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Rolling Technology and Modernization of Chiba Works

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Kenji Ichino, Yoshihiro Kataoka, Tomoya Koseki

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1 Introduction

In order to adapt to the severe hot rolling conditions of a strip mill, a rolling with much higher resistance to wear and surface roughening has been desired. In view of such circumstances, a compound roll with the outer layer made of high alloyed steel corresponding to the high speed tool steel, which is called HSS roll, was developed approximately ten years ago. In the case of high alloyed steel, however, the centrifugal casting process, which is commonly used for its high productivity and cost advantage in Japan, has not been applied to the production of the HSS roll, because carbides which are responsible for improving wear resistance segregate in the inner surface layer of the roll shell during centrifugal casting. Consequently, an HSS roll has been produced only by a special process called CPC process in Japan[1,2]. CPC means a continuous pouring process for cladding. Unfortunately, this process has lower productivity and higher production cost than the centrifugal casting process. Furthermore, it has become clear that the HSS roll increases the rolling load during hot rolling. This increase in rolling load causes various problems in mill operation and product quality, including mill chattering, lowering of rolling reduction and scale defects on the steel strip surface.

To develop a higher wear-resistant roll in the centrifugal casting process, metallurgical studies were systematically carried out on the relations among alloying elements, casting conditions, microstructures and wear conditions, using high-alloyed steels, such as high-speed tool steel. This paper describes the manufacturing concept of the developed roll and its characteristics. The main techniques exist in the prevention of carbide segregation caused by centrifugal force and the suppression of an increase in rolling load during hot rolling. The roll performance at hot strip mills is also reported.

2 Experimental Procedure

Table 1 lists the chemical composition of the materi-

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Table 1 Chemical compositions (mass%)

C	Cr	Mo	V	Nb	W	Ni	Co
1.0 ~3.7	3.6 ~20.0	2.0 ~15.0	3.1 ~8.6	0 ~2.5	0 ~11.1	0 ~3.0	0 ~6.0

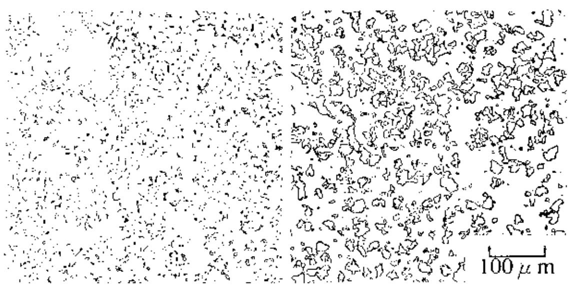
als used for investigating the effect of alloy element on the wear resistance of rolls. These materials were made by the atmospheric melting process and subjected to the same type of heat treatment used in industrial applications. Following the observation and analysis of the microstructure, the properties of the materials were evaluated by the hot wear test and the measurement of frictional coefficient at an elevated temperature. The hot wear test was performed using the slip wear type wear type test[3] whose apparatus consists of two discs (ϕ190 mm × 15 mm counterpart piece and ϕ50 mm × 10 mm test piece), in which the counterpart piece was heated at 1 073 K and contacted with the test piece with a load of 980 N. The test piece was rotated at a speed of 800 r.p.m. with a slip rate of 3.9% or 14.2%.

Molten iron having the optimum chemical composition determined by the above investigation was cast by centrifugal casting (140 G) to make 100 mm thick sleeve samples.

3 Manufacturing Concept and Experimental Results

3.1 Segregation Mechanism of Carbides and Preventive Measures

Segregation of carbides in the outer layer of a centrifugally cast roll of 2.5 mass%C - 6 mass%Cr - 5 mass%Mo - 5 mass%W - 6 mass%V type alloyed steel was observed. **Photo 1**, for example, indicates that the inner surface was mainly occupied by V type granular carbides. As suggested by R. Kesri's work[4,5], it was confirmed that the carbide of VC crystallized as a primary crystal or an eutectic of γ plus VC in the molten steel at the early stage of solidification.



