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Development of High-Speed Tool Steel Rolls and Their Application to Rolling Mills

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Abstract:

Steel rolling technology has progressed in recent years, improving product quality, enhancing productivity, and reducing production costs. This trend has increased the demand for rolling mill rolls of higher performance, longer life, and higher reliability. High-speed tool steel (HSS) rolls were developed to meet the demand. The HSS rolls were initially adopted in the finishing stands of hot strip mills resulting in improved quality of rolled steel products and substantially relaxed rolling operation constraints imposed by rolls. This success has expanded the application of the HSS rolls to other rolling areas. The development, application examples, and benefits of the HSS rolls are described.

1. Introduction

Improvements in steel rolling technology are primarily to achieve better product quality, higher productivity, and lower production cost. These three are ever-lasting targets. A sharp appreciation of the Japanese yen with respect to the U.S. dollar in recent years has raised these targets to particularly stringent levels. Drastic reductions in labor, fuel, and roll consumption were sought as a result. To roll steel products of higher quality while holding fewer rolls on hand to accommodate inventory cutbacks, there are growing needs for rolls with still higher performance and longer life than ever before.

High-speed tool steel (HSS) rolls were developed to meet this demand for higher-performance rolls. The use of HSS rolls, made by the continuous pouring process for cladding (CPC), rapidly spread as work rolls in the finishing stands of hot strip mills, and are now indispensable for strip rolling. This success expanded the usage of HSS rolls to hot strip mill roughing stands, structural mill universal rolling stands, and bar and wire rod mill intermediate stands. The HSS rolls are now manufactured by the CPC process, centrifugal casting (CF) process, or hot isostatic pressing (HIP) process to meet specific requirements.

This report describes the characteristics of HSS, which are drastically changing today's conventional steel rolling scene, and their service conditions in the three rolling sectors of hot strip mills, structural mills, and bar and wire rod mills.

2. HSS Roll Applied Mills and Production Processes

HSS rolls have a surface layer of HSS, as implied by their name. The range of chemical composition of HSS rolls is listed in

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Table 1. The alloy content is higher than that of conventional roll materials, with two or more types of carbides being dispersed. The HSS rolls are harder than roll materials of equivalent carbon content as shown in **Fig. 1** and are expected to provide higher resistance to wear and surface roughening.

The application examples of HSS rolls in the main steel rolling areas are shown in **Fig. 2**. Roll quality increasingly exerts an effect on product surface quality and dimensional accuracy in later stands of rolling mills. High resistance to wear and surface roughening are required of the rolls to be used in such later stands. The high resistance to wear and surface roughening of HSS rolls proves most effective in the intermediate and finishing stands of the various mills. Changes in the typical roll materials of steel rolling mills are shown in **Fig. 3**. Rolls in the early finishing stands of some hot strip mills are almost all made from HSS. Actually, HSS rolls are steadily gaining increased acceptance in intermediate and finishing stands, except for finishing stands of wire rod mills where tungsten carbide rolls of still higher hardness than HSS rolls are employed.

In this way, HSS rolls are extensively applied to the rolling of hot strip, structural shapes, bars and wire rods. They are manufactured by different processes to meet different mill requirements. Today, HSS rolls are made by the CPC process shown in **Fig. 4**, by the CF process shown in **Fig. 5**, and by the HIP process. The mainstream process is the CPC process, which has enabled HSS rolls to be used in large quantities in the finishing stands of hot strip mills.

HSS rolls made by different processes differ in quality properties. The process of making HSS rolls is selected to meet the requirements of specific mills where the HSS rolls are to be used. The sizes and quality of HSS rolls produced by the respective processes are shown in **Fig. 6**.

