase the production capacity of "highly formable, ultra-high-tensile-strength" steel sheets in the US and Japan. In the United States, a third CGL has been added to PRO-TEC Co., and production is scheduled to start in 2019. In Japan, there are plans to equip Kakogawa Works with a manufacturing line for cold-rolled steel sheet and hot-dip galvanized sheet. This line will combine continuous annealing equipment and hot-dip galvanization/alloying equipment and is scheduled to start operation in 2021. Both lines apply state-of-the-art technologies of heat treatment with a cooling function and can produce highly formable ultra-high-tensile-strength steel sheets with industry-leading strength and workability (above 780 MPa or higher). With the addition of China (Kobelco Angang Auto Steel Co., Ltd.), the trilateral supply capacity in Japan, the US and China has been established to supply high-tensile-strength steel sheets with excellent quality to customers, which will contribute to the weight reduction of automobiles and will lead to fuel efficiency improvements and CO_2 reduction in the future.

Conclusions

In the automotive industry, the source of the greatest demand for iron and steel, there has been an increase in the production volume of environment-friendly vehicles such as electric vehicles and fuel-cell vehicles in order to reduce CO_2 emissions and prevent global warming. Great changes are occurring in response to more stringent fuel efficiency regulations and collision safety regulations, which will further increase the need for "lighter and stronger automotive bodies", and the progress of business globalization will increase the need for local production and supply.

In this environmental change, Kobe Steel, the only manufacturer in the world that has welding consumables and dissimilar material joining technology in addition to iron & steel and aluminum products, believes it is necessary to focus on the following initiatives in order to continue contributing to our customers and society:

(1) Responding to customers' needs by proposing new products using highly functional, high-performance steel,
(2) Developing environment-friendly production technology that saves resources and energy, and
(3) Proposing solutions for improving quality, delivery time, cost, etc.

In order to advance these efforts, it is indispensable to make an accurate response to the customers' needs, which continue to progress and diversify. Furthermore, it is necessary to create a process and technology for stably producing highly functional, high quality steel at the minimum cost. To this end, Kobe Steel is actively engaged in multifaceted development, including advanced AI technology for measuring, predicting and controlling the complex behaviors of molten iron, molten steel materials, and the like in steel production, as well as the further use of evaluation technologies.

References

1) Centennial Anniversary Executive Committee. 100 Years of Kobe Steel pp.42-103.
2) N. Yoshihara. *R&D Kobe Steel Engineering Reports*. 2011, Vol.61, No.1, pp.39-42.
3) T. Maruo et al. *R&D Kobe Steel Engineering Reports*. 2011, Vol.61, No.1, pp.43-46.
4) M. Nakaya et al. *R&D Kobe Steel Engineering Reports*. 2009, Vol.59, No.1, pp.46-49.
5) T. Murata et al. *R&D Kobe Steel Engineering Reports*. 2017, Vol.66, No.2, pp.17-20.
6) Y. Utsumi et al. *R&D Kobe Steel Engineering Reports*. 2017,

Vol.66, No.2, pp.3-7.
7) K. Kamo et al. *R&D Kobe Steel Engineering Reports*. 2018, Vol.68, No.2, pp.7-11.
8) S. Yamaguchi et al. *R&D Kobe Steel Engineering Reports*. 2010, Vol.60, No.1, pp.12-21.
9) R. Ito et al. *R&D Kobe Steel Engineering Reports*. 2000, Vol.50, No.3, pp.6-11.
10) S. Kimura et al. *R&D Kobe Steel Engineering Reports*. 2004, Vol.54, No.3, pp.25-28.
11) S. Kimura et al. iron と steel. 2002, Vol.88, No.11, p.53.
12) Tomoko SUGIMURA et al. ISIJ International, 2011, Vol.51, No.12, p.1982.
13) H. Ohta et al. *R&D Kobe Steel Engineering Reports*. 2011, Vol.61, No.1, pp.98-101.
14) Y. Hirano et al. *R&D Kobe Steel Engineering Reports*. 2011, Vol.61, No.2, pp.80-82.
15) Y. Hirano et al. *R&D Kobe Steel Engineering Reports*. 2009, Vol.59, No.1, pp.50-53.
16) H. Irie et al. *R&D Kobe Steel Engineering Reports*. 2002, Vol.52, No.3, pp.35-38.
17) Y. Omiya et al. *R&D Kobe Steel Engineering Reports*. 2009, Vol.59, No.1, pp.40-45.
18) Y. Kobayashi et al. *R&D Kobe Steel Engineering Reports*. 2008, Vol.58, No.1, pp.47-51.
19) K. Abe et al. *R&D Kobe Steel Engineering Reports*. 2005, Vol.55, No.2, pp.26-29.
20) M. Kaneko et al. *R&D Kobe Steel Engineering Reports*. 2008, Vol.58, No.1, pp.39-41.
21) Y. Ichida et al. *R&D Kobe Steel Engineering Reports*. 2000, Vol.50, No.1, pp.6-11.
22) H. Hata et al. *R&D Kobe Steel Engineering Reports*. 2000, Vol.50, No.1, pp.29-32.