Our surface side   Inner surface side

Photo 1 Typical example of segregation of carbide in a conventional centrifugal cast ring of 2.5 mass%C - 6 mass%Cr - 5 mass%Mo - 5 mass%W - 6mass% V type alloyed steel

Consideration of such a solidification process indicates that in the case of the centrifugal cast roll, the carbides of VC with a small specific gravity segregate in the inner surface side of the equiaxed grain region owing to the centrifugal force, as shown in **Fig. 1**. This phenomenon can be explained in terms of the difference in specific gravity between the primary crystal and the residual molten steel. To prevent this carbide segregation, therefore, it is necessary to decrease the difference in specific gravity between them.

The above-mentioned mechanism proves that both the decrease in specific gravity of the residual molten steel and the increase in that of the primary MC type carbides are effective in suppressing the segregation of carbides. Consequently, referring to the gravity of carbides and alloying elements shown in **Table 2**[6,7], this work tried decreasing W content and adding a suitable amount of Nb.

The effects of the alloying elements, mainly Nb and W, on the morphology and composition of a primary crystal of MC type carbides were investigated. **Figure 2** indicates the EDX spectra of such a primary crystal. It became obvious that the addition of an appropriate amount of Nb made the compound carbides of (V, Nb) C as shown in Fig. 2 (b), while the addition of W did not form the compound carbides, as shown in Fig. 2 (a). The EDX analysis proved that the addition of Nb, which increases the specific gravity of the primary MC type carbides, helped to suppress the segregation of carbides while W had a bad effect on that because of an increase in the specific gravity of the residual molten steel.

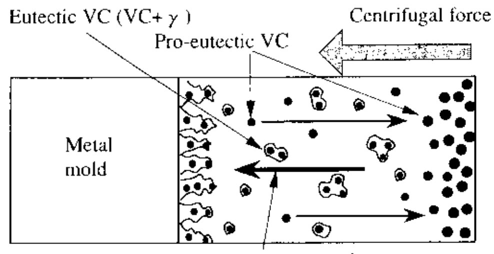


Fig. 1 Segregation mechanism of V carbide in inner layer of a high C - high V steel roll during centrifugal casting

Table 2 Density of carbides and elements

Carbide	W_2C	WC	Mo_2C	NbC	VC	Fe_3C
Density	17.2	15.8	9.1	7.9	5.7	7.2
Element	W	Mo	Nb	Fe	Cr	V
Density	19.3	10.2	8.6	7.9	7.2	6.1

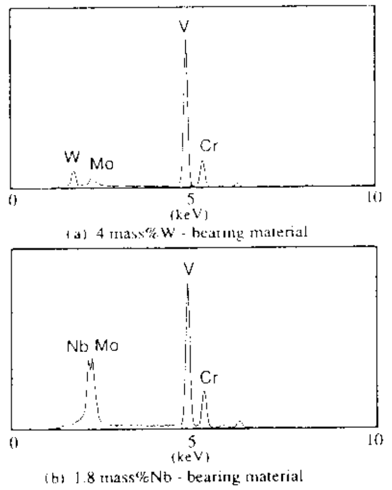


Fig. 2 EDX spectra of pro-eutectic MC type carbide (basic composition: 2 mass%C - 7 mass %Cr - 2.5 mass% Mo - 6 mass%V)

