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Development and Application of High-Speed Tool Steel Rolls in Hot Strip Rolling

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Abstract:

The technical progress of steel rolling and the quality improvement of rolled steel products in recent years have imposed increasingly stringent quality requirements on steel rolling mill rolls. High-performance rolls, generally called high-speed tool steel rolls, were developed to meet these demands. The high-speed tool steel roll is manufactured as a compound roll, mainly by what is called the CPC process, and has a shell of high-speed tool steel. High-speed tool steel rolls are widely used on the finishing stands of hot strip mills, offering high wear resistance, surface roughening resistance, and toughness. They have greatly improved the quality of rolled products and significantly relaxed the rolling operation constraints on rolls. The techniques developed for the manufacture and use of the high-speed tool steel rolls and their performance evaluation and actual operation results are described.

1. Introduction

In recent years, steel rolling technology has advanced with the quality improvement of rolled steel products with closer dimensional tolerances, and throug the pursuit of economical operation of rolling mills. Especially since the mid-1970s, various rolling processes have been developed, including those related to enhancing rolling mill function. Improving the performance of rolls that come into direct contact with the steel to be rolled was also necessary. In 1987, a minimum-diameter work roll rolling mill, designated the ME mill[1], was developed to reduce the edge drop of hot-rolled strip. Prompted by this development, the authors started work on new work rolls, commonly called high-speed tool steel rolls. The high-speed tool steel rolls have achieved substantially better wear resistance than conventional work rolls. After the solution of a few technical problems resulting from their high performance, they have been put to practical use at hot strip mills. The high-speed tool steel rolls are now used on the finishing stands of many hot strip mills, not being limited to small-diameter work rolls. As a result, the quality of hot-rolled strip has been substantially improved, and the rolling operation constraints on work rolls have been greatly relaxed.

This article introduces the techniques developed for the manufacture and use of the high-speed tool steel rolls, and describes their service results.

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2. Basic Concept

2.1 Historical background

The progress of rolling technology in the hot strip mill field is shown in comparison with the changes in rolls in

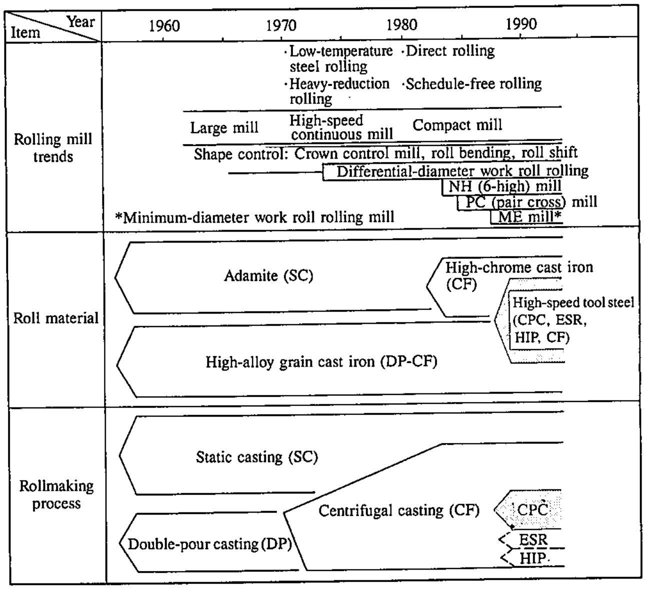

Fig 1 Changes in roll materials and rollmaking processes

Table 1 Rolling loads on typical rolling mills

Rolling process	Rolling load	Applied stress (MPa)	
		Past	Present
NH (6-high) mill	Barrel contact stress	1,000–2,000	2,000–2,500
Pair cross mill	Journal thrust	≦ 50	150–350
ME mill	Barrel horizontal bending stress	≦ 50	250

Fig. 1. **Table 1** lists the loads imposed on rolls used in the main rolling processes. At the six-high (6-hi) mill, the work roll came into contact with a small-diameter intermediate roll in place of a larger-diameter backup roll, and was subjected to high Hertzian contact stress in its body. At the pair cross (PC) mill, the work roll increased in the thrust stress of the journal. As the six-high mills were introduced at steel plants, compound work rolls with a shell of high-chrome cast iron and a core of tough ductile cast iron, made by the centrifugal casting process, were installed on early finishing stands.

At the above-mentioned ME mill, the size reduction of the work rolls and the positive utilization of horizontal bending resulted in the increases in roll bending stress, Hertzian contact stress, and number of rolling cycles. This called for the development of new rolls accompanying the adoption of new rollmaking processes. It was necessary to combine the high toughness of small-diameter rolls, to withstand horizontal bending, with the high wear resistance of tools, to withstand contact pressure and number of rolling cycles. These quality requirements coincided with the demand for low-wear and long-life rolls that would enable continuous rolling by the complete implementation of schedule-free rolling and the extension of rolling campaigns, two issues being pursued in the steel rolling field.

2.2 Quality design of new rolls

2.2.1 Mechanical strength

To ensure resistance to the horizontal bending of the ME mill, the development of the new work roll was based on the adoption of high-strength steel with a rotational bending fatigue strength of 250 MPa or more (equivalent to a tensile strength of 700 MPa or more), as the mechanical property to be met for the new work roll journal. The hardness of the roll body surface was set at Hs 80 or more to allow for the increase in the Hertzian contact stress and number of rolling cycles stemming from the decease in the diameter.

