NIPPON STEEL & SUMITOMO METAL TECHNICAL REPORT No. 116 SEPTEMBER 2017

Technical Report

UDC 669 . 14 - 426 . 2

Manufacturing of Small Diameter Wire Rods

Takao FUNAYAMA*

Abstract

Bars and wire rods are characterized by the long subsequent processing before they are finished to final products as they have to undergo various processing stages such as heat treatment and wire drawing. The need to reduce and/or simplify such processing stages in the secondary and tertiary processing sectors is intensifying year by year in order to reduce the processing cost. In the Kamaishi Works, small-diameter wire rods are manufactured that enable users to simplify the drawing process and omit heat treatment. Employment of such wire rods in a broader range is expected. This paper introduces the manufacturing technology of small diameter wire rods and their features.

1. Introduction

The Kamaishi Iron and Steel Works, inaugurated on the 16th of October 1886 (19th Year of the Meiji era), is the birth place of the modern iron and steel industry that has achieved many great successes including the successful operation of a western-style blast furnace and the production of coke-reduced pig iron for the first time in Japan. In keeping with its illustrious history, the remains of the Hashino Blast Furnace were designated as the "Heritage facilities of the Japanese Industrial Revolution in the Meiji Era" in July 2015. Furthermore, it was decided that the 2019 World Cup Rugby Football Tournament would be held in Kamaishi. The entire region is regaining vigor further activated by the restoration from the earthquake disaster. Under such circumstances, the wire rod mill of the Kamaishi Works has continued to promote improvements in quality and productivity, and has continually maintained the highest quality and productivity domestically. Currently, the mill is operated as a multi-stranded mill producing with high efficiency the high steel grade wire rods represented by steel tire cord use and cold heading use.

Meanwhile, the final products made from bars and wire rods such as automotive parts as a representative example are used in various industrial fields. They are processed to the final products through the secondary and tertiary processing that is characterized by heat treatment and processing stages such as annealing and wire drawing. Therefore, every year demands are increasing for the supply of wire rods that enables the omission of heat treatment and the simplification of processing from the viewpoints of improving their productivity and cost, and the reduction in environmental impact. By responding to such demands, sophistication of the wire rod production technologies has been promoted. Amongst such technologies, the production technology of small diameter wire rods developed to handle the omission of heat treatment and the simplification of processing stages among users is introduced.

2. Small Diameter Wire Rods

To address the feedback on demands and meet the wide variety of user needs, the Bar and Wire Rod Business Division of Nippon Steel & Sumitomo Metal Corporation is expanding its business operation with the brand name of SteeLinC™. As a part of the business, the small diameter wire rods constitute the highly functional merchandize XSTEELIA™. The Kamaishi Works can supply small diameter wire rods ranging in size from 3.6 mm to 5.0 mm, the smallest in the world in terms of diameter obtained by rolling.

For users of wire rods, the final wire of a target diameter is conventionally produced through a wire-drawing process, wherein strain caused by drawing is accumulated within the wire rod, leading to a breaking down of the wire when the strain exceeds the limit of wire-drawing allowed without heat treatment. To avoid such breakage in wire drawing, although intermediate patenting is required to disperse such strain, the accumulation of the strain before reaching the prescribed diameter in the wire drawing is lessened by the smaller starting wire rod diameter. Thereby, reduction in wire-drawing stages and the omission of patenting treatment have become possible.

Furthermore, the cooling effect after rolling is higher in the smaller diameter wire rods, which realizes the more evenly distributed metallurgical structure on the wire rod section and further refines the γ grains, exerting deterrent effects on aging due to wire-

* Senior Manager, Production Div., Kamaishi Works
23-15 Suzuko-cho, Kamaishi City, Iwate Pref. 026-8567

drawing and fragmentation of cementite. With these effects, the limitations of wire drawing without heat treatment can be further expanded, and features the omission of certain processing stages. In addition to the possibility of improving cost in the secondary and tertiary processing sectors with the omission of certain processing stages, productivity is also expected to be enhanced in the case of a bottleneck in the subject process.

From the environmental viewpoint, although the emission of CO_2 per ton of the small diameter wire rod increases in the production stage due to lowered productivity, the reduction of CO_2 emissions by approximately 40% has become possible (comparison between the cases of 5.5 mm diameter and 3.6 mm diameter) due to the reduction in energy in the wire drawing processing and the omission of heat treatment.

