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# Service Life Extension Techniques for Cold-Rolling Rolls

Yuji Sato, Satoru Midorikawa, Yoshiharu Iwashita, Akio Yokogawa, Takeshi Takano

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Research on the various types of rolls in the cold rolling process has been underway to develop materials and surface reforming techniques that can meet the needs for higher-quality sheet steel and surface-treated steel sheets, and improve productivity by extending the periodical repair intervals. Nonwoven-fabric rolls that excel in rigidity, wear resistance, and corrosion resistance were developed as wringer rolls based on a theoretical elucidation of a wringing mechanism. For bridle rolls that control the strip tension on the production line, surface reforming techniques were developed to improve the slip resistance. These include thermal spraying of WC type cermet to maintain the optimal surface roughness and shape, plating, and roughness preparation techniques. Developed for conductor rolls was a coating formation method in which a WC-containing self-fluxing alloy is plasma sprayed and fused to obtain dramatic corrosion and wear resistance. These actions produced highly reliable rolls with a long service life for the cold rolling process.

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# Service Life Extension Techniques for Cold-Rolling Rolls*



Yuji Sato
Staff Assistant Manager, Equipment Technology Sec., Equipment Technology Dept., Chiba Works

Satoru Midorikawa
Equipment Technology Sec., Equipment Technology Dept., Chiba Works

Yoshiharu Iwashita
Equipment Technology Sec., Equipment Technology Dept., Chiba Works


Akio Yokogawa
Assistant to the Vice President, Companhia Siderurgica de Tubarão

Takeshi Takano
General Manager, Equipment Technology Dept., Chiba Works

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## 1 Introduction

The number of rolls in the cold-rolling process at Chiba Works alone exceeds 9 000. These rolls require high reliability and highly advanced control, because they come into contact with cold-rolled final products and, therefore, have a major effect on the surface quality of these products.

To satisfy these demands, research has already been reported on the use of hard Cr-plating and rubber rolls for surface reforming,[1,2] and on the raw materials of rolls.[3,4] At Chiba Works also, improvements[5-8] in surface reforming techniques have been taken up.

The increasing product quality sophistication, and the growing versatility and high speed of production processes made it increasingly difficult for the conventional roll improvement techniques alone to maintain guarantee period for the product quality and the reliability of the entire production line.

To obtain rolls which can guarantee product quality for a long period, we tried to achieve further improvements on the material and surface reforming techniques.

At the time of these technical improvements, all the process rolls were classified according to their uses, and their required functions and performance were clarified. This work made it clear that the life of several thousand rolls can be extended by establishing several kinds of basic techniques.

This report shows the various aspects of performance required of cold-rolling process rolls, and describes the material and surface-reforming techniques of the main wringer rolls, bridle rolls, and conductor rolls in the cold-rolling process.

## 2 Required Performance and Development Approach

The number of wringer rolls, bridle rolls and conductor rolls account for 80% of the total number of rolls used in the cold-rolling process.

The wringer roll is a device for wringing out the warm-water cleansing solution on the sheet surface-

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picking and alkali-rinsing lines. Therefore, the roll surface requires high rigidity to optimize the wringing function on the sheet surface, and suitable elasticity to prevent the solution from wrapping around both edges of the strip.

When high pressure is applied to increase the wringing function, the edge of the strip develops partial wear[1] and cuts; hence wear resistance and cutting resistance are required of the roll. Furthermore, corrosion resistance is also required, because the picking solution and alkali solution are contained in the warm water. In the past, rubber rolls have been used, and although these rolls excel in their corrosion resistance, they are unsatisfactory in their wringing function and mechanical properties.

The bridle roll is used for controlling the line tension of cold-rolled steel sheets on the continuous picking line, continuous annealing line, and continuous plating line. The ability for controlling line tension is generated by the gripping force due to the roughness of the roll surface; hence an appropriate surface roughness to achieve slippage resistance, which can be maintained within a suitable range for a long period, and abrasive wear resistance are both required. In the past, Cr-plating has been applied, but this showed insufficient abrasive wear resistance.

The conductor roll, which becomes an electrode in the manufacture of electrogalvanized sheets, must be made of a material with good electric conductivity. This roll is subjected to corrosion by a strong acidic plating solution and to abrasion by the powder from tin plating, until stable current conduction is disturbed; hence, this roll required both corrosion resistance and abrasive wear resistance.

With the conventional Cr-plated roll, corrosion generated by the tin-plating solution that had entered through cracks and pores caused the Cr-plating layer to peel off, thereby shortening the life of this roll.