The HIP process that uses powders as starting materials has the broadest freedom as to the addition of alloying elements to maintain homogeneity. It is followed by the CPC process in which molten shell metal is poured over the core. The CF process is limited in chemical composition because segregation occurs as the molten metal solidifies during its flow, being subject to centrifugal force. HIPed HSS rolls, made from rapidly solidified powders, are

Table 1 Chemical composition ranges and metallurgical properties of HSS rolls

Chemical composition (wt%)							Microstructure			Hardness (Hsc)
C	Ni	Cr	Mo	V	W	Co	Graphite	Carbide	Matrix	
1.5		2	0	2	0	0	None	MC +	Tempered martensite	75
'	≦2	'	'	'	'	'				'
2.5		10	10	10	10	10		M_6C or M_7C_3		90

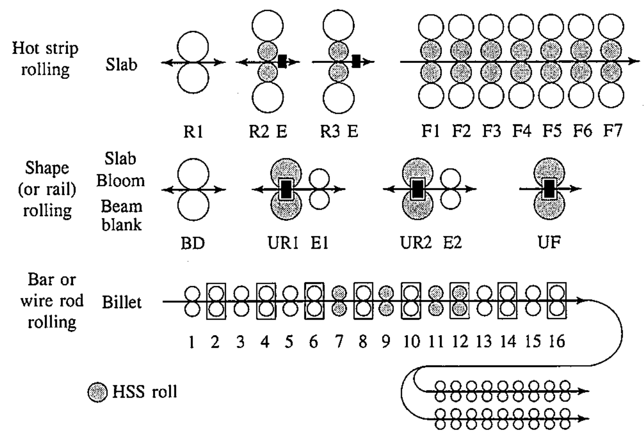

Fig. 2 Rolling mills and stands with HSS rolls

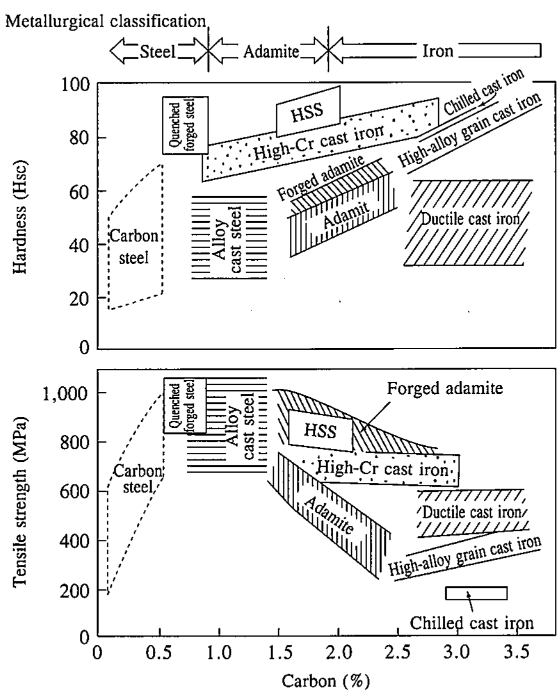

Fig. 1 Tensile strength and hardness of roll materials

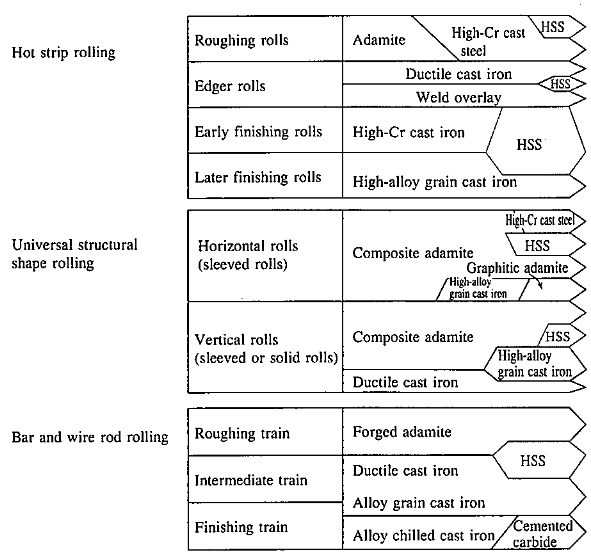

Fig. 3 Changes in roll materials

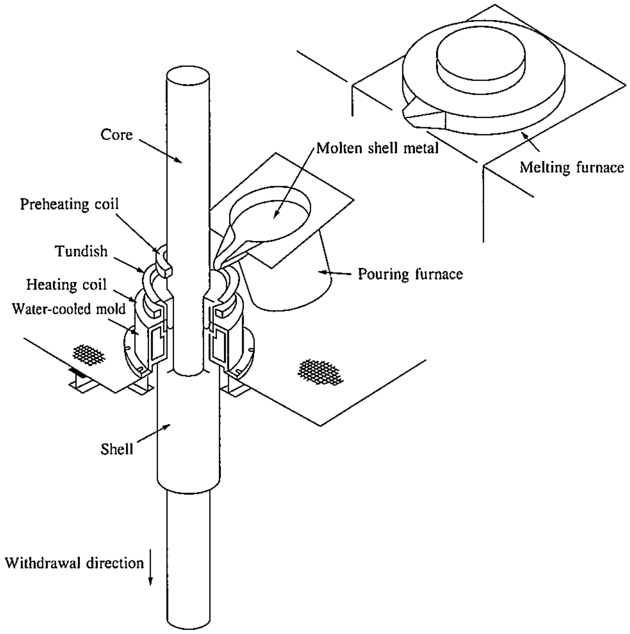

Fig. 4 Schematic of CPC process

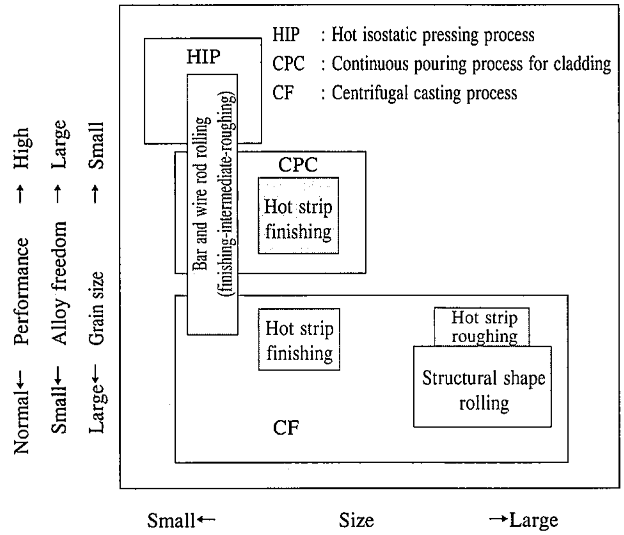

Fig. 6 HSS roll applications and manufacturing processes

