Technical Report

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About the Lifelong Duration of Equipment by a Surface Coating

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Abstract

The service lifetime of equipment and product quality in iron and steel works are greatly influenced by the performance of rolls and other components in the plants of the works. However, the conventional rolls and some of the components deteriorate rapidly due to harsh environments of the plants. To improve the service lifetime of such rolls and components and reduce production cost, the surface modification technologies based on overlaying welding and thermal spray technologies are applied in such plants. As a result, overall cost reduction and improvements in product quality have been achieved through the application of the technologies. These technologies greatly contribute to the development of contemporary industries and have become indispensable to processes in iron and steel works. In this paper are introduced examples of application of the overlaying welding and the thermal spray technologies to rolls in plants in iron and steel works for surface modification.

1. Introduction

The surface modification coating based on overlaying welding and thermal spray can promise significant improvement in such characteristics as corrosion and abrasion resistances; however, designing and selection of material matching the servicing environments are important. Currently, application of overlaying welding and thermal spray to rolls and components used in iron- and steel-making process has made a remarkable progress and has become indispensable to improving quality. Among such indispensable applications, applications of surface modification to the following rolls are introduced: continuous casting rolls in a steel-making plant, down coiler rolls and runout table rolls in a hot strip rolling mill, and the sink roll and hearth rolls in a cold strip rolling mill and a continuous hot-dip galvanizing line.

2. Surface Modification Technologies

2.1 Foot support rolls of continuous casting machine

Small-diameter and split rolls used in the upper section of a continuous casting machine undergo high thermal load and suffer from severe damage such as abrasion, thermal crack, and corrosion under a high-temperature environment. Therefore, countermeasures for such damage were a matter of great concern. Conventionally, overlaying welding materials of the 13Cr and 17Cr-4Ni systems were used, however, as a countermeasure for prolonging service life, "NCA-050," an overlaying welding material of Ni-based alloy system with high-temperature characteristics, was developed and has been applied. The following two points are listed as the features of NCA-050.

(1) Excellent in corrosion resistance and resistance to oxidization
(2) Excellent in abrasion resistance under a high-temperature environment

These features are explained hereafter.

(1) Corrosion resistance and resistance to oxidization

NCA-50 is a Ni-based alloy containing rich corrosion-resistant elements. Accordingly, excellent corrosion resistance and resistance to oxidization are obtained. Corrosion resistance evaluation conditions are shown in **Table 1** and the result of the test is shown in **Fig. 1**. As opposed to the conventional buildup welding material of 13Cr system that shows the corrosion mass loss of about 5.0 mg/mm^2 per unit area for testing time of 100 h, NCA-050 of 13Cr system material shows that the corrosion mass loss drastically improved to 1/500. From this, it is known that the corrosion resistance of NCA-050 to halogen-based corrosive gases is much higher than that of the conventional material.

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(2) Corrosion resistance under a high-temperature environment

The measurement result for tensile strength and 0.2% proof stress of NCA-50 is shown in **Fig. 2**. Further, result of hardness test at high temperature is shown in **Fig. 3**. Additionally, for comparison purpose, the test results of the conventional materials (13 Cr and 17Cr-4Ni systems) are shown together. Since NCA-050 is a material wherein a plurality of inter-metallic compound represented by Ni_3Al of regular lattice phase (γ' phase) precipitated in Ni-solid solution substrate (γ phase) are dispersed and precipitated, it has high-temperature strength and high-temperature hardness and excellent characteristics in high-temperature region. From Figs. 2 and 3, it is found that NCA-050 has higher tensile strength and yielding stress and hardness as compared to those of conventional materials. Accordingly, the material is also excellent in abrasion resistance at high temperature.

