Manufacturing Processes and Products of Bar and Wire Rod in JFE Steel†

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Abstract:

JFE Steel manufactures bar & wire rod and related products at both blast furnace and electric furnace steel works, and responds to the customers' needs by variety of products. By taking advantage of these respective processes, JFE Steel West Japan Works (Kurashiki) and JFE Bars & Shapes Sendai Works established manufacturing system of high quality products and supply system. Furthermore, JFE Steel has made continual development of value-added products and commercialized eco-friendly products with excellent properties. This paper describes features of these plants and processes and introduces typical examples of newly developed bar & wire rod products in JFE Steel.

1. Introduction

In April 2014, JFE Steel Corporation and JFE Bars & Shapes Corporation consolidated their bar and wire rod businesses and unified the sales brands of such products on JFE Steel, and in April 2017, JFE Bars & Shapes Sendai Works was transferred to JFE Steel. For the special steel bar and wire rod business, JFE Steel has established a production/sales system with West Japan Works (Kurashiki) and Sendai Works as bases. Kurashiki uses the blast furnace route, while Sendai Works manufactures products by the electric arc furnace route. Taking advantage of the distinctive features of these two plants, Kurashiki and Sendai Works supply a wide range of product types as JFE brand bars and wire rods in a mutually-complementary relationship.

The following introduces the features of the manufacturing processes at JFE Steel's two bases and the technical features of JFE bar and wire rod products, centering on recently-developed products.

2. Features of Manufacturing Processes

2.1 West Japan Works (Kurashiki)

The steelmaking process at West Japan Works (Kurashiki) consists of large-scale 226 t converter-secondary refining-continuous casting equipment and ingot-casting equipment. Using these facilities, it is possible to manufacture a wide range of steel grades from low carbon steel to high carbon steel and alloy steel in a wide range of product sizes. It is also possible to manufacture high cleanliness steels, centering on bearing steel, by utilizing hot pretreatment and ladle refining mainly using molten iron produced by the blast furnace, the strongly-stirred vacuum degassing process and continuous casing with electromagnetic stirring[1)].

Table 1 shows the available product size ranges of Kurashiki and Sendai Works. The Kurashiki Billet Mill can manufacture the world's largest class of large-diameter rolled products, including round bars with diameters up to ϕ450 mm and square bars with sections up to □750 mm. This was made possible by the use of ingot-casting material and establishment of an

Table 1 Manufacturing facilities and available size of bar and wire rod

	Products	West Japan Works (Kurashiki)	Sendai Works
Billet mill	Round bars	ϕ90-450	−
	Square bars	□250-750	−
Steel bar mill	Straight bars	ϕ16-90	ϕ17-120
	Bars in coil	ϕ16-38	ϕ16.7-52
Wire Rod mill	Square wire rods	□12.7-27	−
	Round wire rods	ϕ4.2-19	ϕ5.5-16.3

(unit: mm)

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integrated manufacture process from rolling to dedicated automated finishing line for round bars. As the name suggest, the Kurashiki Wire Rod & Bar Mill is a "one-strand combined mill" that can roll both wire rods and steel bars with high quality. It is also possible to produce products with excellent product quality, free of scratches and decarburization, by removing the billet surface layer with the billet peeling machine. As a feature of the Wire Rod & Bar Mill, rolling is performed by a flat roll rolling technology which is capable of using both square billets and round billets as material, high dimensional accuracy size-free rolling technology by the 4-roll mill, etc. Using the 4-roll mill, this plant also manufactures square wire rod materials with excellent squareness and opposite-side dimensional accuracy, 4-rib steel reinforcing bars with outstanding bending workability and ultra-fine wire rod material with a minimum diameter of 4.2 mm, among other products.

2.2 Sendai Works

In a modernization project in 2008, Sendai Works introduced equipment that gives full consideration to CO_2 reduction, including a 130 t eco-friendly high efficiency electric arc furnace (ECOARC™ Furnace), and adopted LNG for all fuel in the works, such as fuel for reheating furnaces, etc. Sendai is promoting efficient production by unifying the dimensions of materials for the Bar Mill and Wire Roll Mill on □160 mm and adoption of a 3-roll mill manufactured by Kocks to support size-free rolling. In a construction project at the Wire Rod Mill, the heating furnace was modernized and the rolling equipment was upgraded in order to prevent surface defects. In addition, construction to change the wire rod coil coiling direction and increase the coil diameter was also completed in 2015 with the aim of improving customer satisfaction. At the Bar Mill, a product water-quenching device was installed after the finishing mill. Sendai produces a line of original self-tempering steel bar materials by direct quenching of the surface layer, followed by self-tempering by the residual heat retained in the interior of the material after passing through the quenching device.

3. Bar and Wire Rod Products of JFE Steel

Taking advantage of the features of the mills at Kurashiki and Sendai Works, JFE Steel has constructed the optimum manufacturing system and delivers a wide range of products to customers, centering on automotive products and products for construction machinery. **Table 2** shows the main bar and wire rod products manufactured by JFE Steel. JFE Steel also manufactures special bar and wire rod products responding to the needs of customers. This chapter introduces several examples of those products.