The performance required of these rolls, the R&D tasks, and the approach for extending their service life are shown in **Fig. 1**.

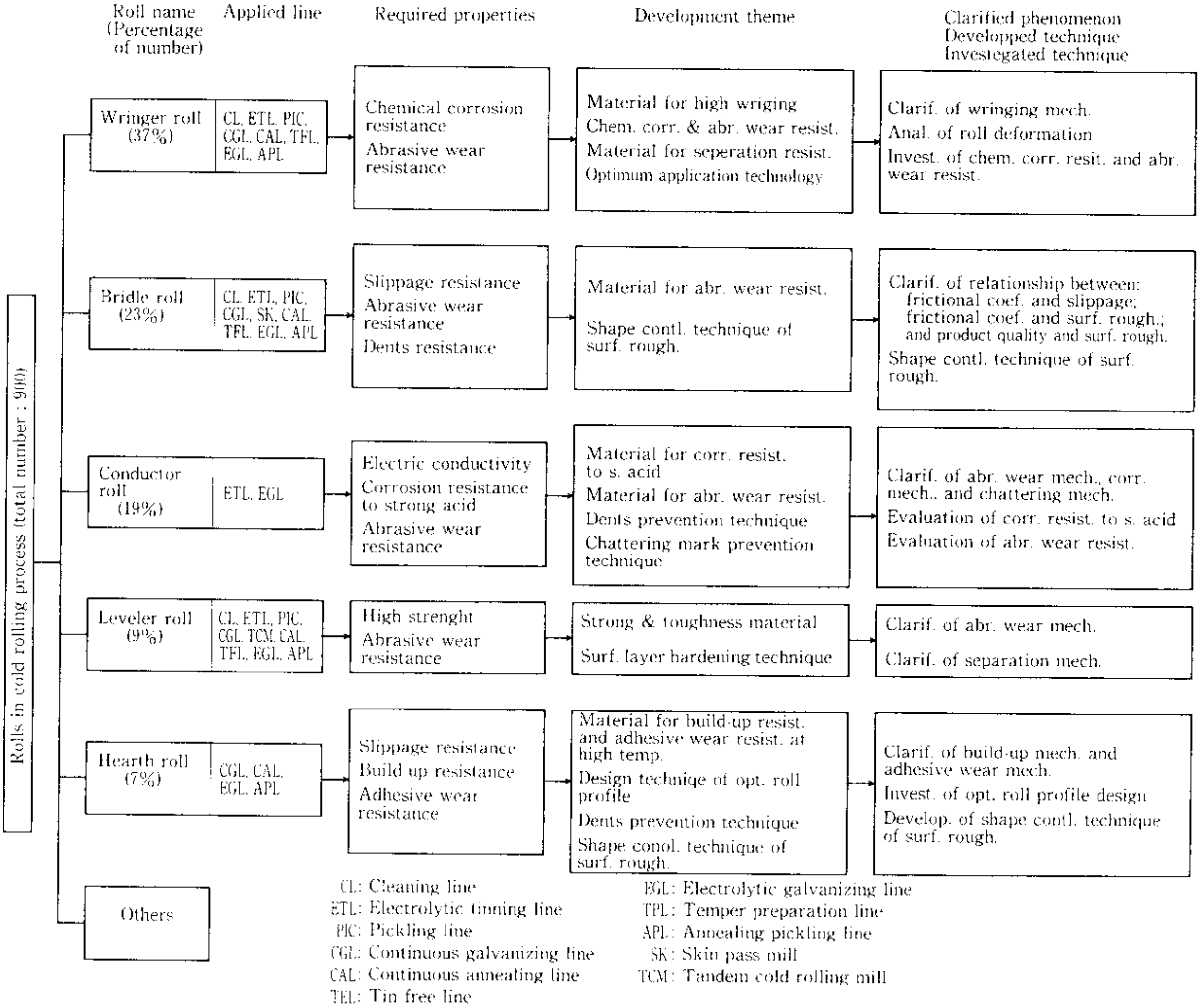


Fig. 1 Approach for extending service life of rolls in cold rolling process

## 3 Extending the Service Life of Wringer Rolls

### 3.1 Examination of the Wringing Properties

The wringer roll is generally covered with such kinds of rubber as neoprene and Hyperon, which are compatible with steel sheets. However, these materials have low hardness and rigidity, and assume an hourglass-shaped form due to wear and cuts at the edges of the rolled strip,[1] thus reducing their wringing properties and ends their service life. Further, in the recent high-speed production line where the wringer roll is used under high pressure to secure wringing properties, high-speed rotation of rolls and a risinging roll-contacting pressure generate heat to accumulate within the material, thus raising its temperature. Eventually, heat-resistance limit of the roll material is exceeded, causing peeling to layers, thus depriving the wringing function. In extending the service life of the rolls, therefore, it is necessary to maintain the wringing properties at the conventional level, while using roll-covering material excellent in resisting abrasion, cutting and heat. We, therefore, applied the Herrerugh equation,[9] which is generally used to estimate oil-film on gears, to investigate the relationship between the material properties which affect wringing property and the conditions of use.