Table 1 Conditions of corrosion-resisting evaluation test

Corrosion solution	5% solution of hydrofluoric acid (corrosion solution exchanged every 24 hours)
Temperature	Room temperature
Time	100 hours
Evaluation	Mass loss

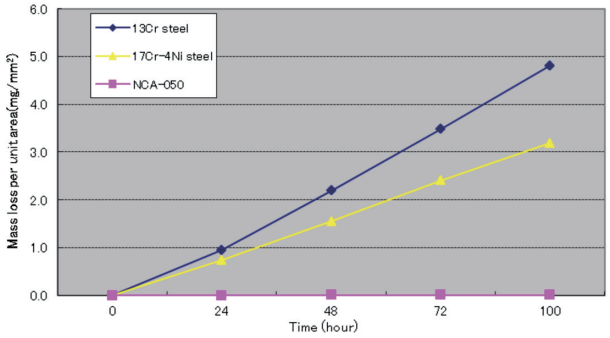

Fig. 1 Result of corrosion-resisting test

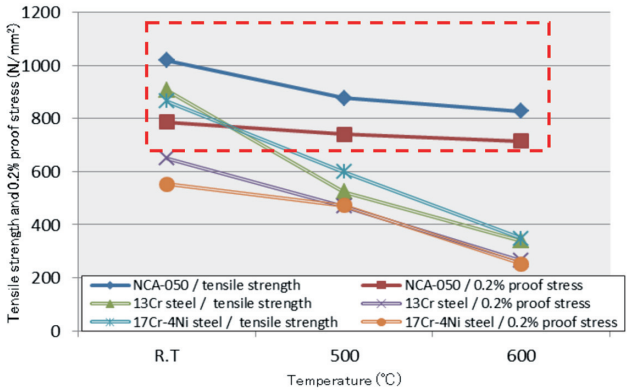

Fig. 2 Result of tensile strength and 0.2% proof stress test

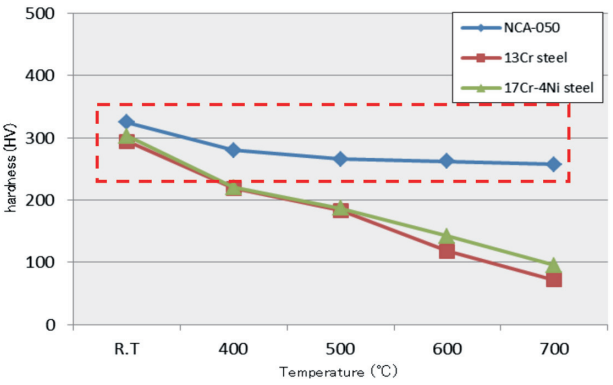

Fig. 3 Result of hardness test at high temperature

From the above, characteristics required to foot support rolls used at the upper section of a continuous casting machine has been greatly improved by NCA-050 as compared to conventional materials, and service lifetime of actual rolls has been prolonged as compared to rolls of conventional material.

2.2 Runout table roll in hot strip mill

Runout table in a hot strip mill is an equipment that transfers steel strip sheet to a down coiler after finish rolling wherein the cooling rate of the steel strip sheet is controlled by water cooling headers installed and steel properties are determined. Runout table rolls are operated under a moistening environment and transfer high-temperature steel strip sheet at a high speed; therefore, damages such as wear and corrosion are serious, and the influence of seizure on the surface quality of steel strip sheet become a matter of deep concern. Conventionally, high Cr cast iron rolls were used; however, damage by wear was large and conditioning for removing seizure was necessary. In recent years, application of Ni-based self-fluxing alloy metal thermal spraying to runout table rolls was attempted; however, the coefficient of friction was low as compared to that of conventional cast steel rolls and a problem of steel strip sheet slip emerged.

Then, by adding an optimum amount of Fe, N-11 thermal spray coating was developed, which has the same value of coefficient of friction as the conventional high Cr cast iron rolls and the problem of slip was solved. By applying N-11 thermal spraying, following merits have been obtained (**Fig. 4** and **Fig. 5**).

(1) Excellent in abrasion and corrosion resistances, deterioration in roll outer diameter profile is small even after prolonged usage, and retention of stabilized pass line is possible with de-

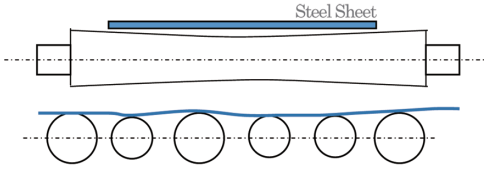

Fig. 4 Conventional cast-iron rolls
Change in roll profile by wear is developed and it tends to develop diameter differences among rolls and improper steel strip sheet pass line.