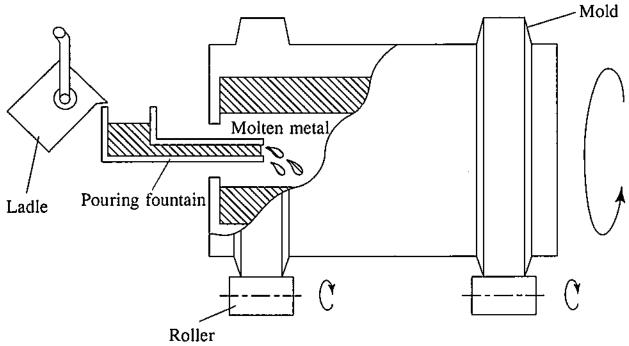

Fig. 5 Schematic of horizontal CF machine

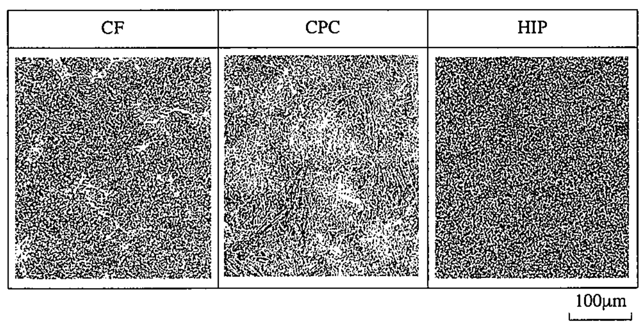

Photo 1 Microstructures of HSS rolls made by different processes

most dense, while the CF process, which has a low solidification rate, tends to provide coarse grain size. The microstructures of HSS rolls made by the CPC, CF, and HIP processes are compared in **Photo 1**. These HSS rolls differ in carbide morphology and grain size.

Concerning shape adaptability, HIPed rolls are limited to small diameters by the constraint of containers in which the roll is pressed at high temperature. The CF process can produce small-diameter to large-diameter rolls by the selection of appropriate molds. Consequently, the bar and wire rod mills that impose the most exacting surface quality requirements use HIPed HSS rolls in the later stands of the intermediate train and use CPC HSS rolls in the later stands of the roughing train and the early stands of the intermediate train. CF HSS rolls are beginning to see use as horizontal sleeved rolls of universal structural mills and as work rolls in the 4-High roughing stands of hot strip mills, both with relatively large barrel diameters.