2.2.2 Metallurgical requirements

A hard and dense shell material was required that would be capable of withstanding the increase in the contact stress and number of rolling cycles resulting from decrease in the diameter and that would reduce wear by one-fifth or more to maintain good surface conditions. It was also necessary to provide high elevated-temperature strength for use in hot rolling. The following targets were thus established:

(1) Utilization of hard carbides
(2) Size reduction and dispersion of carbides
(3) Matrix structure to maintain hardness at elevated temperatures
(4) Fine solidification structure

First, MC and M_6C carbides shown in **Table 2** are formed as hard and fine carbides to be dispersed.

Precipitation-hardening alloying elements (such as chromium and molybdenum) and heat-resisting alloying elements (such as cobalt) are added to maintain high matrix hardness at elevated temperatures. Rapid solidification causes the solidification structure to become denser.

2.3 Manufacture of new rolls

New work rolls were made to evaluate their performance in actual rolling. The continuous pouring process for cladding (CPC process) with the following characteristics was adopted to achieve the quality targets described in 2.2:

(1) The shell can be easily made from a high-alloy steel.
(2) The solidification cooling rate can be changed over a wide range.
(3) The core can be made from a tough forged steel.

A compound roll with a high-speed tool steel shell and a forged steel core was made by the CPC process. The CPC process is schematically illustrated in **Fig. 2**. The molten metal is poured into the gap between the vertical solid core and the water-cooled mold. It gradually solidifies into a shell while being bonded to the core, and is intermittently drawn downward to make a compound roll. The solid core metal and the melt are heated by high-frequency induction to achieve full bonding between them.

Some high-speed tool steel rolls are also produced as monoblock forged rolls by the electroslag remelting (ESR) process and as compound rolls by the centrifugal casting (CF) process.

3. Characteristics and Performance of High-Speed Tool Steel Rolls

3.1 Quality of high-speed tool steel rolls[2)]

New work rolls with a high-speed tool steel shell and a forged steel core were produced as rolling mill rolls with satisfac-

Table 2 Physical properties of main carbides

Type of carbide	Hardness (Hv)	Morphology	Roll material
Fe_3C	840	Network	High-alloy grain cast iron
Cr_7C_3	2,100	Network	High-chrome cast iron
M(V)C	2,800	Granular	High-speed tool steel
M_6C	1,500–1,800	Rod-like/dense	High-speed tool steel

tory quality. **Photo 1** shows the macrostructure of a section through a new work roll, and **Table 3** gives the mechanical properties of the roll.

With values higher than that of conventional rolls, high-speed tool steel rolls with a Shore hardness of 80 to 85 are now used. The cylindrical contact yield stress that corresponds to the Hertzian contact stress is 3,200 MPa, and the rolling contact fatigue strength is 2,200 MPa.

A steel-base core of high toughness and Young's modulus provides the high-speed tool steel rolls with bending strength and flexural rigidity about 2 and 1.2 times higher than those of the conventional rolls, respectively. A similar improvement in flattening resistance is also achieved. The microstructure of the shell of the high-speed tool steel roll is shown in **Photo 2**, the chemical composition and metallurgical properties of the high-speed tool steel roll are listed in **Table 4**, and the physical properties of the high-speed tool steel roll are given in **Table 5**. The microstruc-