This equation is as follows:

$$h = 3.1E^{-0.2}R^{0.6}\eta^{0.6}U^{0.6}W^{-0.2} \quad \cdots\cdots\cdots\cdots (1)$$

where $h$: Liquid film thickness ($\mu$m)
$E$: Elastic coefficient (Pa)
$R$: Radius of curvature (m)
$\eta$: Viscosity at atmospheric pressure (Pa·a)
$U$: Peripheral speed of the roll (m/s)
$W$: Line pressure (N/m)

When the facility specifications are constant, Eq. (1) becomes as follows:

$$h = 3.1E^{-0.2}W^{-0.2} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

According to Eq. (2), a material whose liquid film thickness can be reduced has a high elastic coefficient and can be used with a high line pressure.

Next, an investigation was made to find whether or not this equation could be applied to wringing properties between cylinder and a steel sheet. The test method is shown in **Fig. 2**. The steel sheet was first immersed in oil, pulled up out of the oil through the wringing rolls, and the weight difference before immersion and after wringing is measured. This weight difference is defined as the quantity of oil which had not been completely wrung (residual oil quantity), and was used to evaluate the wringing properties. The roll materials tested were the combination of two neoprene rolls and also the combination of one neoprene roll and one steel roll (S35C). The test results are shown in **Fig. 3**, and indicate that the residual oil quantity was less when the steel roll, having the larger elastic coefficient, was used. Consequently, it was found that Eq. (2) could be used for examining the wringing properties.

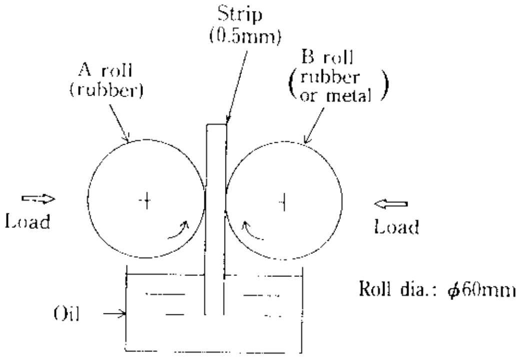


Fig. 2 Schematic diagram of wringing test

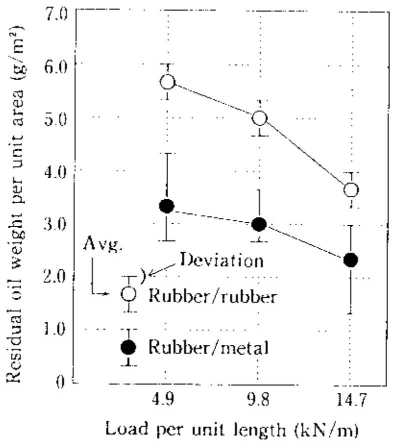


Fig. 3 Results of wringing test

The steel roll has good mechanical and thermal properties, and was found to also have good wringing properties by the test. It has also been found that a steel sheet may be subjected to plastic strain and scratching by a steel roll, resulting in a poor shape and abrasive flaws in the steel sheet. Therefore, an FEM analysis was used to calculate the relationship between the surface pressure and the line pressure for combinations of various roll materials. For the analysis, the general-purpose FEM analysis program "MARC" was used. An example of the analyzed materials is shown in **Table 1**, and the analytical results are shown in **Fig. 4**.

The combination of the high-rigidity nonwoven fabric roll and the rubber roll shown in Table 1[10] produced a surface pressure nearly 30 times greater than that obtained with the combination of the two rubber rolls. The stress distribution at a line pressure of 1.8 kN/m is shown in **Fig. 5**.