The required properties and applications of HSS rolls that are finding increasing usage in the respective steel rolling areas are described below.

3. Application of HSS Rolls to Various Rolling Mills

3.1 Rolls for hot strip mills

The technological innovation of hot strip mills is remarkable. The appearance of highly functional mills, such as the six-high mill and pair cross mill, increased the rolling load, accelerated the trend toward schedule-free rolling, and increased the severity of roll quality requirements. CPC HSS rolls that combine a shell of excellent wear resistance with a core of high strength and toughness were developed to meet the demand. The aims and expected benefits of HSS rolls used for hot strip mill roughing stand work are shown in **Fig. 7**. HSS rolls then rapidly increased their share as work rolls in the finishing stands of the hot strip mills. Nippon Steel has substituted HSS rolls for nearly all work rolls in the early stands of its hot strip mills and uses HSS rolls in the later stands, except for the last, in most of its hot strip mills.

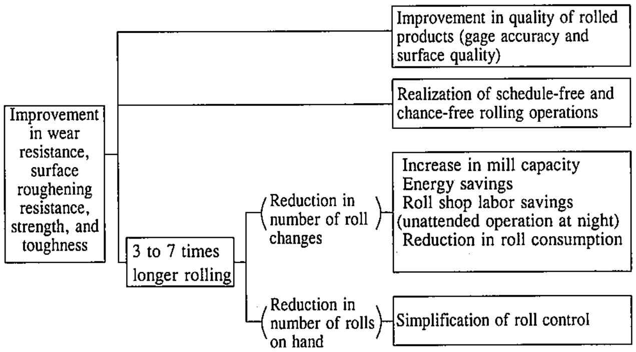

Fig. 7 Benefits expected from introduction of HSS steel rolls

This extensive adoption of HSS rolls as finishing rolls prompted their use as CF sleeve roll onto arbors in roughing and edger stands.

3.1.1 Finishing work rolls

The largest issue with work rolls in the early finishing stands of a hot strip mill is surface roughening resistance. In-service contact with hot strip forms an oxide film (black scale) on the surface of the work roll. When the scale grows excessively large, it partially peels, develops severe surface roughening, called banding, and causes rolled-in-scale defects in the strip product. In comparison with conventional high-Cr cast iron rolls, HSS rolls have thinner scale. When the thin scale peels, the resultant damage to the roll is minimized. To improve surface roughening resistance, it is ideal that a protective scale film be thinly formed to inhibit the rapid growth of oxide. HSS rolls that can retard the growth rate of scale after its formation are suited for use in the early finishing stands of hot strip mills. A chemical composition with a strong tendency to this is now being studied.

Work rolls in the later finishing stands encounter particularly severe wear and demand extremely high wear resistance. They must also be highly resistant to rolling troubles such as chew-up. For this reason, high-alloy grain cast iron, expected to offer the lubrication effect of graphite and to lower the crack propagation rate, was widely employed as material for the work rolls in the later finishing stands. Wear resistance is substantially improved when HSS rolls are applied in the early finishing stands. When the surfaces of an HSS roll and a high-alloy grain cast iron roll are examined with an on-line profile meter, the HSS roll is worn to a much smaller degree than the high-alloy grain cast iron roll, as shown in **Fig. 8**. HSS rolls are compared with high-alloy grain cast iron rolls and high-Cr cast iron rolls in terms of wear performance in **Fig. 9**. They perform at least five times longer than the conventional rolls. Another advantage of applying HSS rolls is the increase in the tonnage rolled per campaign. The change in the tonnage rolled per campaign before and after the introduction of HSS rolls is shown in **Fig. 10**. The tonnage rolled per campaign increased by 250% with the HSS rolls, which in turn reduced the roll grinding frequency and roll cost.