Thus, the small diameter wire rod enables improvements in cost, productivity and environmental load on the part of users, and hereafter, application to a variety of wire rods such as for steel tire cords, cold heading use and spring is expected.

3. Production Technology of Small Diameter Wire Rod

As shown in **Table 1**, the wire rod mill of the Kamaishi Works started its operation as a Schloemann type, four-stranded mill producing 500 kg coils in 1961. In 1976, the reheating furnace was remodeled to handle two-ton billets, a no-twist mill (hereinafter referred to as NT mill) was installed and the line was converted to a two-strand mill with a finishing rolling speed of 61 m/s. Furthermore, in 1981, another strand was added and the production capacity was enhanced.

In 1995, a mini block mill (hereinafter referred to as MBM) was introduced to the No. 3 course in 1995 and to the No. 2 course in 2000, respectively. Then, the mill was reborn as a high-speed, two-strand mill with increased rolling speed and the unified roll groove profile series, and it became capable of producing high-end quality products with high efficiency. As shown in **Fig. 1**, MBM was installed after the NT mill and the rolling speed were increased remarkably from 61 m/s to 100 m/s. Presently, 122 mm square billets are rolled to prescribed sizes continuously with 28 rolling mill stands.

Table 1 History of Kamaishi wire rod mill

	Event	Strands	Speed	Coil weight
1969	Beginning operations (Schloemann type)	4	30 m/s	500 kg
1976	No-twist mill	2	61 m/s	2 000 kg
1989	Walking beam type reheating furnace	3	↓	↓
2000	Mini block mill	2	100 m/s	↓

3.1 Development of production technology of small diameter wire rod

3.1.1 Securing rolling speed and reduction of area

In the wire rod mill of the Kamaishi Works, a study was conducted on the production of small diameter wire rods that enable the omission of certain processing stages in users. The first subject was to secure the rolling speed and appropriate reduction of area. In the continuous rolling of wire rods, once the rolling speed of the finishing mill is determined, the rolling speed of each rolling mill of the roughing mills and the intermediate mills is determined. In the case of producing the small diameter wire rods, when the material section size is fixed, the rolling speed of the No. 1 stand becomes lower than those of other sizes as the finishing speed is constant. In the meantime, unless a rolling speed higher than a certain value is secured, the rolling rolls are damaged due to thermal load and/or a drop in steel material temperature takes place due to prolonged rolling time, rolling encounters difficult conditions. The first subject to be tackled in the production of small diameter wire rods is to secure the rolling speed. In the wire rod mill of the Kamaishi Works, this subject was settled by realizing the rolling speed increase through the introduction of MBM.

Furthermore, in the continuous rolling of wire rods, an optimum range of the area of reduction exists in each rolling mill stand to secure the stabilized passage of material. In the wire rod mill of the Kamaishi Works, by increasing the number of the rolling mill stands from the former 26 to 28 through the introduction of MBM, the production of small diameter wire rods with a diameter of 4.0 mm or below from a 122 mm square billet was made possible while securing the overall reduction of area in the entire line, and while securing the optimum reduction of the area in the optimum range in each rolling mill stand (**Table 2**).

3.1.2 Securing stabilized passage of material

In the rolling of wire rods, rolls are grooved and to provide the rolled steel material with the correct dimensions and prevent surface defects, it is necessary to guide the rolled steel material properly into the groove. In order for the rolled steel material to be properly guided into the groove, the rolling rolls are equipped with a roller

Table 2 Rolling speed limit and reduction of area at the small diameter wire rod rolling

	Velocity of No.1 mill		Reduction of area	
Number of rolling mill	26	28	26	28
5.5 mm diameter	○	○	○	○
5.0 mm diameter	○	○	○	○
4.0 mm diameter	×	○	×	○

