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Development of High Dimensional Accuracy Smaller Diameter Wire Rods and Square Coils Manufactured by 4-Roll Mill*


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Synopsis:

After introducing 4-roll mills for steel bars in 1994, Kawasaki Steel developed and introduced 4-roll mills for wire rods in 1998. Then, thanks to the development of various new technologies based on the characteristics of 4-roll rolling method, the company succeeded in establishing a highly precise-measurement and size-free rolling production system for steel bars and wire rods ranging from 4.2 to 85 mm in diameter and steel square coils from 12.7 to 27 mm on a side. Able to manufacture hot-rolled steel bars and wire rods with such high measurement precision, Kawasaki Steel can provide products to the automobile steel and other special steel markets in sizes and shapes as similar as possible to the finished products, thus minimizing further processing.

1 Introduction

Wire rods and bars are often used for producing automobile parts and various industrial machines. In recent years, due to customers' need to reduce processing cost,[1)] customers have sought to simplify additional secondary processing, such as surface machining, drawing, cutting, and forging. This lead to an earnest desire to develop hot-rolled wire rods and bars that have high dimensional accuracy in sizes and can minimize further processing.

Sumitomo Heavy Industries, Ltd. and Kawasaki Steel jointly developed a 4-roll bar mill in 1994 and a 4-roll wire rod mill in 1998. These mills were then introduced into Kawasaki Steel's wire rod and bar plant. These mills allow the production of high dimensional accuracy, hot-rolled wire rods and bars in arbitrary sizes with a pitch of 0.1 mm within the conventional size range of 5.5 to 85 mm in diameter.

Wire rods are generally drawn down to a specific diameter before being subjected to forging or other forming operations in secondary processing. In some cases, the size of the wire rods before being subjected to these forming operations is less than the minimum size of 5.5 mm that can be supplied as rolled. The new 4-roll wire rod mill can produce wire rods with diameters as small as 4.2 mm, which can eliminate the necessity for drawing during secondary processing. Thus, for example, these products make as-rolled heading operations possible.

Automobiles, electrical equipment, and industrial machines have many component parts, that can be more economically produced by starting with square cross-sections materials as compared with round materials. The 4-roll mill can manufacture square products that are superior to those of a conventional 2-roll mill in shape and dimensional accuracy, such as squareness and the uniformity of opposite side dimensions. It can also flexibly control the radius on the corner. These characteristics of 4-roll rolling are effective for eliminating or simplifying secondary processing. This article compares the characteristics of 4-roll bar rolling with those of 4-roll wire rod rolling and introduces the process to develop small diameter wire rods and square bars that utilize the advantages of 4-roll rolling. Some examples of applications of these products are also described.

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2 4-Roll Rolling Technology

2.1 Characteristics of 4-Roll Rolling

The 2-roll and 3-roll rolling methods were developed and introduced for sizing rolling and applied to steel bar production.[2,3] To date, however, only the 2-roll method has been used for wire rod production.

Figure 1 shows the geometrically estimated relationship between the ovality of the product (difference between the maximum and minimum diameters) and the amount of roll gap for each rolling method. The size-free rolling range corresponds to the difference between the minimum and maximum roll gaps that are applicable to the production of products with ovality within the allowable limits. Figure 1 indicates that the 4-roll method has the widest size-free rolling range. **Figure 2** shows the width spread for three kinds of rolling methods. The 2-roll method gives the largest spread ratio, while the 4-roll method has almost no spread but rather tends to make the width narrower. This suggests that the 4-roll method is the most suitable method for rolling with high dimensional accuracy.

These potential advantages of the 4-roll method for producing wire rods and bars with high dimensional accuracy led to the adoption of this method for the new sizing mills. The mills were also simplified and successfully put into commercial operation.