HSS rolls are now being improved to increase the ratio of their application to later finishing stands. When a roll encounters rolling trouble such as chew-up and cracks form, the amount of grinding performed to remove the cracks greatly increases the roll cost. The stability of strip being rolled with HSS rolls is improved, lowering the incidence of rolling troubles, and roll materials with increased

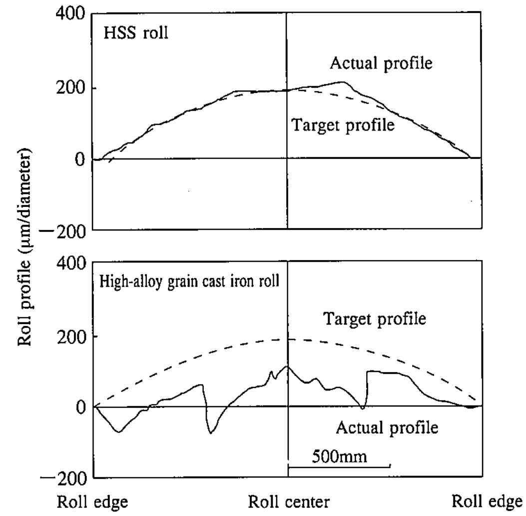

Fig. 8 Roll profile measured with on-line profile meter during rolling

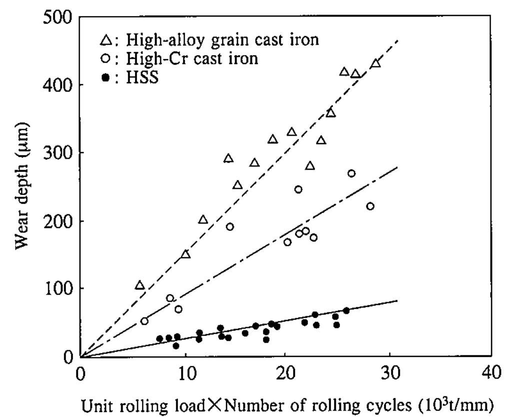

Fig. 9 Roll wear during finish rolling at hot strip mill

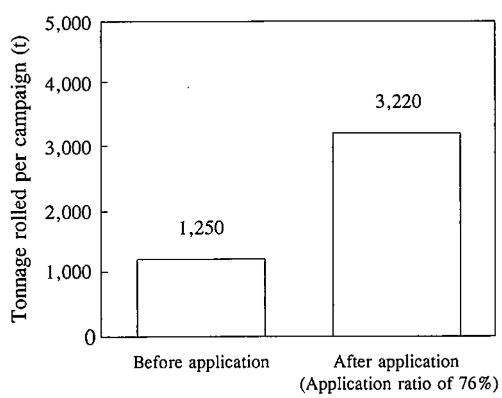

Fig. 10 Change in tonnage rolled per campaign with application of HSS rolls to finishing stands of hot strip mill

fracture toughness to resist rolling troubles are developed. Further research is under way in these areas.

3.1.2 work rolls

Strip is usually rough rolled by the combination of two-high and four-high stands. Some steel plants rough roll strip in a single four-high mill. In use as four-high stand work rolls, adamite rolls were replaced by high-Cr cast steel rolls to greatly improve wear resistance. The recent introduction of HSS rolls has significantly extended the tonnage rolled per campaign by finishing work rolls. This has enhanced the need for increasing the tonnage rolled per campaign by roughing work rolls as well and has accelerated the substitution of HSS rolls for high-Cr cast steel rolls.

To meet the needs noted above, HSS rolls of the sleeve type are made by the CF process and evaluated for their service performance. Multiple-element high-alloy white cast iron such as HSS generally has the problem of carbide segregation due to centrifugal separation. Finishing work rolls were made from HSS that has the carbide content reduced to increase firecrack resistance and features lower alloy content and hardness than that of conventional high-Cr cast steel and adamite. The service performance of the roughing work rolls is shown in **Fig. 11**. The HSS rolls performed 1.5 to 2 times longer than the high-Cr cast steel rolls and greatly increased the tonnage rolled per campaign as well. The increased hardness greatly contributes to improved performance of the HSS rolls. The HSS rolls are now being evaluated. Work is also under way to identify factors governing the performance of HSS rolls and to investigate the correlation of such factors with mechanical properties and microstructures.