As shown in Fig. 5, a high surface pressure occurs in

Table 1 Mechanical properties of lining materials

| Material | Hardness* $H_s$ (JIS A) | Elastic coefficient (N/mm$^2$) | Temperature of heat resis tance (°C) |
|---|---|---|---|
| Nonwoven fabric | 95 | 1000 | 375 |
| Rubber (CR) | 75 | 4 | 120 |

* JIS K6301

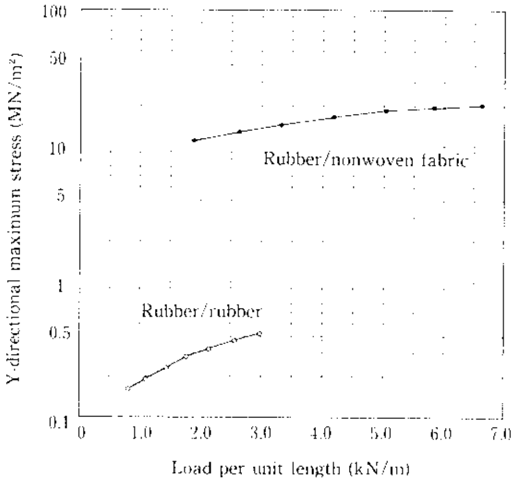


Fig. 4 Comparison of Y-directional maximum stress (compression) between rubber/nonwoven fabric and rubber/rubber rolls

the contact area between a high-rigidity roll and a steel sheet when a high-rigidity material is used on one side only under the same line pressure. From these results, it can be seen that, in order to improve the wringing properties, the roll rigidity must be increased and in order to obtain the same wringing properties with a high-rigidity roll, the line pressure can be reduced.

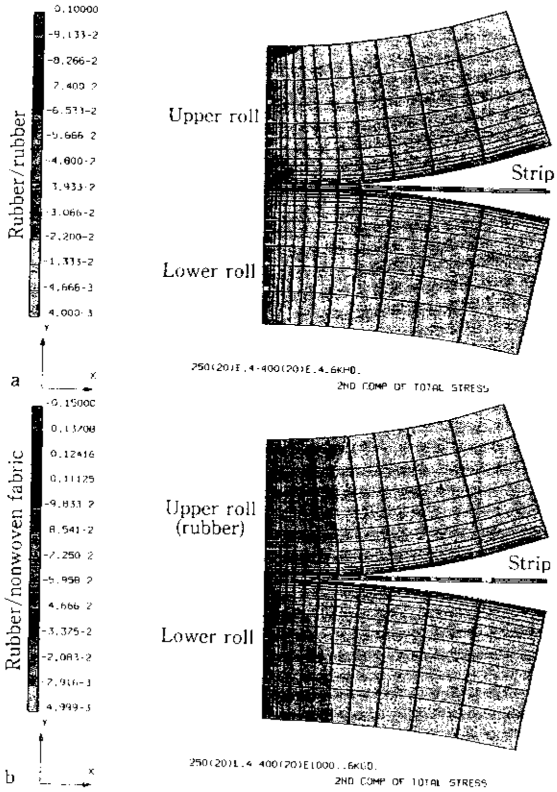
Consequently, it can be understood that the line pressure can be reduced with the optimum roll combination to improve the wear resistance.

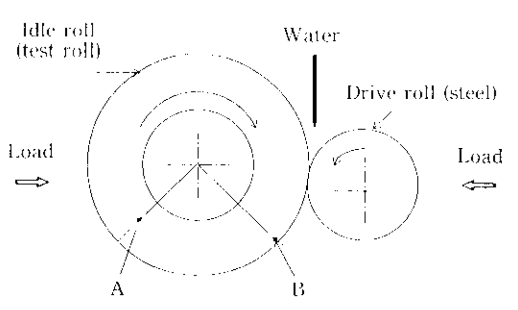
### 3.2 Evaluation of the Thermal Resistance of Coating Materials

It has been found that the use of high-rigidity nonwoven fabric rolls can improve the wringing properties. However, since nonwoven fabric is a similar high-polymer material to rubber, the thermal conductivity is low. Therefore, heat is generated within the material under high rotational speed and high pressure; hence, a temperature rise test was carried out by the method shown in **Fig. 6**. Thermocouples were set in two positions (1/2 thickness of the coating material and 5 mm under the coating surface), and while pressing the test roll against the driving roll under high-speed rotation and high-pressure conditions, the temperature inside the test roll was measured. Neoprene (rubber) and nonwoven fabric (resin) test rolls were used.