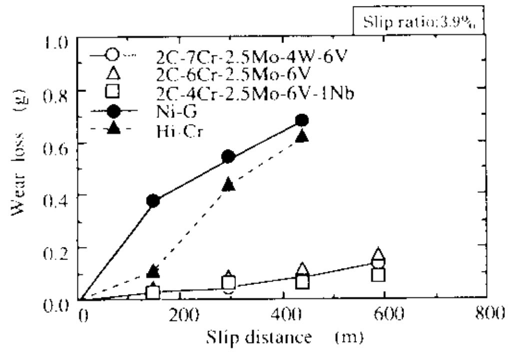


Fig. 3 Wear resistance of high C - high V type alloyed steels

3.2 Metallurgical Factors Determining Wear Resistance

The effects of alloying elements on hot wear resistance were systematically investigated in terms of carbide, matrix-constituent and microstructure[8-11]. In the manufacturing process of the authors, it was found that the wear resistance of the roll for hot rolling was significantly improved by the MC type fine granular V carbides which dispersed uniformly in the matrix, while the other metallurgical factors had little effect. As shown in **Fig. 3**, the high C - high V type alloyed rolls had wear resistance of more than 5 times as high as conventional roll. Though W has an important role in high-speed tool steel, it has been shown that W has only a small effect on wear resistance when applied to a large roll for hot rolling. This is because most W remains in the eutectic carbides crystallized between dendrites. Therefore, W apparently makes almost no contribution to the wear resistance of the roll produced by the process of the authors.

Photo 2 SEM images of wear surface of HSS type alloyed steel after hot wear test disk

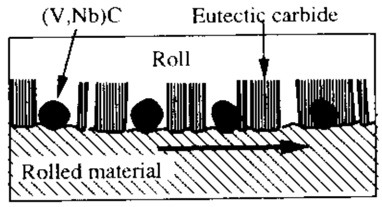


Fig. 4 Illustration of roll surface with low frictional resistance

3.3 Improvement of Wear Characteristics[12]

The main reason for the increase in rolling load is considered to be the high frictional force between the HSS roll and the strip. As shown in **Photo 2**, the HSS roll surface became rough due to the projection of MC type carbides and the dent of matrix during hot rolling. The microscopic roughness of the roll surface increased frictional force, causing scale defects on the strip surface. This proves that smoothing the roll surface is effective in reducing the rolling load.

In order to make the roll surface smooth during hot rolling, eutectic carbides in the matrix shown in **Fig. 4** were increased. Eutectic carbides have the second highest hardness in the structure of the roll material in which the primary MC type carbides have the highest hardness.

The effects of C, Cr and Mo on the volume fraction of carbide are shown in **Fig. 5**. The volume fraction of carbide increases with the increase in C, Cr and Mo content. Consequently, it became clear that the volume fraction of carbide can be controlled by the content of Cr and Mo as well as C.

Figure 6 shows the relation between the volume fraction of carbide and wear loss. Though the increase in the content of C and Cr increases the volume fraction of carbide, wear loss becomes greater. It became obvious, however, that the addition of suitable amounts of Cr and Mo was effective in improving the wear resistance of the material.

Photo 3 shows the microstructure of the worn surface observed by SEM. It was proved that the addition of suitable amounts of Cr and Mo improve the toughness of