3.1.3 Edger rolls

Edger rolls were traditionally ductile cast iron rolls or weld overlaid rolls. The addition to edger rolls of the steel sizing function has increased the calls for improving their wear resistance and sticking resistance. Since the changing of edger rolls is time-consuming, reducing the change frequency is highly effective in minimizing production shutdowns due to edger roll changes.

HSS rolls to meet the above needs were made by the method of centrifugally casting a sleeve onto an arbor, and they were evaluated for service performance. The results are shown in **Table 2**. The HSS rolls outperformed the conventional weld overlaid rolls by about 4 times and achieved 1.5 to 2 times greater tonnage rolled per campaign life. They are being evaluated for longer campaign life.

Table 2 Service performance of rolls in edger stands of hot strip mill

Stand	Evaluation item	Service performance		Performance improvement
		Conventional weld-overlaid rolls Hsc 60	HSS rolls Hsc 78	
E_2	t/campaign (t/mm)	150,000 (40,000)	300,000 (150,000)	2 times (4 times)
$E_{3,4}$	t/campaign (t/mm)	300,000 (36,000)	450,000 (160,000)	1.5 times (4 times)

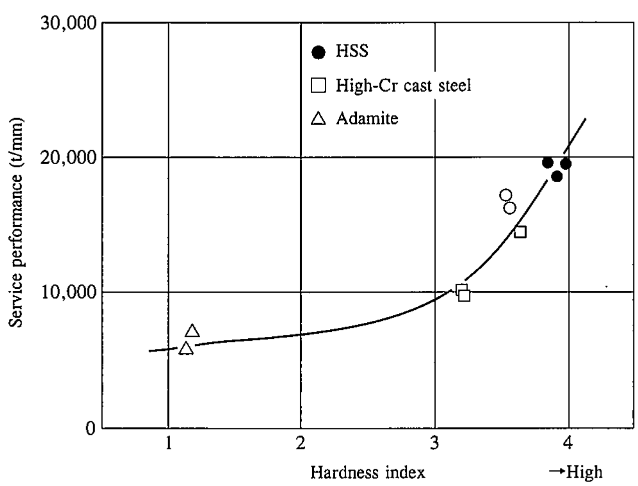

Fig. 11 Effect of hardness on service performance of rolls in roughing stands of hot strip mill

3.2 HSS rolls for structural mills

H shapes and rails are rolled by universal intermediate and finishing stands at structural mills. Universal rolling with the combination of horizontal and vertical rolls is superior to caliber rolling in the ease of adjustment, roll consumption, and product dimensional accuracy. Composite adamite rolls, chiefly made by the CF process, were traditionally used as universal rolling mill rolls. The revision of applicable Japanese Industrial Standards (JIS) in 1994 increased the need for shape rolling to close dimensional tolerances and prompted demand for rolls with high wear resistance.

3.2.1 Universal horizontal rolls

As already shown in **Fig. 3**, horizontal rolls are mainly sleeve type rolls comprising an adamite outer layer and a graphitic steel inner layer. Graphitic adamite with equivalent hardness is used for stands and products with a severe sticking tendency. Traditionally, however, horizontal sleeve type rolls had few needs for enhanced performance because under their conditions of use, they are reground down and reused with the progress of their sidewall wear. When such a horizontal roll was made from a higher-performance material, the increased regrinding cost was considered to offset the improved service performance and to reduce the life cycle advantage.

Recent years have seen the beginning of a movement toward rough rolling sleeves with a certain taper that are used at the same size without grinding them down. As a result, high-performance sleeves are beginning to find rapidly increasing acceptance for the purposes shown in **Fig. 12**. These sleeves must have an extremely deep hardened layer, and high-Cr steel as well as HSS is evaluated for use in this application.