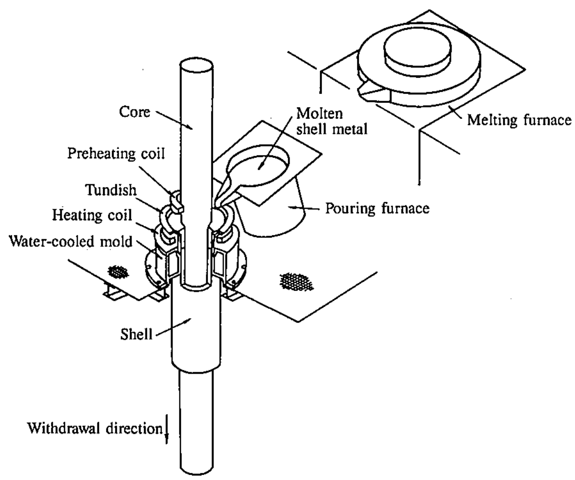

Fig. 2 Schematic of CPC process

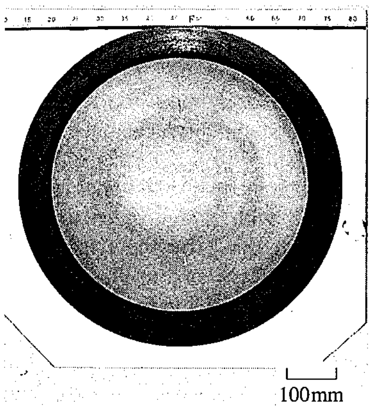

Photo 1 Section of high-speed tool steel roll

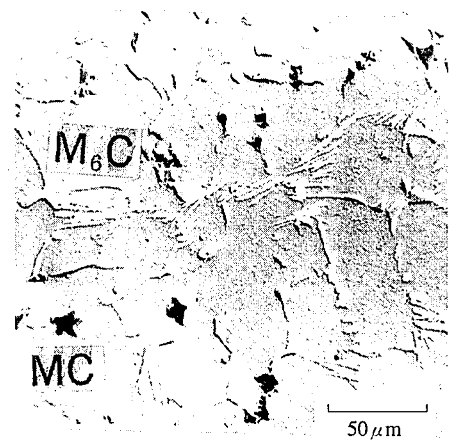

Photo 2 Microstructure of high-speed tool steel roll

Table 3 Mechanical properties of main types of work rolls

Division	Item	Unit	Roll material (shell)		
			High-speed tool steel	High-chrome cast iron	High-alloy grain cast iron
Shell	Hardness	Hsc	70-90	70-80	75-85
	Tensile strength	MPa	700-1,000	700-900	400-600
	Compressive strength	MPa	2,500-3,200	1,700-2,200	1,900-2,500
	Fracture toughness	MPa · $m^{0.5}$	25-28	21-34	18-35
Core	Tensile strength	MPa	700-1,000	400-500	300-500

Table 4 Chemical compositions and metallurgical properties of main-types of work rolls

Roll material	Chemical composition (wt %)	Microstructure (Top:Graphite, Middle:Carbide, Bottom:Matrix)	Hardness (Hsc)
High-speed tool steel	C :1.5-2.4 V:2-10 Ni : — W:2-10 Cr :2-10 Co:≦10 Mo:2-10	None MC+M_6C Tempered martensite	80-90
High-chrome cast iron	C :1.0-3.0 V:≦3 Ni :1-2 Cr :10-25 Mo:1-3	None M_7C_3 Tempered martensite	70-90
High-alloy grain cast iron	C :3.0-3.4 Ni : 4-5 Cr :≦2 Mo:≦1	≦5% Fe_3C Bainite	70-85

Table 5 Physical properties of main types of work rolls

Rollmaking process	Material (Shell / Core)	Thermal conductivity k(W/m·K)	Specific heat C(kJ/kg·K)	Specific weight γ (kg/m^3)	Linear expansion coefficient α (10^{-6}/K)	Young's modulus E(10^4MPa)	Poisson's ratio ν
CPC	Hight-speed tool steel	25.5	0.50	7,700	13.0	23.5	0.27
	Alloy forged steel	42.0	0.50	7,850	14.0	20.6	0.29
Centrifugal casting	Hight-chrome cast iron	20.0	0.59	7,600	13.0	22.0	0.30
	Ductile cast iron	27.0	0.59	7,200	12.0	20.5	0.30
	Hight-alloy grain cast iron	23.5	0.54	7,500	8.0	17.5	0.27
	Ductile cast iron	27.0	0.59	7,200	12.0	20.5	0.30

ture consists of fine proeutectic MC carbide mainly formed by vanadium, fine eutectic M_6C carbide mainly formed by iron, chromium, molybdenum and tungsten and distributed at grain boundaries, and a quenched and tempered martensite matrix. The amount of carbides is determined according to roll use conditions. It is increased for wear resistance and decreased for crack resistance. The elevated-temperature hardness of the high-speed tool steel rolls is shown in **Fig. 3**. The high-speed tool steel rolls can maintain hardness at high temperatures. This trend is accentuated by adding cobalt, an element that preferentially distributes in the matrix. In terms of physical properties, the high-speed tool steel rolls feature high thermal expansion in the shell compared with conventional work rolls, and have good thermal conductivity in the core.

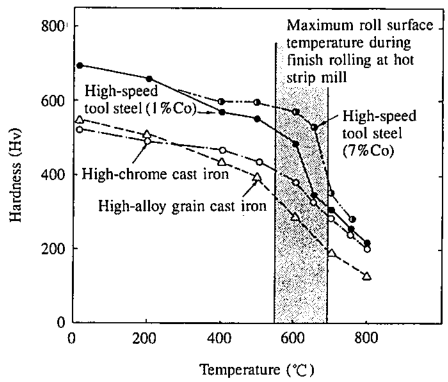

Fig. 3 Elevated-temperature hardness of main types of work roll materials

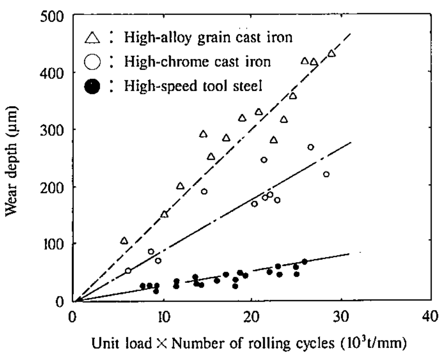

Fig. 4 Roll wear during finish rolling at hot strip mill

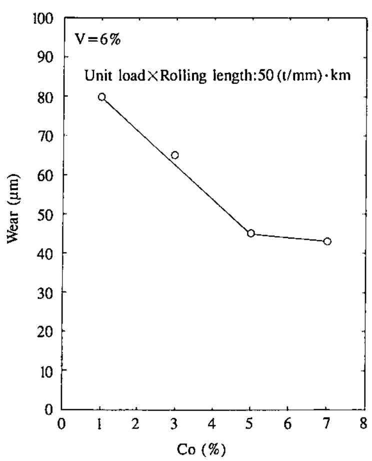

Fig. 5 Effect of cobalt addition on wear of high-speed tool steel rolls

3.2 Roll performance on an actual mill[3,4)]

The high-speed tool steel rolls were used on the finishing stands of a hot strip mill. They were found to perform better than conventional centrifugally cast high-alloy grain cast iron rolls, as evidenced by:

(1) At least 5 times higher wear resistance;
(2) At least 4 times higher surface roughening resistance; and
(3) At least 2 times higher toughness.