The measured temperatures are shown in **Fig. 7**. The temperature at point A in the neoprene roll rose to

Fig. 5 Stress distribution in the contact area of wringing rolls by MARC





A, B : a position of thermo couple

Fig. 6 Schematic diagram of measurement of the temperature of wringer roll

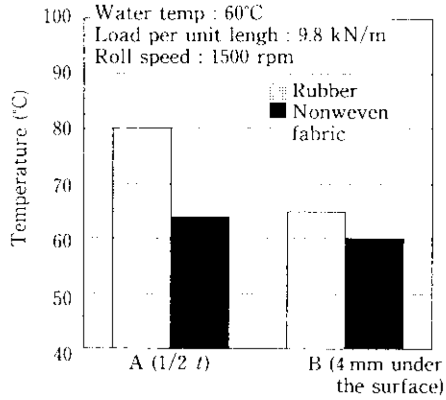


Fig. 7 Results of measurement of the temperature of wringer roll

about 80°C, while that at point A in the nonwoven fabric roll rose to 65°C. Thus, the nonwoven fabric showed less internal heat generation at high speed and under high pressure, and since the heat-resistance limit of the fabric is 350°C or more, it can be seen that this material has superior thermal properties to those of rubber.

### 3.3 Overall Evaluation under Production Conditions

It was found that a coating material with a large elastic coefficient had superior wringing properties and heat resistance, and in addition, it had high hardness and excellent wear resistance; hence, a test was carried out at the outlet side of the cleaning tank on the electrolytic cleaning line. The coating material tested was high-rigidity nonwoven fabric.

A comparison of the service periods is shown in **Fig. 8**. The conventional rubber roll had deteriorated wringing properties due to wear after one month's use and had to be replaced, but the high-rigidity nonwoven fabric roll, which has now replaced the rubber roll, had a much lower wear rate and could be used for seven months.

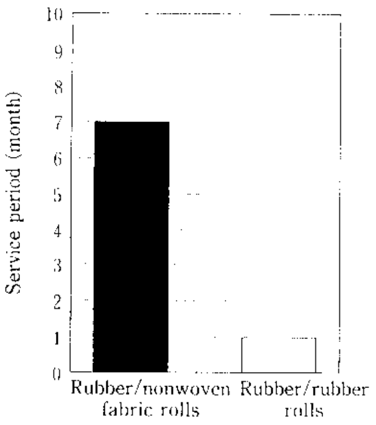


Fig. 8 Results of field test in electrolytic cleaning line

## 4 Extending the Service Life of Bridle Rolls

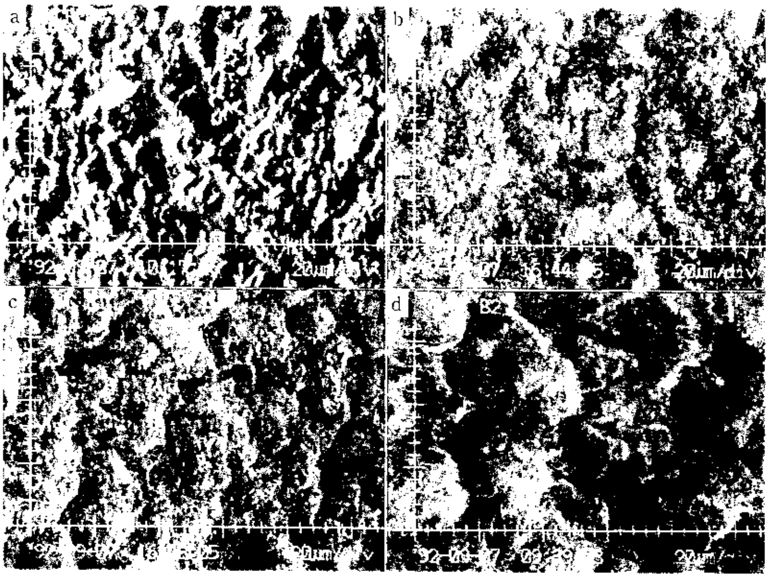
### 4.1 Surface-Reforming Method and Selection of Materials

When the surface roughness drops, the bridle rolls develop slippage between themselves and a cold-rolled steel sheet, and hence lose their tension-control function. However, if this tension-control function is to be provided for a longer period by increasing the initial surface roughness, the bridle roll embosses its roughness pattern on the cold-rolled steel sheet. Consequently, the surface-reforming method and material to enable the bridle roll to maintain its optimum roughness are critical. We selected the detonation flame spraying,[11] which makes it difficult for hard powder material to melt and disappear and whereby a fine-textured coating can be obtained, compared with the plasma spraying, and in addition, out of cermet, WC-type cermet, which gives high hardness. This 88WC-12Co material gives a Vickers hardness of 1 150, so that high abrasive wear resistance can be expected.