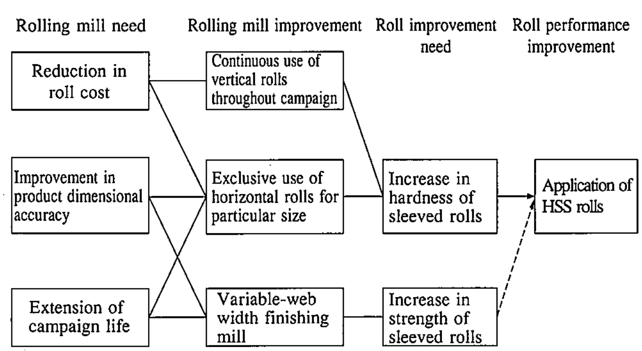

Fig. 12 Purposes of introducing HSS rolls at structural mill

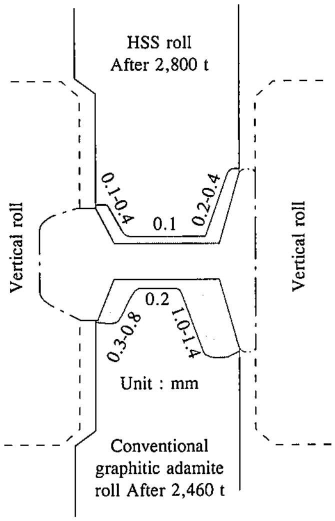

Fig. 13 Wear of rolls in roughing stand of rail mill (wear shown enlarged)

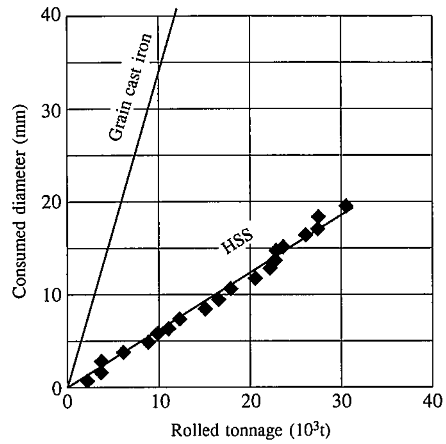

Fig. 14 Service performance of vertical rolls at rail mill

Fig. 13 shows an example of wear in CF composite sleeves used on horizontal rolls at an intermediate mill for rail rolling. When the side wall of the flange side (right side in the figure) where the horizontal sleeve is worn most severely is examined, the wear of HSS is one-third or less of that of conventional graphitic adamite. While graphitic adamite is close to the end of its campaign life, HSS is worn but reusable. HSS is expected to improve in quality and hence in wear resistance.

3.2.2 Universal vertical rolls

Vertical rolls for the universal rolling of structural shapes are sleeved rolls with built-in bearings for H shapes and small-diameter work rolls with backup rolls for rails. Vertical rolls for rolling H shapes are composite adamite rolls or ductile cast iron rolls. Rolls of this type have a small overall sleeve thickness, and hence shell thickness, and are easy to regrind, so that they should be ideal candidates for the application of high-performance materials. Vertical rolls are susceptible to damage by rolling troubles. As a result, they are not as advanced as horizontal rolls as far as the application of high-performance sleeves is concerned. When the semifinished product being rolled has a shape defect such as unequal web thickness, the vertical rolls are subject to a far higher rolling load than assumed and are likely to split at an inner layer. High rolling stability is a prerequisite for the application of vertical rolls.

Vertical work rolls for rolling rails are made from alloy grain cast iron. They are also subject to damage by rolling troubles, most of which are surface spalls arising from the accumulation of rolling fatigue stress. These conditions are improved by the application of HSS.

Fig. 14 shows the performance of CPC HSS rolls used in the intermediate stands of a rail mill. The CPC HSS rolls performed five times longer than the conventional alloy grain cast iron rolls. They exhibit satisfactory tonnage rolled per campaign and are expected to replace conventional rolls.

3.3 HSS rolls for bar and wire rod mills

Many of the problems with bar and wire rod mill rolls concern high-speed rolling for productivity improvement. Now that specialty steels have overtaken carbon steels in the percentage of rolled steel products, there are mounting needs for rolls with higher wear and surface roughening resistance to increase dimensional accuracy and tonnage rolled per campaign.

3.3.1 Intermediate train rolls

Bars are rolled from billets by grooved rolls in 16 to 20 two-high stands, and wire rods are rolled from billets by grooved rolls in 16 to 20 stands and then in a finishing train of cemented carbide rolls. The roll materials are as shown above in **Fig. 3**.

Forged adamite rolls with resistance to thermal shock, wear, and breakage are mainly used in the early roughing stands where the piece being rolled is fed at an extremely low speed. These rolls are improved to increase breakage resistance under excessive rolling load developed when specialty steel is rolled at low temperature. Roll materials and rollmaking conditions are improved to increase strength while maintaining wear resistance.