2.2 Application of 4-Roll Mills

As shown in **Fig. 3**, Kawasaki Steel's wire rod and bar plant is composed of a combination of a wire rod mill and bar mill. The wire rod rolling line was added to the existing bar rolling line. The 4-roll bar mill was installed in the space created by removing the last two stands in the bar finishing train. The new 4-roll wire rod mill was added downstream of the existing block mill for wire rod finishing. **Figures 4** (a) and (b) are views of the 4-roll mill for bar rolling and for wire rod rolling, respectively. The specifications are summarized in **Table 1**. The 4-roll mill can form round-section material into a round-section product using only two stands. The new bar mill has this two-pass configuration, while the new wire rod mill has a three-pass configuration to provide a larger total cross-section reduction ratio. Each stand is mounted on a sled car. On-line roll changes are completed within about 3 min owing to the use of automatic couplers and rapid shifting of the sled cars.

The two new mills have other common features in addition to their compactness. They have highly rigid structures and fine-tuning mechanisms that can adjust the roll gap in a 0.01 mm pitch by remote control system. This system makes it easy to manufacture products

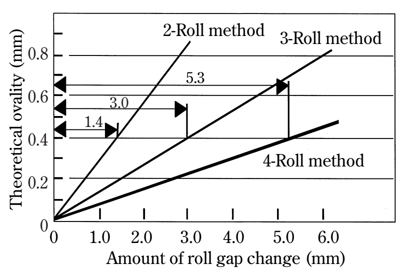


Fig. 1 Relationships between ovality of product and amount of roll gap change for three different roll mathods

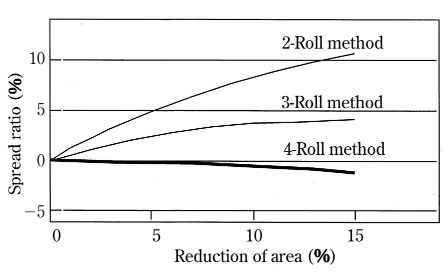


Fig. 2 Relationships between spread ratio and area reduction for three different roll methods

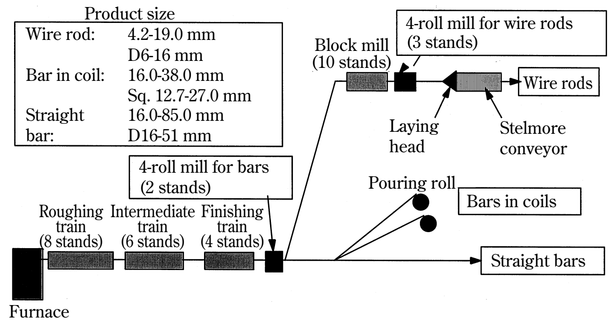


Fig. 3 Layout of bar and wire rod mill

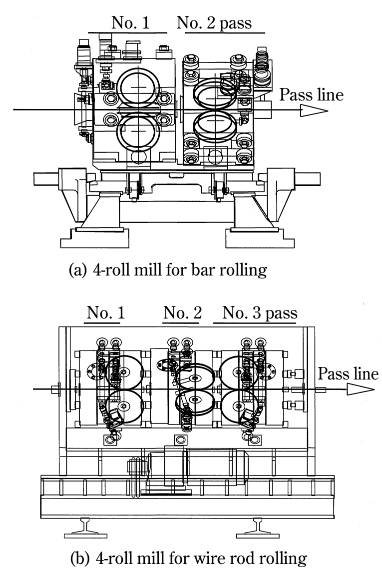


Fig. 4 Outside view of 4-roll mills

Table 1 Main specifications of 4-roll mills for bar rolling and wire rod rolling

Items	Specifications of 4-roll mill	
	For bar rolling	For wire rod rolling
Organization of mill	2 stands per unit Roll arrangement: "+" → "×"	3 stands per unit Roll arrangement: "+" → "×" → "+"
Product size (mm)	16〜85 ϕ, 12.7〜27 □	4.2〜19.0 ϕ
Rolling speed (m/s)	0.8〜16	15〜110
Roll diameter (mm)	400 ϕ	220 ϕ
Roll drive	2 rolls driven by motor and 2 rolls rotated by water presure pulsation	4 rolls driven by motor
Roll gap adjustment	Remote control system Control accuracy = ±0.01 mm	Remote control system Control accuracy = ±0.01 mm
Stand-change system	Automatic change system Changing time = 3.5 min/unit	Automatic change system Changing time = 3 min/unit

that have high dimensional accuracy.