Fig. 4 shows the wear of rolls as determined by considering the rolling load per unit length in the axial direction and the number of rolling cycles. The wear of the high-speed tool steel rolls is far smaller than that of the conventional rolls. As shown in **Fig. 5**, the wear of the high-speed tool steel rolls decreases with increasing cobalt addition. The roll surface condition after rolling is another important property. As shown in **Photo 3**, the high-speed tool steel rolls exhibit a beautiful metallic luster and have minimal surface roughness. This tendency is particularly marked in the post finishing stands where abrasive wear is predominant. **Fig. 6** shows the effect of the grain size on the surface roughness of rolls after use in the post finishing stands of a hot strip mill. The surface roughness of the roll decreases with diminishing grain size.

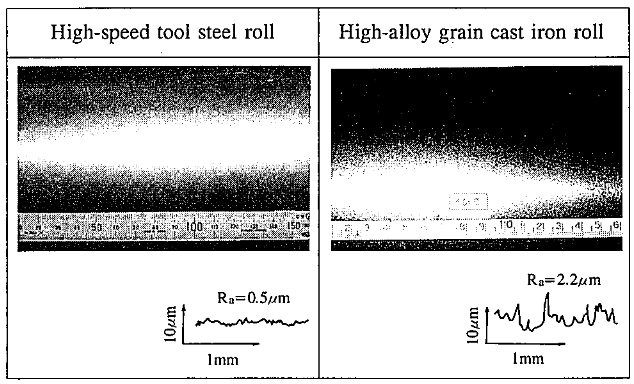

Photo 3 Surface texture of roll after use in finish rolling at hot strip mill

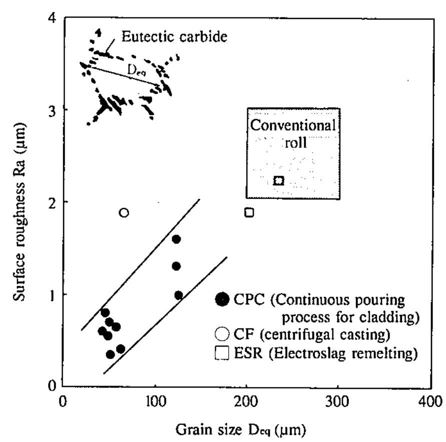

Fig. 6 Effect of grain size on surface roughness of roll after use in finish rolling at hot strip mill

Contact with a hot strip forms an oxide film (commonly called scale) on the roll surface, especially on the early stands of the hot strip mill. Peeling of the scale causes roughening of the banding-type surface of the roll and induces scale defects in the hot strip. The oxide film was also detected on the high-speed tool steel rolls in the post finishing stands of the hot strip mill, but was very thin. Peeling of the oxide film did not heavily damage the high-speed tool steel rolls, which performed relatively well. Efforts are now being expended to reduce the thickness of the oxide film that causes the surface roughening of hot strip mill work rolls. **Table 6** shows the composition and thickness of oxide film formed on the main types of hot strip mill work rolls.

The depth of cracks caused by rolling troubles is shown in **Table 7**. Cracks caused by "mill stoppage" were shallow, but cracks caused by "chew-up" on the post finishing stands of the hot strip mill were deep. The crack depth of the high-speed tool steel rolls has been improved to the level of the conventional rolls, but must be reduced further.

4. Problems During Usage and Solutions

4.1 Development of rolling techniques[5,6]

The excellent wear resistance of the high-speed tool steel rolls makes it all the more necessary to solve some problems associated with their use in the post finishing stands of the hot strip mill.

4.1.1 Rolling stability

When strip is hot rolled with the high-speed tool steel rolls under conventional operating conditions, it tends to thin at the center. This central thinning increases the meandering of the strip and in the worst case intensifies chew-up. When the high-speed tool steel rolls were initially used, their large thermal expansion was blamed as the cause for chew-up. The profiles of the high-speed tool steel roll and the conventional high-alloy grain cast iron roll during rolling are shown in **Fig. 7**. The thermal expansion of the high-speed tool steel roll and the wear of the conventional roll are readily known. The change in gagemeter error with the progress of rolling is shown for large rolling tonnage in **Fig. 8** and for normal rolling tonnage in **Fig. 9**.

The conventional roll thermally expands and changes from the initial crown to a plus side as its temperature rises with the progress of rolling. With further rolling, the conventional roll increases in wear, changes to a minus crown, and reaches the critical crown at which it must be replaced. The high-speed tool steel roll wears to such a small degree that its crown converges to a constant value as it thermally expands.