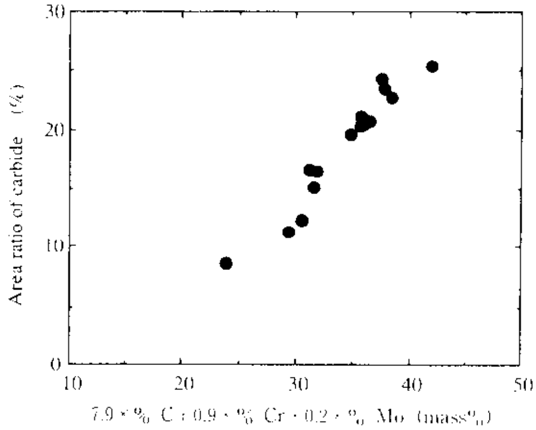


Fig. 5 Effect of chemical composition on volume fraction of carbide

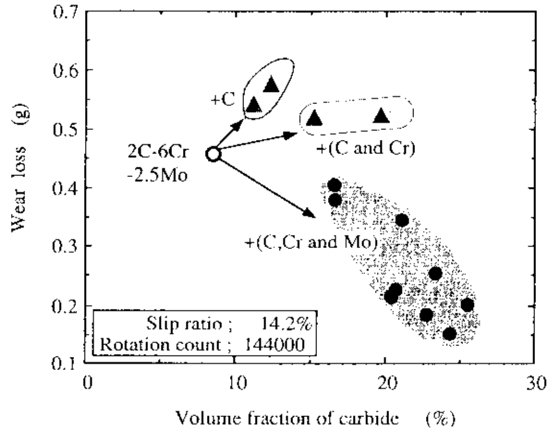
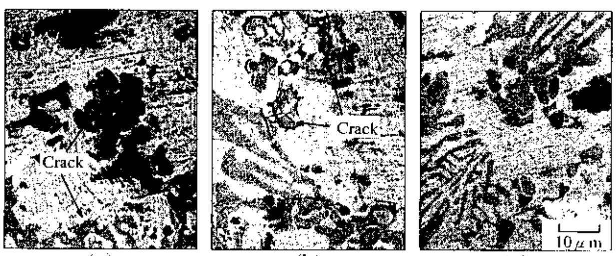


Fig. 6 Relation between volume fraction of carbide and wear loss



(a) (b) (c)

(a) Basic chemistry (2 mass%C - 6 mass%Cr - 2.5 mass%Mo - 5 mass%V - 1.5 mass%Nb)

(b) Increased in C content

(c) Increased in C, Cr and Mo contents

Photo 3 SEM images of wear surface of hot wear test disks (dark area: carbide, white area: matrix)

carbides. Rolls having such tough carbides combined with suitable amounts of Cr and Mo are expected to provide higher wear resistance than ordinary HSS rolls.

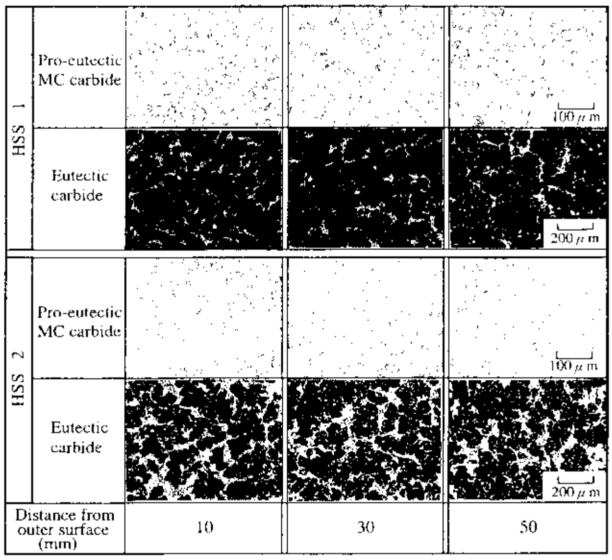


Photo 4 Micrographs of crystallized carbides in the diameter-direction of centrifugal cast HSS rolls

4 Manufacture of Commercial Roll and Result of Practical Use

4.1 Manufacture of Work Rolls for Finishing Stands in a Hot Strip Mill

On the basis of the fundamental studies described previously, two kinds of commercial rolls for finishing stands in a hot strip mill were manufactured by the centrifugal casting process. One roll, called HSS1, is a prototype made of 2.2 mass%C - 5 mass%V - 1.5 mass%Nb - Cr - Mo steel. The other one, named HSS2, is a new type roll whose C, Cr and Mo content are increased to reduce the rolling load. They were compound rolls having three layers. A new intermediate layer of graphite steel, which was introduced between the outer and the inner layers, plays an important role in preventing the decrease in toughness in the inner layer of ductile cast iron. Since Cr, V and Nb alloyed in the outer layer steel move partially into the inner layer of ductile cast iron during casting when there is no intermediate layer, the inner layer is embrittled by being alloyed with these elements.