Forged adamite, high-hardness adamite, and high-hardness ductile cast iron rolls have been used in the later finishing train stands and intermediate train of bar and wire rod mills. Wear resistance is a chief concern with rolls of this type. HSS rolls are predicted to prove most effective in these stands. Since the rolling of bars and wire rods demands a more beautiful surface quality than that of hot strip, attention must be given not only to wear but also to groove surface roughness of the rolls used. HSS rolls to be introduced should be made by a process that can meet these quality requirements.

Following the study results mentioned above, HSS rolls are mainly used in the later roughing stands and intermediate stands of both bar and wire rod mills. **Fig. 15** shows the performance of CPC HSS rolls used in the No. 7 and No. 9 stands of a bar mill. The HSS rolls achieved wear resistance at least four times greater than the conventional ductile cast iron rolls. The CPC-made HSS rolls had far smaller surface roughness than the conventional rolls after they rolled 6 times greater tonnage of steel. Cooling water must be copiously applied to accomplish this level of performance. Since HSS rolls cannot expect lubrication by graphite, as is possible with ductile cast iron, they must be water cooled to eliminate the adverse effect of frictional heat generated by the difference in peripheral speed in the groove.

HIPed HSS rolls with higher surface roughening resistance than CPC-made HSS rolls are employed in the No. 11 and subse-

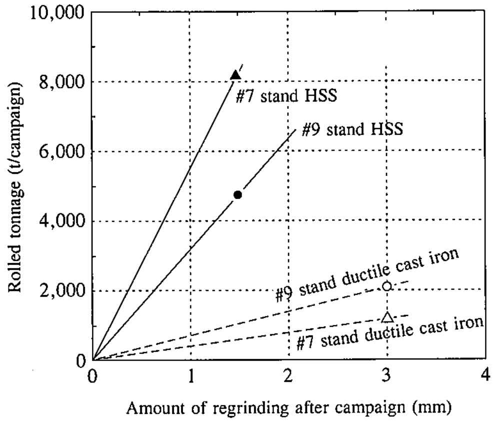

Fig. 15 Service performance of rolls in intermediate stands of bar mill

quent finishing stands of the bar mill. Since the HIPed HSS rolls are extremely fine grained, they call for greater attention to be given to firecracking. If properly cooled, they are expected to perform better than the CPC HSS rolls.

4. Future Development Strategy

As was noted in the previous chapter, HSS rolls are finding increasing favor as work rolls in the finishing stands of hot strip mills and as rolls at many other mills. For HSS rolls to perform with the highest possible results, they must be made by processes that meet specific quality requirements, and rolling conditions must be optimized. To this end, it is effective to evaluate the performance of HSS rolls and to improve utilities for the use of HSS rolls. It is particularly desirable that HSS roll users develop technology for the most effective use of HSS rolls.

When used in the finishing stands of a hot strip mill, for example, HSS rolls have extremely low wear and exhibit a marked thermal crown as shown in **Fig. 8**. HSS rolls had their profile estimated with high accuracy during rolling, had their initial crown compensated, and were water cooled where they contacted the strip being rolled, thereby stabilizing the rolling operation. As a result of these efforts, gage accuracy was improved by making good use of their extremely low wear, and the rolling of large tonnage was made possible. For grooved rolls, which are finding increasing usage in the rolling of structural shapes, bars, and wire rods as noted above, it is necessary to use specialized tools for regrinding and to acquire machining technology for high-hardness roll materials.

These challenges should be met by roll manufacturers and users in cooperation.

5. Conclusions

The recent trends of rolling mill rolls and the features and benefits of HSS rolls, mainly those developed by the Plant & Machinery Division, have been described above. The HSS rolls have demonstrated excellent resistance to wear and surface roughening at the mills where they are employed, and they have improved roll campaign life and reliability. As a result, the grade sophistication of rolled steel products and the enhancement of productivity have been accomplished. The successful performance of HSS rolls in the finishing stands of hot strip mills is expanding their applications. HSS rolls of optimum quality will be supplied in increasing quantities to meet a variety of rolling mill needs.

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