3 Development of Small Diameter Wire Rods with High Dimensional Accuracy

One of the reasons for adding the 4-roll mill to the existing wire rod line was to enable the production of small diameter wire rods (less than 5.5 mm) with high dimensional accuracy. The developed technology for stablly production of small diameter wire rods is described below.

3.1 Stable Material Feed to 4-Roll Wire Rod Mill

Extensive theoretical and experimental investigations were carried out to determine how to maintain high dimensional accuracy in rolling small diameter wire rods while ensuring stable roll passes all of the time. The investigations concluded that strict control of the dimensions and shape of the roll material at the entry side of the 4-roll mill is important. In other words, strict control is essential at the exit side of the existing block mill.

As a means of achieving this objective, the hot-rolling profile meter shown in **Photo 1** was developed in-house and installed at the entry side of the 4-roll wire rod mill in June 1999.

Control of the dimensions and shape at the entry side of the existing block mill is also important to stablilize the dimensions and shape of the material at the exit side of the block mill. Since the block mill receives its material from the new 4-roll bar mill, excellent dimensional accuracy of the intermediate cross section of the material rolled by the block mill is steadily ensured. As a result, control within strict specifications of the dimensions and shape of the material at the exit side of the block mill is possible over the entire length of the material. Stable production of small diameter wire rods is thereby achieved.

3.2 Strict Roll Alignment for 4-Roll Wire Rod Mill

Stable production of small diameter wire rods to high dimensional accuracy requires highly accurate off-line roll alignment. A dedicated roll alignment device was introduced for the 4-roll wire rod mill. This device is used to accurately align the rolls by applying a prestress to eliminate any mechanical play. The mill also has an on-line, fine-tuning roll gap mechanism that was newly developed for this mill. A highly accurate selsyn indicator detects the angle eccentricity. The roll gap is adjusted with 0.01 mm pitch by remote control from the control station. In actual operation, the roll gap is easily and quickly fine-tuned based on the profile meter reading and other dimensional information obtained from the rolled material. This system greatly enhances the dimensional accuracy of the rolled product.

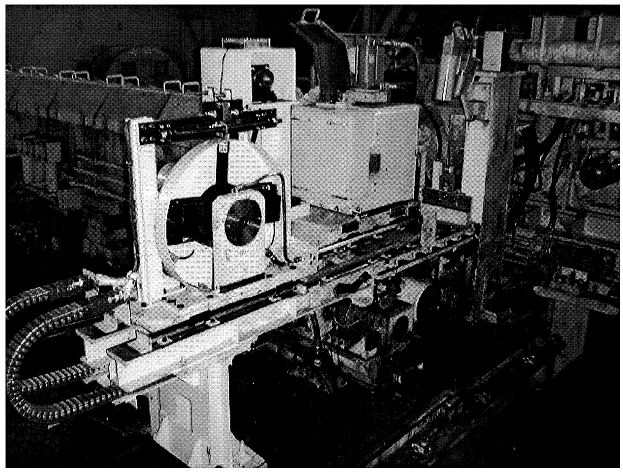


Photo 1 Profile meter in front of 4-roll mill for wire rod

3.3 High-speed and Stable Roll Pass of Small Diameter Wire Rods

For example, a wire rod of 4.2 mm diameter, the minimum size produced by the new mill, has a section modulus of 44.5%, less than half of that for a 5.5 mm diameter rod. Such small diameter materials can easily cause buckling, leading to a misroll. In particular, for high-speed hot rolling with speeds exceeding 100 m/s, strict control is required over such factors as straightness of the pass line and tension between mill stands. When rolling small diameter materials, a stable roll pass is achieved by controlling the mill motor speed so that the sum of the rolling torque and the tension torque is equal to the appropriate target torque. A high-speed, stable roll pass with a speed of 110 m/s was achieved by applying various types of dynamic control methods during rolling. These control methods included severe material tracking and impact drop compensation control at the moment when the material goes into the rolls, and on-off control of the water cooling.