### 4.2 Preparation Method of Surface Roughness Profile

Photographs of the surface roughness profile of Cr-plated and detonation flame-sprayed bridle rolls are shown in **Photo 1**. The Cr-plated surface-roughness profile shows a rounded form, due to the cube-shaped grain growth that occurs with plating adhesion, while the sprayed surface is a continuous body of sharp rough shapes. Consequently, a bridle roll in the as-sprayed state would emboss its surface pattern on the cold-rolled steel sheet.

In addition iron powder would be liable to adhere and pile up, forming convex protuberances that would also emboss the sheet. The adhesion and piling-up of iron powder can be prevented by smooting the sharp suface peaks with grinding or buffing. However, too much



a : Cr plating b : WC/Co (null baffing)
c : WC/Co (2 times baffing) d : WC/Co (4 times baffing)

Photo 1 Optical microphotographs of surface roughness shape of bridle rolls

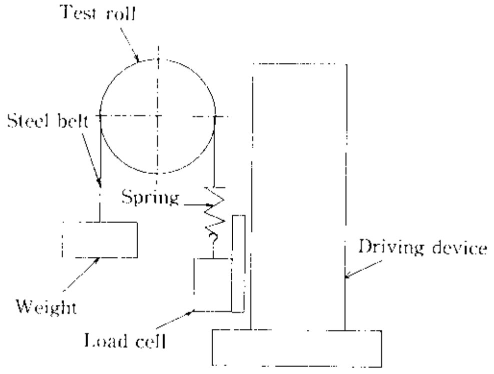


Fig. 9 Test method for measuring frictional coefficient of bridle roll

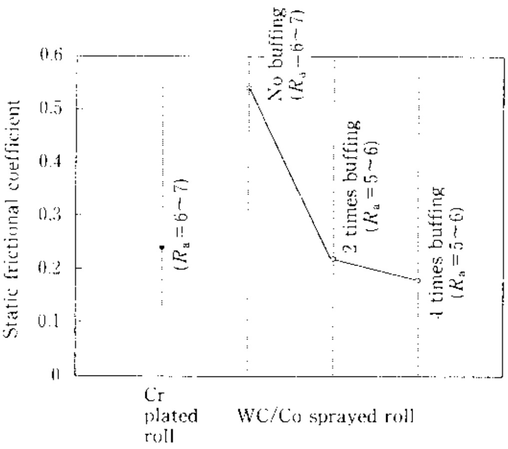


Fig. 10 Comparison of frictional coefficients of bridle roll

grinding will reduce the friction coefficient and generate slippage. Therefore, we examined a buffing process which can maintain the necessary friction coefficient.

To clarify the relationship between the surface roughness profile and the friction coefficient, we produced the friction coefficient-measuring device that is shown in **Fig. 9**. With the test roll securely located, a weight is fitted to one side of the cold-rolled steel sheet to apply a constant tension. The tension is increased on the other side when the roll is rotated and drags the steel sheet, so that the increased tension can be measured by a load cell.

The friction coefficient was calculated by using the following formula:

$$T/W = \exp(\mu\theta)$$

where $T$: Measured tension (N)
$W$: Mass of the weight (N)
$\mu$: Friction coefficient
$\theta$: Angle of contact (°)

The measured friction coefficient is shown in **Fig. 10**. The $R_a$ symbol in this figure shows the centerline average surface height (according to JIS B0601), and $R_{max}$ shows the maximum surface height (JIS B0601). The WC/Co-sprayed roll buffed twice so that the $R_{max}$ value is reduced to 50%, has less than one-half the friction coefficient of the as-sprayed roll. When buffed four times, so that the $R_{max}$ value is reduced to 70%, the friction coefficient drops to less than 0.2. This is in comparison to the friction coefficient of the Cr-plated roll of 0.24.

Therefore, in order to produce a surface roughness profile similar to that of the Cr-plated roll, two times buffing was necessary.[12,13] In addition, Cr-plating was added[14] to prevent the deposition of iron powder in the troughs of the surface profile.

### 4.3 Overall Evaluation under Production Conditions

WC-type detonation flame spraying was applied to the bridle rolls before and after the tension leveller on the continuous annealing line, and a comparative test was carried out between these detonation flame-sprayed bridle rolls and the conventional Cr-plated rolls. The results are shown in **Fig. 11**. The conventional Cr-plated roll had a roughness reduction from 6.0 to 2.0 $\mu$m $R_a$ in eight months and then slippage developed.

In contrast, the sprayed roll worked for 36 months before its roughness was reduced from 6.0 to 3.0 $\mu$m $R_a$, and could be further used. There was no evidence of embossing from the start.