Table 2 Type of steels for manufacturing

Carbon steels for machine structural use: S10C–58C, S09CK–20CK
Alloy steels for machine structural use: SMn420–443, SMnC420, 443, SCr415–440, SCM415–822, SNCM220–815, (H)
Spring steels: SUP9, 12, 9A
High carbon chromium bearing steels: SUJ2, SUJ3
Boron steels: 10B21–10B38 KF10T, 15B23–15B41 S35BC, S40BC, S48BC
Free-cutting steels: SUM22–31, 22L, 23L, 24L SAE(AISI) 1117, 1213, 1215, 12L14 1215M, 1215MU, 1215ML
Free-cutting steels for machine structural use: Lead free-cutting steels (symbol ...L1, L2) Lead free free-cutting steels (symbol ...S0, S1, S2)
Microalloyed steels: NH45MV, NH48MV, S45CVS1, etc.
Chrome-vanadium steels: S32CC5V–55CC4V
Wires for high-strength hoops: SD785
Piano wire rods: SWRS 62A, B–87A, B
Low carbon steel wire rods: SWRM 6K–22K
High carbon steel wire rods: SWRH 27–37, 42A, B–82A, B
Carbon steels for cold heading Part 1: Wire rods: SWRCH 6A–22A, 10K–50K
Rolled steel for general structure: SS330–540
Rolled carbon steel for cold-finished steel bars: SGD A, B, 1K–4K, 3KM–4KM

3.1 Case–Hardening Steels

Case-hardening steel is used in gears, shafts and other power transmitting parts of automobiles and machinery. In addition to fatigue strength after surface hardening, various other properties are also required. JFE Steel has developed case-hardening steels that achieve high fatigue strength and possess various functions.

Many parts are formed by forging, and softening annealing is performed to reduce deformation resistance during forging. Similarly, normalizing is often performed before carburizing of cold forged products to avoid coarsening of austenite grains in the carburizing process. However, case-hardening steels that make it possible to omit these heat treatment processes had been demanded, as heat treatment increases part manufacturing costs. To solve this problem, JFE Steel developed high cold forgeability case-hardening steel, which has the low deformation resistance of the original material in combination with a high capacity to suppress grain coarsening during carburizing by precipitate control[3]. Fatigue strength after carburizing is equal or superior to that of JIS SCM420. Application of the

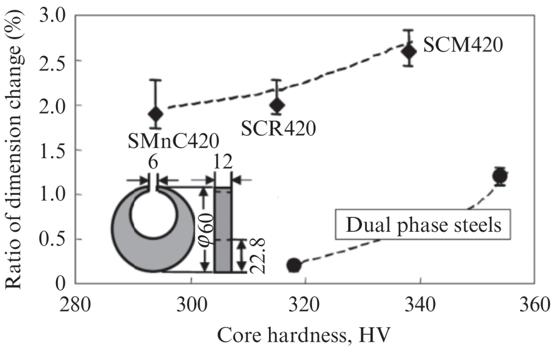

Fig. 1 Distortion in carburizing and quenching: Dual phase steel and conventional low-alloyed steels[4)]

developed steel makes it possible to omit processes in part manufacturing, thereby contributing to cost reduction.

JFE Steel also developed a dual-phase carburizing steel with high contact pressure resistance[4)], in which the Ac_3 transformation point is increased by addition of Si and V and a ferrite-martensite dual-phase microstructure is secured as the internal microstructure after carburizing at the normal carburizing temperature. (The carburized surface layer is a single phase of martensite.) This reduces heat-treatment distortion due to quenching following carburizing, and also achieves improved pitting resistance under high contact pressure simultaneously with low strain. **Figure 1** shows an example of the results of a comparison of the heat-treatment distortion of the conventional JIS equivalent steel and the dual-phase carburizing steel with high contact pressure resistance[4)]. The change in the opening of the test piece shown in the figure before/after carburizing was investigated. Although all of the test pieces display a tendency in which deformation increases with increasing hardness, in other words, increasing hardenability, it can be understood that the heat-treatment deformation of the dual-phase steel was suppressed to less than 1/2 that of the conventional steels.

The soft nitriding process enables low temperature surface hardening, and as a result, heat-treatment distortion is small and the dimensional accuracy of parts is excellent in comparison with carburizing. However, the range of applicable parts had been limited, as surface hardness and internal strength after soft nitriding were low in comparison with carburized materials. High strength soft nitriding steel[5)] is a steel in which dramatically higher surface hardness and internal strength can be obtained in comparison with conventional soft nitriding steels by utilizing precipitation strengthening and transformation strengthening by a unique composition design. This greatly improves fatigue strength. Since forgeability and machinability are also equal or superior to that of the conventional steel, application to practical parts is expected.