3.4 Results of Rolling Small Diameter Wire Rods

Figure 5 shows the fluctuations of maximum and minimum diameters in the cross section of a 4.2 mm diameter rod. The ovality is less than 0.1 mm along the entire length, which demonstrates stable rolling with high dimensional accuracy. **Figure 6** shows an example of the dimensional accuracy in size-free rolling of small diameter wire rods.[4)] The abscissa shows changes in the roll gap which is expressed as a difference between the product diameter and the groove gauge diameter. The ordinate shows the ovality. An ovality of less than ±0.07 mm is achieved within the size-free rolling range. Products with a diameter that is close to the groove gauge diameter can be produced with much higher dimensional accuracy, and with an ovality that is less than ±0.05 mm.

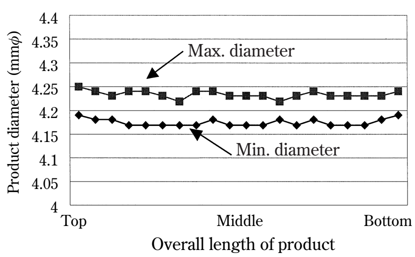


Fig. 5 Product diameter along entire length for a product of ϕ4.2 mm

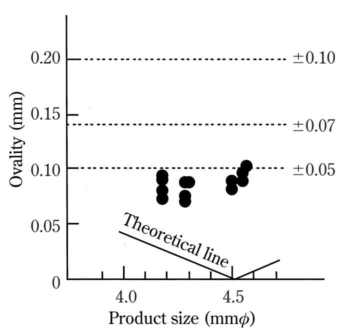


Fig. 6 Results of ovality in wire rods of smaller diameter

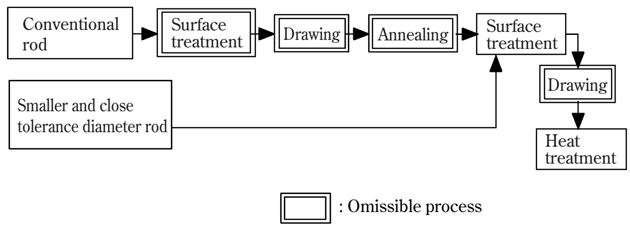


Fig. 7 Example of process applying close tolerance or smaller diameter rod

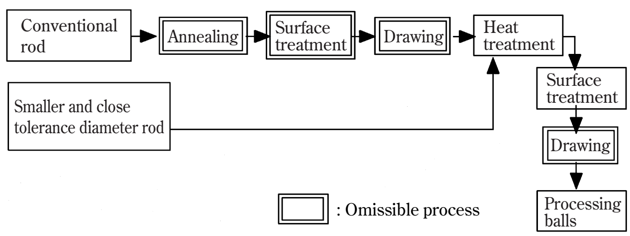


Fig. 8 Example of process applying smaller diameter rod for bearing steel

3.5 Applications of Small Diameter Wire Rods

Figure 7 shows the potential change in secondary processing that results when small diameter, high-carbon steel wire rods are used in place of conventional large diameter wire rod. In the traditional processing, high-carbon wire rod is usually required to be annealed because of hardness of material resulting from the drawing processing. On the contrary, the new 4-roll mill can produce wire rods in diameters small enough to eliminate the need for drawing in secondary processing. Along with drawing, the need for annealing and surface treatment are also eliminated. **Figure 8** shows an example applying small diameter wire rods to bearing ball use. As with high-carbon steel rods, a considerable part of the processing needed to fabricate final balls can be eliminated.

4 Development of Square Bars with High Dimensional Accuracy

Automobiles, electrical equipment, and industrial machines have many component parts that can be more economically produced if using steel products with square cross sections. These types of steel products are widely distributed in the market, as represented by cold-finished square steel bars. They are generally produced through many complicated processing that includes several cycles of drawing of round bars and annealing.