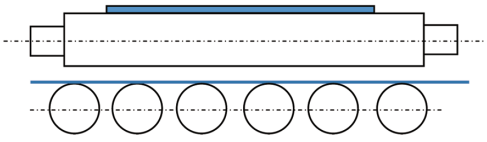

Fig. 5 N-11 thermal spraying roll
Wear developed in the long-term operation is small and roll outer diameter remains unchanged, maintaining proper strip sheet pass line, realizing maintenance-free.

creased tendency of steel strip sheet slip; therefore, threading speed of the thin strip sheet has been enhanced, improving productivity.

(2) Since a Ni-based alloy is used for thermal spray coating, seizure resistance against the steel strip sheet is excellent; therefore, roll conditioning time for removal of seizure and frequency of such roll conditioning have been shortened and lessened, contributing to maintenance-free.

(3) Reduction of motor load and electricity cost is realized by reducing the roll weight and moment of inertia (GD_2) along with the reduction of roll shell thickness.

Application of N-11 thermal spray rolls to runout table rolls has come to be adopted seriously since around 2000, and currently used in a number of lines. As an example, amount of wear of hot strip mill runout table rolls is shown in **Fig. 6**. As compared to the result of conventional high Cr cast iron rolls, abrasion resistance characteristic of 10 times larger is displayed. Further, some of the rolls put into online in the early period of years 2000 have been in operation for longer than 10 years consecutively. Among many cases of practical application of N-11, there are some reports of the cases of shorter service life due to local edge wear developed by a bent edge of the strip steel sheet caused by pressing force on the partially installed disc rolls in the side guide section. Presently, in order to further improve the roll life in such a section, development of thermal spray coating is under way for improving abrasion resistance.

2.3 Down coiler roll in hot strip mill

For down coiler rolls in a hot strip mill, rolls of higher performance are being demanded to satisfy severer hot strip mill operating conditions such as production of high-tensile strength steel rolled materials and of high quality, and higher rolling speed to comply with enhancing productivity (**Fig. 7**). For upper and bottom pinch rolls, hardened buildup welded rolls (Cr-Mo system) were used conventionally; however, early periodical replacing due to roll wear was necessary because of deep concern over the problems of deterioration in roll profile producing poor coil form, seizure of steel sheet material giving significant influence upon steel sheet quality. In order to solve the problems, "SFW-10" roll has been developed and has replaced the conventional rolls with its drastically prolonged service lifetime and the ability to continue to maintain steel sheet quality. As a result of application; it could solve the problems drastically.

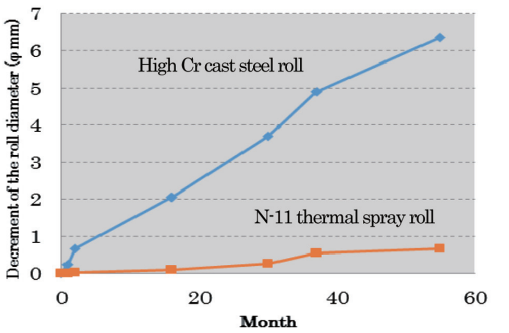

Fig. 6 Example of amount of abrasion at N-11 thermal spraying roll

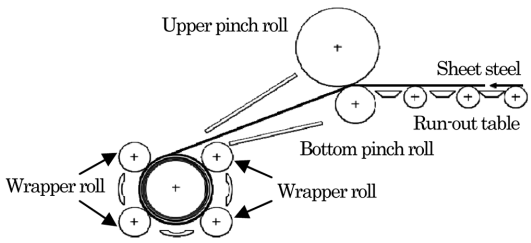

Fig. 7 Down coiler roll at hot strip mill

Hot strip rolling steel sheet delivered from the finishing mill stands enters between the upper and bottom pinch rolls as shown in Fig. 7 at a high speed under high temperature, changes its travelling course downward toward the coiler below and coiled. In order for the down coiler to wind smoothly steel strip sheet travelling at a high speed, speed difference (circumferential speed difference) is given in between finishing mill stands, upper and bottom pinch rolls and wrapper rolls in order to provide a tension in between such equipment. By the slip due to the circumferential speed difference, wear and seizure are developed. Furthermore, the pinch rolls suffer from very stringent environment of heavy impact load at the time of a steel strip sheet hitting the roll gap and the thermal shock rendered by the steel strip sheet.