3.2 Bearing Steels

In addition to manufacturing high cleanliness bearing steel, Kurashiki has also developed medium carbon bearing steel based on a new design technique, bearing steel with excellent rolling fatigue life in the normal-to-medium temperature range, and other new products by focusing on the mechanism of microstructural defects under rolling environments. Kurashiki also manufactures small-diameter bearing wire rod materials, including SUJ3, down to ϕ4.2 mm in size using the above-mentioned 4-roll mill and Stelmor cooling control.

Regarding nonmetallic inclusions, although observation by conventional microscopy has become increasingly difficult accompanying the trend toward higher cleanliness, JFE steel has developed an inclusion detection method using ultrasonic flaw detection technology, which enables high speed, high accuracy measurement of nonmetallic inclusions with a large volume of material.

3.3 Micro Alloying Steels

As steel materials which make it possible to omit the tempering treatment required with carbon steel for machine structural use and alloy steel for machine structural use, JFE Steel offers a lineup of micro alloying steels for hot forging and micro alloying steels for direct cutting. In the micro alloying steel for hot forging, toughness is secured by appropriate addition of Ti and strength is secured by addition of V. The precipitation-strengthened type THF Series is a medium carbon-based steel with a ferrite-pearlite microstructure. In the TBH Series, strength variations due to the cooling rate are suppressed by balancing microstructural strengthening by bainite and precipitation strengthening by V. In response to customers' requests, JFE has also developed a steel with high proof stress in the low strain region and higher strength/higher toughness based on the TBH Series.

As direct cutting steels, JFE produces the NH Series of micro alloying steel in large-diameter round bars by utilizing the manufacturing equipment at Kurashiki. Sendai Works has commercialized the TQF Series of micro alloying steels as outstanding materials for shaft applications. In these steels, a tempered martensite surface layer and a fine ferrite-pearlite internal microstructure are secured by direct quenching utilizing the water-quenching device installed immediately after the steel bar finishing mill.

3.4 Free Cutting Steels

Sendai Works has steelmaking equipment that

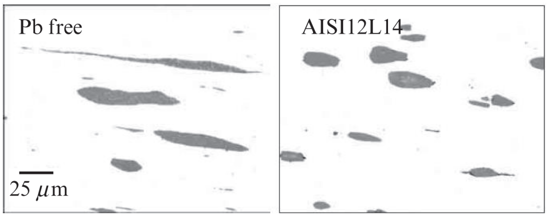

Fig. 2 Comparison of size of sulfide inclusion in free-cutting steels[8)]

enables Pb addition and had manufactured Pb-added free-cutting steel. However, in response to the global environmental problems of recent years, Sendai developed several substitute steels in order to realize Pb-free free cutting steels. As low carbon materials, Sendai produces AISI12L14 substitute CCC (Clean Cut Chrome) steel[6-8)] with improved machinability and an AISI1215 based Pb-free free cutting steel with excellent cost performance; these steels are widely used in printer shafts and other OA equipment parts. **Figure 2** shows examples of observation of the sulfide inclusions in Pb-free CCC steel and Pb-added free cutting steel. In the CCC steel, large inclusion which contribute to improved machinability are dispersed through the material. **Figure 3** shows the relationship between the number of holes and drill wear in a hole drilling test using a high speed steel drill. It can be understood that the CCC steel has excellent drilling machinability.

3.5 High Strength Shear Reinforcements

Kurashiki and Sendai Works, in cooperation with JFE Techno-wire Corporation, commercialized a 1 275 MPa class shear reinforcement[9)] with excellent ductility after closure welding, and 785 MPa class shear reinforcement[10)] which realizes alloying saving by controlled cooling.

4. Conclusion

JFE Steel Corporation produces a lineup of steel bar and wire rod products responding to the needs of customers by utilizing the features of its two manufacturing bases, and has established a high quality manufacturing system and supply system for those products. The company also has a full lineup of newly-developed products with special features for various fields. In the future, JFE will continue to promote the development of high value-added bar and wire rod products that contribute to an environment-friendly society by making the maximum use of its technological capabilities as a total iron and steel manufacturer.

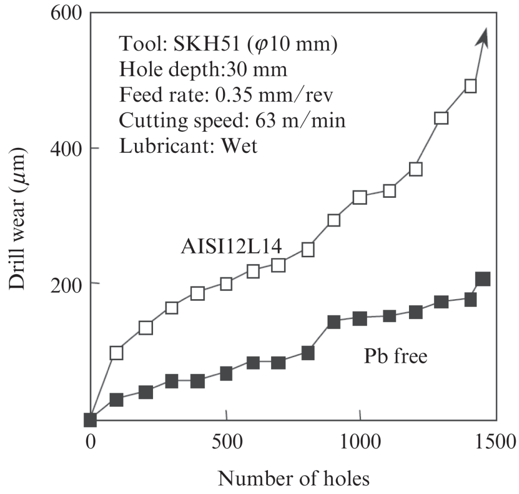

Fig. 3 Drilling machinability of free-cutting steels[8)]

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