In contrast, the 4-roll mill has four symmetrically-aligned rolls and can roll square products directly. The process for rolling square bars with high dimensional accuracy was developed by utilizing the excellent rolling characteristics of the 4-roll mill. The rolling process for square bars and the results of the development are described below.

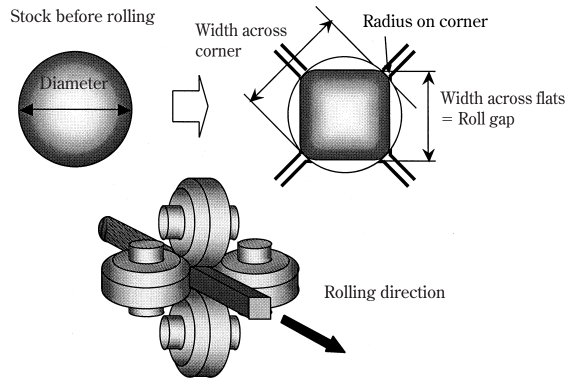


Fig. 9 Rolling method of square bars by 4-roll mill

4.1 Process for Rolling Square Bars

Square bars are produced with the 4-roll bar mill in a size range of 12.7 to 27 mm. The bars are finished in coils. As shown in **Fig. 9**, a round material is formed into a square product by one pass through a set of four rolls with flat grooves.

The rolling process is characterized by its simplicity. Problems encountered during the development were:

(1) Radius control on the corner, and

(2) Twist along the longitudinal direction of the material.

FEM analysis was carried out to evaluate radius control. The analysis results demonstrated that the material is slightly widened by the 4-roll flat groove rolling process, as shown in **Fig. 10**. However, changing the reduction rate can flexibly control the corner radius, as shown in **Fig. 11**. With regard to twist, it was found that the material does not easily twist in the flat groove during rolling, and the small amount of twist is effectively corrected by applying adequate pressure to the material before coiling at the end of the line by pinch rolls with proper groove shapes. The twist was thus suppressed to less than ±45° over the entire length.

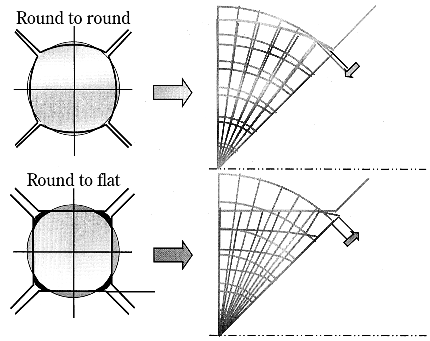


Fig. 10 Spread of 4-roll flat groove

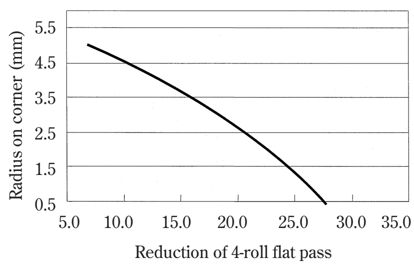


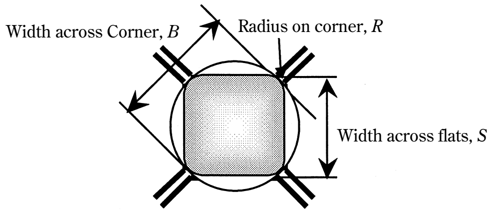
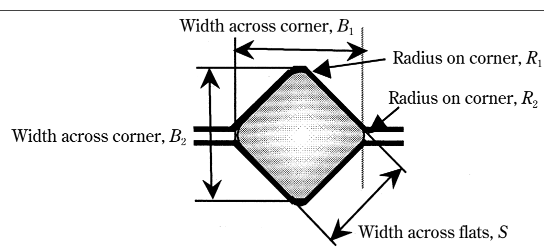
Fig. 11 Relation between reduction and radius on corner of 18 mm

4.2 Dimensional Accuracy of Square Bar Rolling

Table 2 compares the dimensional accuracy of the square cross section obtained by 2-roll square groove rolling against that by 4-roll flat groove rolling. The results show clearly the high dimensional accuracy of 4-roll rolling. The corner radius can be flexibly modified to meet customers' requirements.