The casting conditions of each layer were determined by the computer simulation of solidification. No casting fault was formed in the interfaces of neighbouring layers owing to perfect fusion bonding. **Photo 4** shows the micrographs of the outer layers, which exhibit uniformly dispersed MC-type granular carbides in a wide region from the outer surface to the inner. Hence, it is clearly shown that the prevention of segregation is effective.

The tensile strength of the joint of two layers was greater than 490 MPa and that of the inner layer was

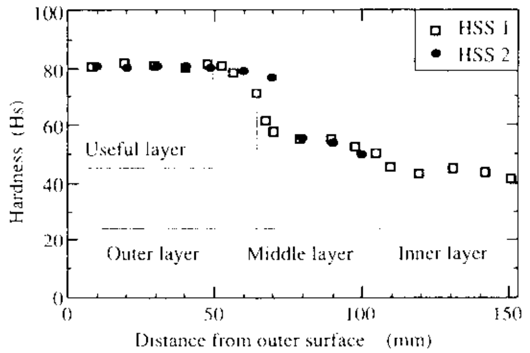


Fig. 7 Distribution of hardness of centrifugal cast HSS rolls

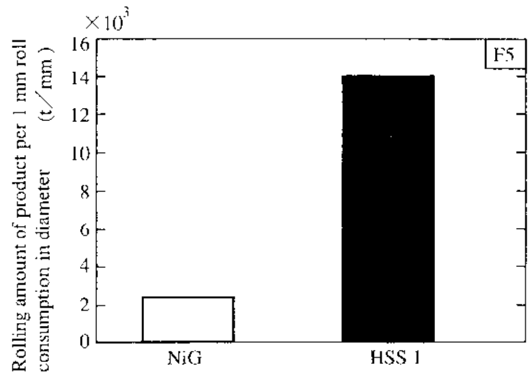


Fig. 8 Result of actual use at F5 stand of hot strip mill

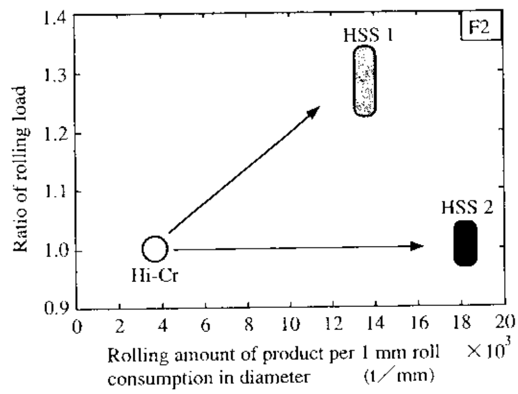
greater than 410 MPa, which are sufficient for the roll used in hot rolling. The hardness distribution in both rolls is shown in **Fig. 7**. The hardness in the outer layers has a uniform value ranging between Hs 81 and Hs 83 in the wide region from the outer surface to the position of 50 mm in depth, which corresponds to the ordinary operating range of the mill roll.

4.2 Performance of Rolls in Actual Use

One example of the characteristics of the developed HSS1 roll is shown in **Fig. 8**. In the latter stand of the finishing mill, the wear resistivity is much higher than that of the conventional Ni-grain cast iron roll. In terms of the rolling amount of product per 1 mm diameter roll consumption, the HSS1 roll has wear resistance more than 4 times as high as the Ni-grain roll. In addition, the resistance to roll surface roughening is also excellent[13]. In the early stand of the finishing mill shown in **Fig. 9**, the developed HSS1 and HSS2 rolls also show superior wear resistance as compared with the high Cr cast iron roll. The HSS2 roll containing tough carbides makes the rolling load equal to that of the high Cr cast iron roll, and makes the wear resistance higher than that of the HSS1 roll. In this case, the HSS2 roll has wear resistance more than 5 times as high as the conventional high Cr cast iron roll.