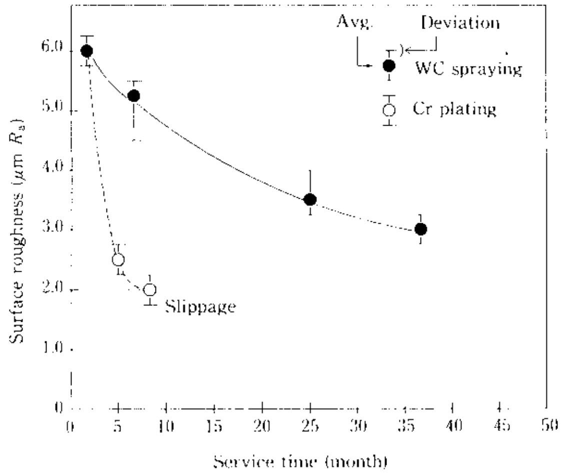


Fig. 11 Change in surface roughness of bridle rolls at continuous annealing line

## 5 Extending the Service Life of Conductor Rolls

### 5.1 Selection of Covering Materials and Thermal Spraying Methods

The conductor roll requires corrosion resistance and abrasive wear resistance, together with electrical conductivity. Thermally sprayable materials that have electrical conductivity and high corrosive and abrasive wear resistance are Ni-base and Co-base self-fluxing alloys. However, since the plating solution on the electrogalvanizing line is a strongly acidic aqueous solution of hydrochloric acid and hydrofluoric acid, it was necessary to evaluate the corrosion resistance to the plating solution.

Of the self-fluxing alloys stipulated in JIS H8303, Ni-base self-fluxing alloy, WC-containing Ni-base, and Co-base self-fluxing alloy, were selected and their characteristics were compared with that of Cr plating, which is the conventional roll coating material.

The chemical composition and hardness of each coating materials are shown in **Table 2**. In general, the powder flame-spraying method stipulated in JIS Z3001 is used for applying a self-fluxing alloy, and since the movement of the sprayed particles is comparatively slow, the formed coating is liable to become porous.[15] Therefore, the plasma flame-spraying method was used to produce an as-sprayed material of low porosity. In addition, fusing has been added. The hardness of MSF-WC2 is HV 500 or more, and since the contained WC particles have a hardness of HV 1 800 to 2 000,[16] high corrosion and abrasive wear resistance can be expected from MSF-WC2, together with a fine-texture coating.

### 5.2 Corrosion Resistance Evaluation Test

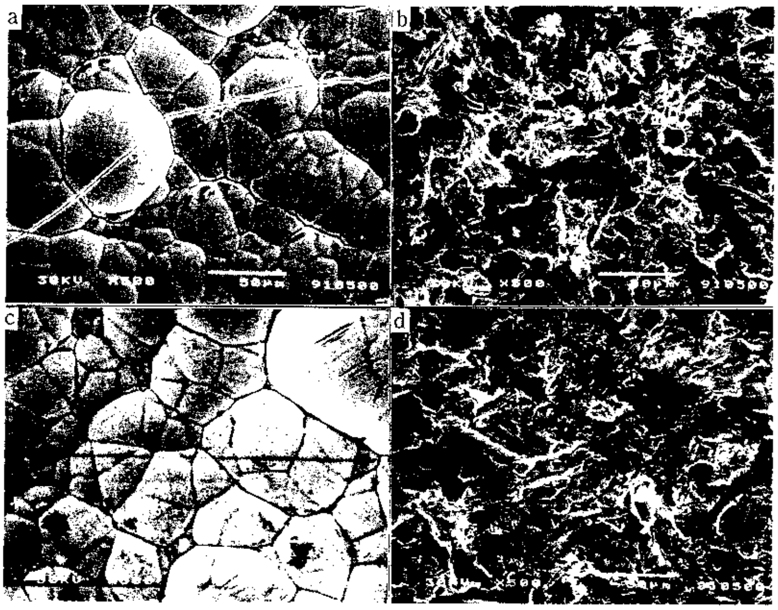
The solution used in the corrosion test was a general tin-plating solution set at 90°C, which is slightly higher than that for practical use to promote the corrosion reaction. The uncoated roll areas were masked with carbon resin. We evaluated the corrosion resistance by the mass loss, after immersing the specimen in a stationary solution for 48 h. The test result are shown in **Fig. 12**.