The 4-roll rolling process can be used to make rectangular section products as well as square section products, as shown in **Fig. 12**. When rolling rectangular section products, the horizontal and vertical rolls rotate at different speeds. This is possible because the two sets

Table 2 Comparison of rolling results for square section bars

4-roll rolling		(S) ±0.1 mm (B) ±0.2 mm Angles of corner are precisely 90°. Corner roundness (R) is controllable.
2-roll rolling		(S) ±0.2 mm (B_1) ±0.2 mm (B_2) ±0.5 mm Corner roundnesses R_1 and R_2 are not equal. Angle of corner is not precisely 90°, because of roll wear.

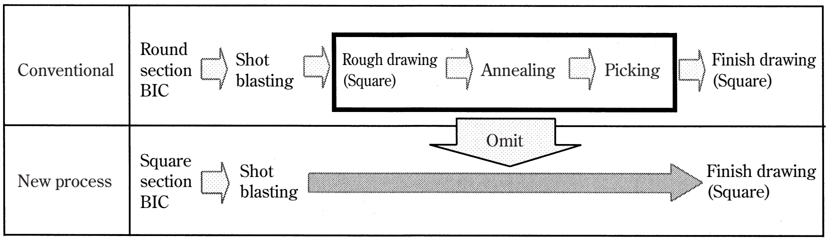


Fig. 13 Process comparison of square section cold finished bar

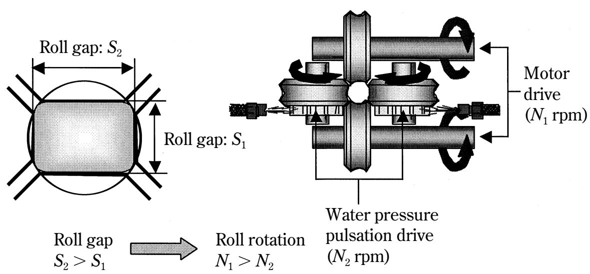


Fig. 12 Rolling method of rectangular section

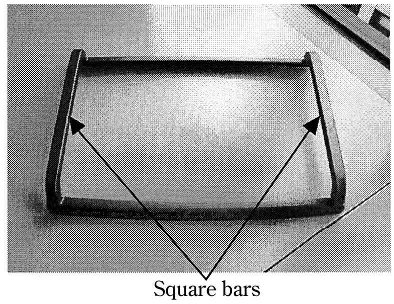


Photo 2 Application example: CRT frame

of rolls have separate drive systems. The vertical rolls of the 4-roll bar mill have a water pressure pulsation drive to simplify the system, while the horizontal rolls have a motor drive. The 4-roll mill can easily roll rectangular products because of these separate drive systems.

4.3 Applications of Square Bars

Figure 13 shows an example of process simplification by using square bars in customers' application. These hot-rolled square bars have such a high dimensional accuracy that the customer can form them into the final cross section by drawing them only once. This also eliminates the annealing process, markedly reducing the overall cost. **Photo 2** shows a CRT frame for a TV set. Although the frame is formed by drawing the material only once, its dimension, shape, strength, and twist are all ensured within the specifications. Thus, customers can use the newly developed square bars to eliminate significantly secondary processing.

5 Conclusions

Kawasaki Steel's Mizushima wire rod and bar plant introduced the 4-roll mill to bar production and then to wire rod production. By developing 4-roll rolling technology that permits size-free rolling with high dimensional accuracy, the company can now quickly respond to customer requirements, even in small-lot orders. The small diameter wire rods and square bars with high dimensional accuracy were developed to further expand strategic utilization of the 4-roll rollng technology. These products have made a significant contribution to eliminating or simplifying secondary processing at customers' sites. The company plans to advance this technology in line with customers' drive for higher-quality products and further elimination of processing.

References

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4) T. Ogawa, R. Takeda, M. Kawaberi, and T. Tange, *Kawasaki Steel Giho*, **32**(2000)1, 54