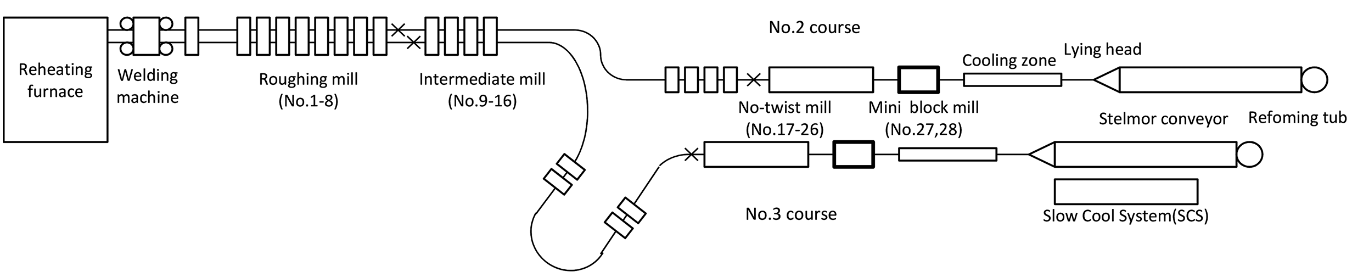


Fig. 1 Layout of Kamaishi wire rod mill

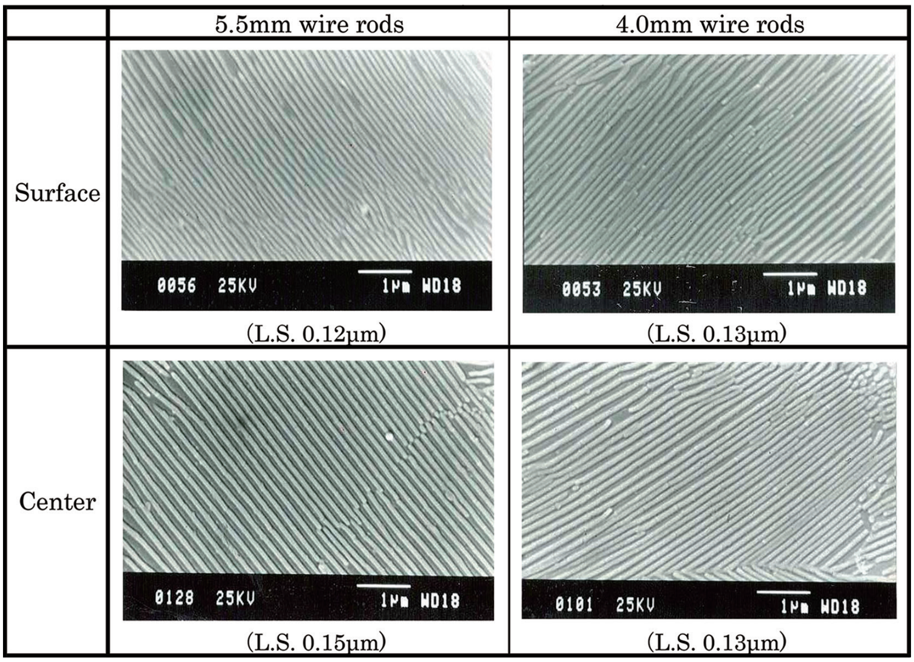
guide on their entry side. In the case of rolling small diameter wire rods, the closer the rolled material is to the finishing stand, the finer and the less rigid the rolled steel material becomes. Accordingly, near the final rolling stage close to finishing, tight constraint of the rolled steel material to the extent possible is required to prevent buckling in its rolling direction. To this end, the distance between the rolls and the guide rollers, the inside spaces of the cooling box and of the pass line guide box need to be properly provided to prevent space for unnecessary free movement of the rolled steel material therein. Furthermore, since the groove of the roll is not designed to be deep enough to render constraining force within the groove, the profile of the groove needs to be designed in such a way as to prevent the development of spreading to the extent possible. As a result of repeated trials, appropriate roll groove design and guide roller design have been achieved and the production of the small diameter wire rods has become possible.