All the self-fluxing alloy flame-sprayed coatings had superior corrosion resistance to that of the conventional Cr-plated coating, and among them, the MSF-WC2

Table 2 Typical chemical composition and hardness of self-fluxing alloy for conductor rolls

| Type | Chemical composition (wt%) | | | | | | | | | | | Hardness (HV) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ni | Cr | B | Si | C | Fe | Co | Mo | Cu | W | WC* | |
| MSF-Ni 4 | Bal. | 16.0 | 4.0 | 4.0 | 0.5 | 2.5 | — | 3.0 | 3.0 | — | — | 500~700 |
| MSF-Co 2 | 13.0 | 19.0 | 3.0 | 3.0 | 1.0 | 4.0 | Bal. | — | — | 13.0 | — | 500~800 |
| MSF-WC 2 | Bal. | 11.0 | 2.5 | 2.5 | 0.5 | 2.5 | — | — | — | — | 35.0 | 500~700 |
| Cr plating | — | >99.8 | — | — | — | — | — | — | — | — | — | 700~1 000 |

* WC: 1 800~2 000



a : Cr plating before corrosion test  b : MSF-WC2 before corrosion test
c : Cr plating after corrosion test  d : MSF-WC2 after corrosion test

Photo 2 SEM photographs of Cr-plating and MSF-WC2 plasma spray

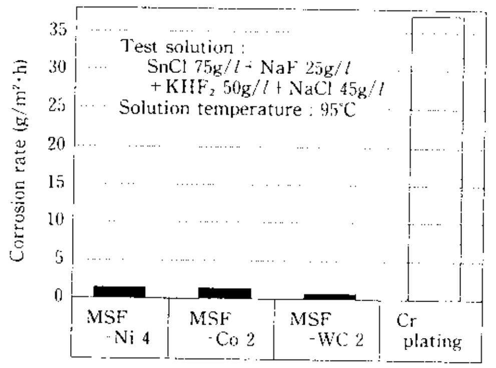


Fig. 12 Comparison of corrosion rate between self-fluxing alloys and Cr plating used for conductor roll

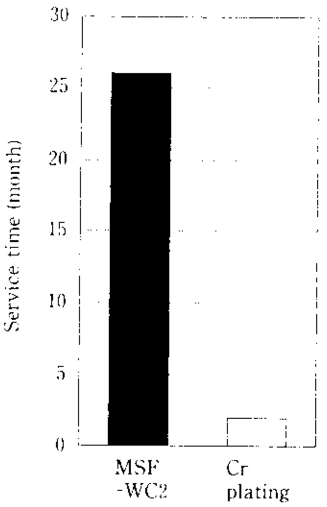


Fig. 13 Result of field test in electrolytic tinning line

coating had a mass loss of about 1/50 that of the Cr-plated coating. The surface condition of these two specimens before and after the corrosion test is shown in **Photo 2**.

In the case of the Cr-plated coating, the grain boundary is selectively corroded, whereas in the case of the MSF-WC2 coating, almost no corrosion is evident.

Under such a corrosive environment, the Cr-plated coating is considered difficult to maintain in a uniformly passive state.

### 5.3 Overall Evaluation under Production Conditions

It was found that the MSF-WC2 plasma-sprayed coating had high corrosion resistance and adequate hardness. Therefore, we produced a conductor roll with an MSF-WC2 coating thickness of 1.0 mm, and tested it on the electrogalvanizing line. The results are shown in **Fig. 13**. The conventional Cr-plated roll had a life of only two months because of base-material exposure. On the other hand, the plasma-sprayed roll could be used for 26 months and still maintained a coating thickness of 0.4 mm. As a result, the plasma-sprayed roll can offer a coating life expectancy of four years or more by regrinding the roll.

## 6 Conclusions

Chiba Works has been promoting the R&D and practical application of materials and surface-forming techniques to improve the performance of cold-rolling process roll. This has been necessary to enhance product quality and provide greater diversity and speed in the production process.

The following improvements have been obtained:

(1) For the wringer rolls, a nonwoven fabric roll, which is high in rigidity and has high wear and corrosion resistance, has been developed, resulting in a service life seven times that of the conventional ringer rolls.

(2) For the bridle rolls, WC-type cermet detonation flame spraying combined with Cr plating have been applied, and the surface-reforming techniques necessary to produce the required roughness have been developed, thereby obtaining a service life 5 times that of the conventional bridle rolls.

(3) For the condutor rolls, a WC-containing self-fluxing alloy is plasma-sprayed, and coating formation method with added fusing has been developed, thereby extending the service life of the rolls by as much as 13 times that of conventional conductor rolls.

These improvements will each contribute to the supply of high-quality cold-rolled steel products and more stable plant operation. The authors would like to express their deep appreciation for kind and valuable cooperation given by the relevant personnel of Tocalo Co., Ltd., and Dai-ichi High Frequency Corp.

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