Large thermal expansion was formerly cited as the cause of unstable rolling of strip with the high-speed tool steel rolls. It is more reasonable to think that their thermal crown conspicuously appears because their wear is small. The authors separated the unstable strip rolling phenomenon with the high-speed tool steel rolls into wear and thermal crown, and modeled these two parts,as shown in **Fig 10**. Accordingly, they estimated the roll profile during rolling with high accuracy, as shown in **Fig. 9**, and succeeded in stabilizing the hot rolling of strip with the high-speed tool steel rolls.

It is clear that the high-speed tool steel rolls should be initially provided with a minus crown. The initial crown changes made

Table 6 Composition and thickness of oxide film formed on rolls in early finishing stands of hot strip mill

Roll material	Composition	Thickness
High-speed tool steel	$Fe_2O_3+Fe_3O_4$	5-15μm
High-chrome cast iron	Fe_2O_3	10-30 μm
High-alloy grain cast iron	$Fe_2O_3+Fe_3O_4$	—

Table 7 Depth of cracks caused in surface of rolls due to rolling trouble in finishing stands at Hirohata hot strip mill

Roll material	Type of trouble	
	Mill stoppage in early stand	Chew-up in post stand
High-speed tool steel	0.41mm	0.28mm
High-chrome cast iron	1.66mm	—
High-alloy grain cast iron	—	0.22mm

Note: Average crack depth at time of grinding

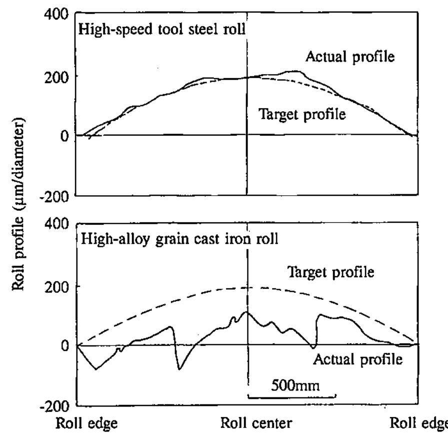

Fig. 7 Roll profile measured with on-line profilemeter during rolling

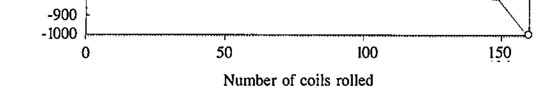

Fig. 8 Change in gagemeter error in rolling schedule (for high rolling tonnage)

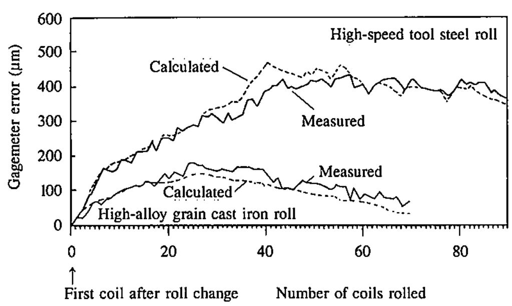

Fig. 9 Change in gate meter error in rolling schedule (for low rolling tonnage)

with the high-speed tool steel rolls are given in **Table 8**. The initial crown is generally about −200 to −50 μm.

The thermal crown should be as small as possible. This called for the work rolls to be rapidly cooled at the center. The change in the work roll cooling water flow rate is shown in **Fig. 11**, and the resultant change in the roll surface temperature is shown in **Fig. 12**. As a result, the incidence of strip tail chew-up with the high-speed tool steel rolls was held to the level prevailing before their introduction, as shown in **Fig. 13**. The work rolls thermally expand by about 100 μm as they roll a single coil. The elimination of this thermal expansion by roll benders translates into better strip rolling controllability. The axial roll profile mismatch between the strip-contact portion and non-strip-contact portion due to the difference in thermal expansion can be optimized by the roll shift mechanism.

As far as the work rolls are concerned, their initial crown, thermal crown, and wear are three important factors in hot strip rolling. Wear has been traditionally a serious constraint, but the problem of wear has been practically solved by the use of the high-speed tool steel rolls. Although not substantial problem, the initial crown compensates for the differences of thermal expansion between the high-speed tool steel rolls and the conventional work rolls. It is thus desirable to stabilize the rolling operation with the high-speed tool steel rolls by mainly considering their thermal crown control.

4.1.2 Setup accuracy

With some work rolls of this type, the friction coefficient increases in the roll bite to increase the rolling load by about 10%. The difference between the predicted and measured rolling loads is taken as deformation resistance error, and is reflected in the setup of the mill for the next coil to be rolled. This conventional method reduces gage accuracy, however, because the difference in the friction coefficient is actually responsible.

To solve this problem, the friction coefficient was separately set for each work roll, including the high-speed tool steel rolls, to maintain and improve gage accuracy. The results achieved are shown in **Fig. 14**, and the friction coefficients used are given

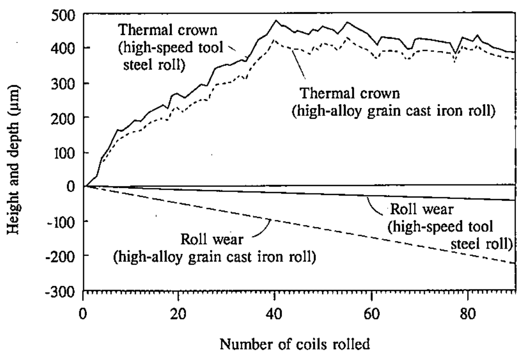

Fig. 10 Changes in roll wear and thermal crown

Table 8 Initial crown changes with introduction of high-speed tool steel

Stand No.	Before introduction		After introduction	
	Work rolls	Backup rolls	Work rolls	Backup rolls
F_1-F_3	0 (flat)	0 (flat)	−50	0 (flat)
F_4	0 (flat)	0 (flat)	−200	0 (flat)
F_5-F_6	0 (flat)	0 (flat)	−200	−100