3.1.3 Effect of small diameter on material quality

Wire rods are cooled by water and blast air after hot rolling and the required quality characteristics such as metallurgical structure, strength and scale have been implanted. In the cooling after hot rolling, as the difference in cooling rates is developed between the subsurface and the central area, a difference in metallurgical structure is developed between the subsurface and the central area of the steel material. Therefore, the cooling method of wire rods is contrived to eliminate the difference in the cooling rates between the subsurface and the central area. On the other hand, as the diameter of the subject wire rod is small, the difference in the cooling rates between the subsurface and the central area is small. Accordingly, as compared to the general 5.5 mm diameter wire rods, the cooling rate inside of the rolled steel material is higher and therefore, the cooling rate inside the rolled steel material is made even, and the metallurgical structure of the rolled steel material becomes homogenized. This is exemplified by the photograph of an actual metallurgical structure shown in **Fig. 2**. There is no difference in metallurgical structure between the subsurface and the central area of the wire rod 4.0 mm in diameter as compared to the wire rod 5.5 mm in diameter. This is considered to contribute to the improvement in the limitation of drawability in the wire drawing without heat treatment in secondary processors, further contributing to the omission and/or the simplification of certain processing stages in customers (**Table 3**).

3.1.4 Drawability of small diameter wire rod

In the drawing of a wire rod in secondary processing, there is a limitation in drawability that relates to the carbon content. As shown in **Fig. 3**, the limitation of wire drawing deteriorates in the low carbon content range and in the high carbon content range. The deterioration in the low carbon content range is due to the increase in

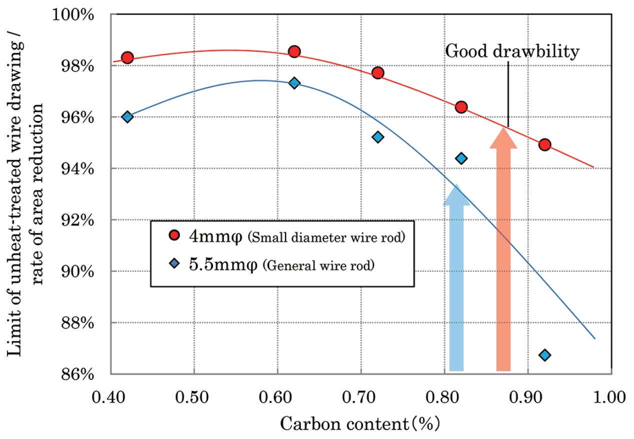


L.S.: Lamellar Space

Fig. 2 Microstructure of 5.5 mm diameter and 4.0 mm diameter wire rod

Table 3 Examples of omitted drawing process by small diameter wire

	Wire rod	Drawing process		
Carbon 0.7%	5.5 mm diameter →	3.0 mm diameter →	0.9 mm diameter →	0.175 mm diameter →
	4.0 mm diameter →	[omitted] →	0.9 mm diameter →	0.175 mm diameter →
Carbon 0.8%	5.5 mm diameter →	3.0 mm diameter →	1.1 mm diameter →	0.20 mm diameter →
	4.0 mm diameter →	[omitted] →	1.1 mm diameter →	0.20 mm diameter →
Carbon 0.9%	5.5 mm diameter →	2.3 mm diameter →	1.0 mm diameter →	0.40 mm diameter →
	4.0 mm diameter →	[omitted] →	1.0 mm diameter →	0.40 mm diameter →



Note : Judgment criteria for the drawing limitation
(1) Reduction of area ≧ 35%
(2) Number of twist ≧ 25 times (l=100d)
(3) Wrapping and unwrapping testes ≧ Pass rate : 90%
(Wrapping around a core with the same diameter as that of the wire tested : 8times)

Fig. 3 Relationship between limit of unheat-treated wiredrawing and carbon content

boundary ferrite thickness and the deterioration in the high carbon content range is considered to be attributed to the refinement of lamellar spacing, increase in boundary cementite and the thickness of cementite. Figure 3 shows the limitations of drawability of the 5.5 mm wire rod and the 4.0 mm wire rod, and the higher the carbon content, the larger the difference in drawability. The material of carbon content of 0.9 wt% or higher is practically used for steel tire cords to obtain higher strength, and employment of the small diameter wire rod is effective in the said carbon content range in realizing omission and/or simplification of certain wire drawing stages in the secondary processing, namely, the improvement in drawability.

4. Conclusion

Due to the establishment of the production technology for wire rods with a diameter of 4.0 mm or smaller, the omission of heat treatment and the simplification of certain wire drawing stages have been realized, contributing to the enhancement of productivity.

Takao FUNAYAMA
Senior Manager
Production Div.
Kamaishi Works
23-15 Suzuko-cho, Kamaishi City, Iwate Pref. 026-8567