Figure 10 shows the roughness of a roll surface after hot rolling in the early stand F2, which was measured after hot rolling of 1 300 t per run. The high Cr cast iron roll cannot be applied to continuous rolling, because the roll surface is severely deteriorated as shown in Fig. 10. In contrast to the high Cr cast iron roll, the developed HSS2 roll has superior resistance to surface roughening and can be applied to continuous rolling. In the early stand of the finishing mill at Kawasaki Steel, the longevity of the developed HSS2 roll was three times greater than that of the high Cr cast iron roll, if both wear resistance and surface roughness of roll are taken into account.

Many work rolls have already been manufactured and



$$\text{Ratio of rolling load} = \frac{\text{Rolling load in use of HSS roll}}{\text{Rolling load in use of Hi-Cr roll}}$$

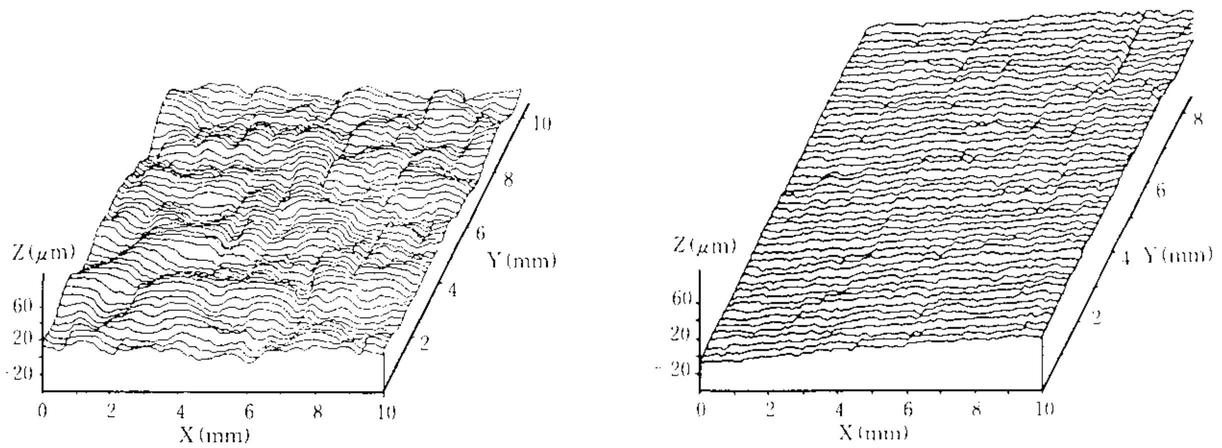
Fig. 9 Result of actual use at F2 stand of hot strip mill

actually used in the finishing rolls of hot strip mills in both Chiba Works and Mizushima Works of Kawasaki Steel. The HSS rolls are being used 100% of the time as work rolls in all of the early stands and in approximately 80% of the latter stands because a different type of roll is required in the latter stand and roll usage is limited in order to suppress damage caused by "crimp," particularly for the final F7 stand. Furthermore, this production process can be easily applied to sleeve rolls and caliber rolls. The application of this process has been extended to the rolls used in shape and seamless pipe rolling.

5 Conclusions

(1) The difference in specific gravity between primary crystals and residual molten steel generates segregation of VC in the inner layer of the roll during centrifugal casting.

(2) The addition of an appropriate amount of Nb makes the compound carbides of (V, Nb)C, which have a specific gravity similar to that of the residual molten steel.



1) Hi-Cr roll   2) HSS 2

Fig. 10 Surface roughness of roll after hot rolling

(3) The uniform distribution of MC type granular carbides has been achieved in the roll of 2 mass%C - high V - Nb bearing type alloyed steel.

(4) Increasing tough carbides by enrichment with C, Cr and Mo is effective in suppressing the increase in rolling load and improving wear resistance.

(5) The developed rolls have wear resistance that is more than 4 times as high as conventional rolls and have been successfully used at the finishing stands of hot strip mills.

(6) The same process has been applied to the production of sleeve rolls and caliber rolls used in shape and seamless pipe rolling.

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