Note 1: Unit: μm/diameter
Note 2: Work rolls used before introduction of high-speed tool steel work rolls
F1 to F3: High-chrome cast iron rolls
F4 to F6: High-alloy grain cast iron rolls

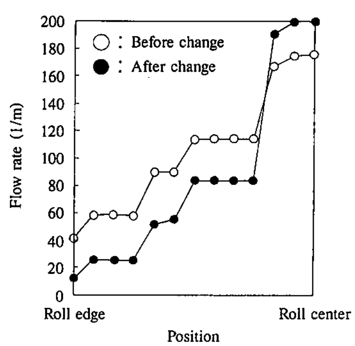

Fig. 11 Work roll cooling water flow rate

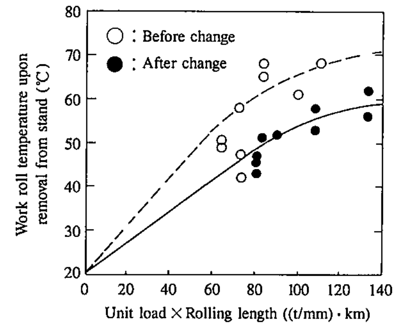

Fig. 12 Effect of cooling water flow rate on work roll extraction temperature

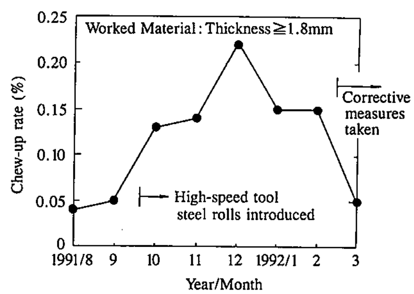

Fig. 13 Change in tail chew-up rate of rolled coils

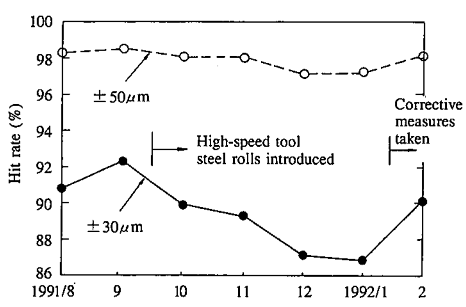

Fig. 14 Change in head gage accuracy of rolled coils

in **Table 9**. The increase in the friction coefficient was attributed to the preferential wear of the matrix structure and the spalling of very hard granular MC carbides (called the spike phenomenon). The spike phenomenon was solved by the addition of cobalt to achieve an improvement in matrix structure performanc, coupled with an improvement in wear resistance. The values of the resultant rolling load are shown in **Fig. 15**. The rolling loads with the high-speed tool steel rolls are lower compared with those with the conventional work rolls.

Fig. 16 shows the change in the friction coefficient between the work roll and strip with increasing rolling time in the early finishing stands of the hot strip mill. The friction coefficient between the work roll and strip decreases with time for the high-chrome cast iron rolls, but changes little with time for the high-speed tool steel rolls. The resultant absence of slip helped to improve setup accuracy throughout the rolling schedule.

Table 9 Values of coefficient of friction used for setup of main types of work rolls

Roll material \ Stand No.		F_1-F_5	F_6
High-speed tool steel	Co≦3%	0.35	0.25
	Co≦5%	0.25	0.25
High-chrome cast iron		0.25	0.25
High-alloy grain cast iron		0.25	0.25

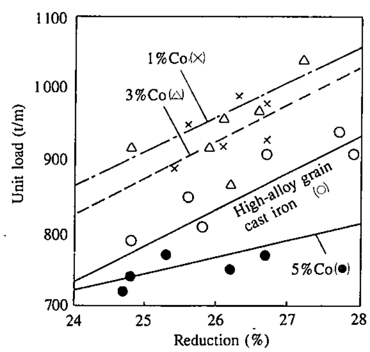

Fig. 15 Relationship between reduction and unit load of high-speed tool steel rolls with different cobalt contents

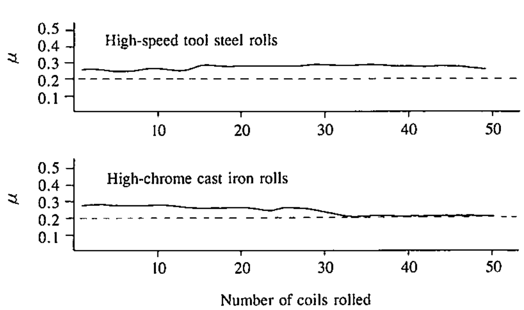

Fig. 16 Change in friction coefficient between roll and strip in rolling schedule

4.2 Development of related techniques

4.2.1 Roll flaw inspection

Any flaws in the work rolls caused by rolling troubles must be completely removed. If the work rolls are used with flaw, a serious accident such as spalling may occur. The work rolls is must be inspected for flaws with greater care than in the past. Eddy current testing is most popular for rolls, but is easaily affected by material properties such as magnetism and is unreliable with high-speed tool steel rolls with a mixture of metallurgical structures of different physical properties. To overcome these problems, a new ultrasonic testing method relatively free from the effects of material properties was developed.

The new ultrasonic testing method combines the flaw inspection of the outermost surface by the surface wave technique with that of the subsurface by the longitudinal wave angle-beam technique (also called the creeping wave technique). It can locate 0.2-mm surface flaws and 0.5-mm subsurface flaws, and can automatically inspect for flaws in many directions[7].

4.2.2 Grinding

Rolls generally decrease in grinding efficiency with increasing wear resistance.

It should be noted that high-speed tool steel rolls are likely to be scratched by the loading of a grinding wheel with fine hard carbides contained in the high-speed tool steel. The grinding wheel for the work rolls of the post finishing stand should preferably be composed of hard and friable abrasive grains and a regenerating, tightly holding bond. At present, fine ceramic alumina (FCA) abrasive grains are recommended. Except for the work rolls of the post finishing stand, #36 green carborundum (GC) abrasive is basically acceptable for the high-speed tool steel work rolls. In this case, the maximum allowable depth of scratches is 10 μm. The net grinding time is increased by 20 to 50% for each type of work roll as shown in **Table 10**, but the total grinding time is sharply reduced by the improvement in roll performance and the resultant reduction in the number of grindings to be made per campaign.

5. Achieved Results

The high-speed tool steel work rolls have demonstrated their high performance. The principal benefits of the high-speed tool steel rolls are summarized in **Fig. 17**. They are specifically described below.

Table 10 Grinding time required for main types of work rolls

Roll material	High-speed tool steel rolls	High-alloy grain cast iron rolls
Grinding wheel	GC #36 (Post stand: FCA #36)	GC #36
Grinding time	30 min	20 min

Note:Roll barrel dimensions:660mm diameter×1,840mm length

5.1 Improvement in product quality

The gage accuracy has been improved by a dramatic reduction in gagemeter error resulting from less wear of the work rolls as noted above. **Fig. 18** compares the gage hit rate of the high-speed tool steel rolls and conventional work rolls. When the high-speed tool steel rolls are used in the early finishing stands, their banding due to the peeling of the surface oxide film is improved as shown in **Fig. 19**. The incidence of rolled-in scale defects due to the surface roughening of the work rolls is reduced by 80 %.

The high-speed tool steel rolls are also improved in contact pressure resistance to such a degree that they can easily roll steels considered difficult to roll in the past, including stainless steel.

5.2 Improvement in rolling operation

The reduction in wear and the facilitation of rolling of traditionally difficult-to-roll steels by the improvement in contact pressure resistance have enabled the full implementation of schedule-free and chance-free rolling operations.

Since the high-speed tool steel rolls were introduced, the tonnage rolled with them per campaign (schedule) has been increased while checking the quality of rolled strip, tinplate and re-rolled steel products, which have the most stringent profile and surface quality requirements. The tonnage rolled per campaign (schedule) has more than doubled as shown in **Fig. 20**. The tonnage rolled between grindings totaled 15,210 and 6,618 tons in the early and post finishing stands, respectively, on a test basis, and the cumulative tonnage rolled between grindings has increased approximately three fold . **Fig. 21** illustrates a model for expanding the rolling schedule. The high-speed tool steel rolls can increase the rolling campaign without need for changing rolls due to wear or surface roughening, and can relax the schedule constraints by strip width and dissimilar steel grade mixes.

The resultant decrease in the number of roll changes has combined with the reduction in the required amount of roll grinding to improve the roll change time ratio, furnace reheating fuel consumption, electric power consumption, and roll consumption as shown in **Figs. 22**, **23**, **24**, and **25**, respectively.

Further improvement in rolling operation efficiency, reduction in energy consumption, and reduction in grinding work are expected from useing the high-speed tool steel rolls.

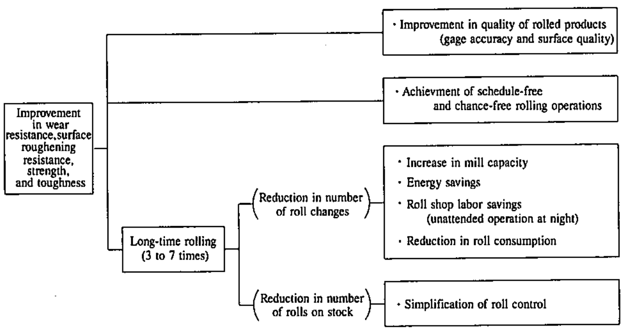

Fig. 17 Benefits expected from introduction of high-speed tool steel rolls

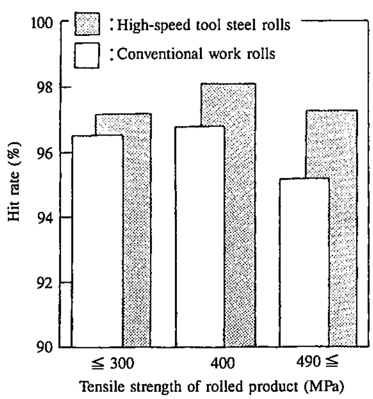

Fig. 18 Gage hit rate (±30 μm full width)

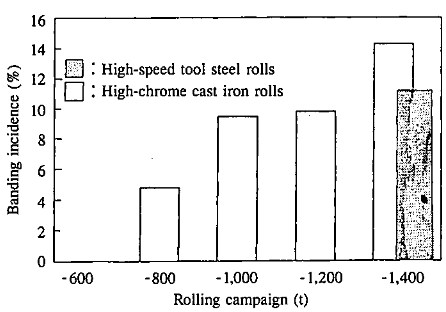

Fig. 19 Banding of work rolls in early finishing stands of hot strip mill

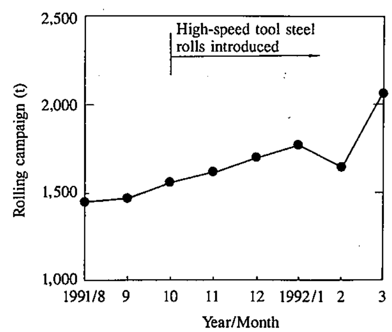

Fig. 20 Change in rolling campaign

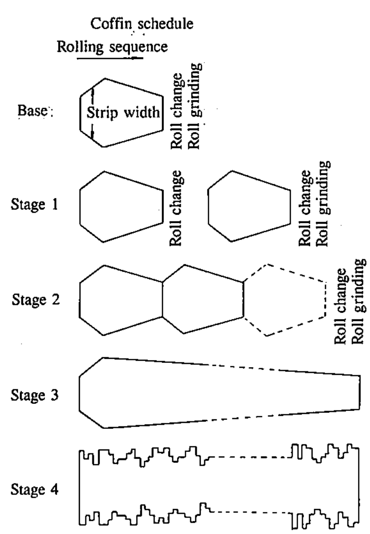

Fig. 21 Model for extending rolling campaign

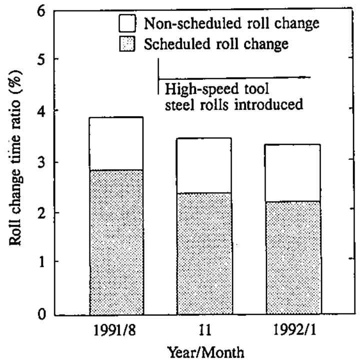

Fig. 22 Change in roll change time ratio

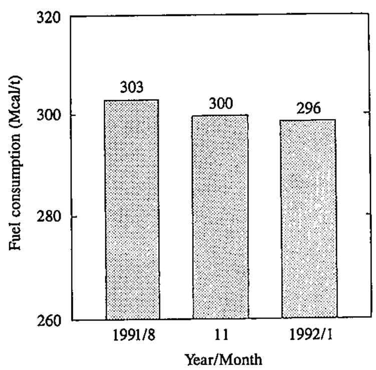

Fig. 23 Fuel consumption

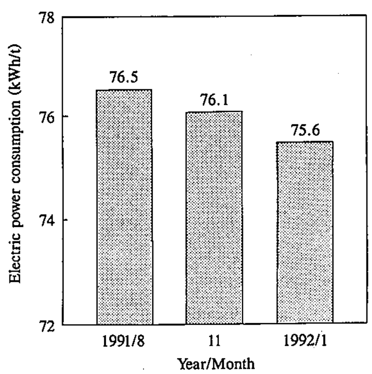

Fig. 24 Electric power consumption

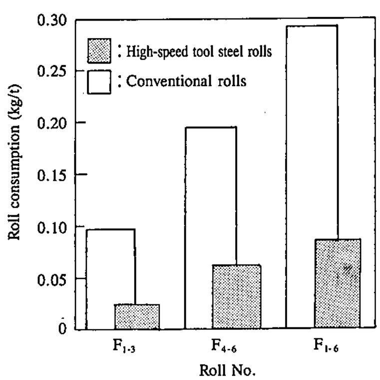

Fig. 25 Roll consumption

6. Conclusions

The basic ideas and results of high-speed tool steel roll development have been reported in consideration of the recent rolling mill roll trends. The high-speed tool steel rolls have dramatically improved wear resistance, surface roughening resistance, strength, and toughness by adding a high-alloy shell of fine-grained structure and a strong and tough core. They have greatly relaxed the hot strip rolling constraints imposed by rolls and have helped produce rolled steel products of greater sophistication and boosted production efficiency.

References

1) Kurahashi, R. et al.: J. Jpn. Soc. Technol. Plast. 32 (369), 1236 (1991)
2) Hashimoto, M. et al.: Seitetsu Kenkyu. (338), 62 (1990)
3) Hashimoto, M. et al.: CAMP-ISIJ. 4, 450 (1991)
4) Hashimoto, M. et al.: ISIJ Int. 32 (11), 1202 (1992)
5) Kurahashi, R. et al.: Technical Exchange Session. Madrid, 1992, IISI
6) Hashimoto, M. et al.: 36th Mechanical Working and Steel Processing Conference Proceedings, Baltimore, 1994, ISS
7) Hashimoto, M. et al.: CAMP-ISIJ. 5, 514 (1992)