Under such a stringent environment, rolls of steel family are unable to comply with drastic long service lifetime, continuously maintaining steel strip sheet quality and therefore SFW-10, a self-fluxing alloy containing dispersed carbide, has been developed. Technology developed for applying SFW-10 to a down coiler is explained.

(1) Material having ultrahigh abrasion resistance

A self-fluxing alloy excellent in abrasion resistance and corrosion resistance characteristics containing dispersed carbide was employed. As a thermal-sprayed self-fluxing alloy is relatively brittle, a material that can suppress the occurrence of heat crack by thermal shock, minute exfoliation caused by shock and development of wear has been developed.

(2) Roll excellent in mechanical shock resistance

As a self-fluxing alloy material is relatively brittle and resistance to fracture due to mechanical shock is poor, hardened buildup welding is supplied as a substrate material to strongly protect thermal spray coating.

(3) Seizure-pick-up resistant material

Have excellent seizure-pick-up resistance characteristics to steel strip sheets of ordinary quality steel, Ni system, stainless steel of Cr system and Ti material.

(4) Manufacturing technology of hollow large diameter roll

Though manufacturing was limited to the bottom pinch roll in size of 400–500 mm in diameter, manufacturing technology of an upper pinch roll of 920 mm in diameter has been developed (**Fig. 8**).

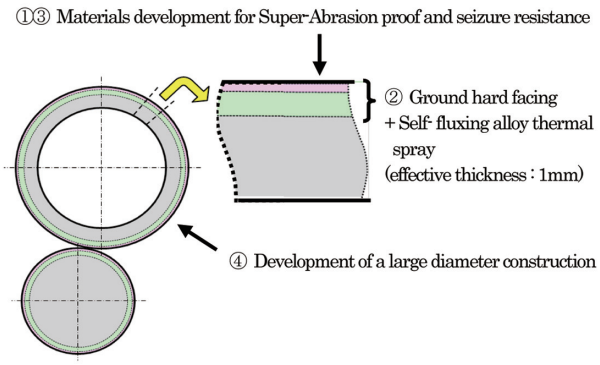

Fig. 8 Section of a pinch roll

The result of application of SFW-10 to actual equipment showed; as compared to the conventional hardened buildup welded roll, abrasion resistance was increased by 10–15 times, replacing cycle was prolonged by 10 times and roll profile was maintained owing to lessened amount of wear, improving stability in operation. Furthermore, roll conditioning for seizure has been almost eliminated. SFW-10 has displayed high performance in the pinch rolls of a coiling equipment of a hot strip rolling mill and currently used in a number of domestic and overseas steel works. Materials meeting the operating conditions of respective steel works are being developed and applied and further development is in progress.

2.4 Continuous annealing and pickling line hearth roll

In the continuous annealing furnaces of a continuous annealing and pickling line (CAPL) and a continuous galvanizing line (CGL), steel strip sheets are transferred by hearth rolls under a high-temperature reducing atmosphere. Presently, generation of buildup on a hearth roll has become a problem developed due to oxidizes of Fe and Mn formed on a steel strip sheet and then sticking to a hearth roll surface and then, undergoing reaction (**Fig. 9**). Buildup developed on the roll surface becomes the cause of such problems as dent on steel strip sheet surface and deterioration in surface roughness. As a countermeasure therefore, thermal spray coating of a cermet material consisting of a heat-resistant alloy and ceramics is being applied.

Nippon Steel & Sumikin Hardfacing Co., Ltd., as countermeasures for this problem, has developed a cermet thermal spray material "HG-360M2" which has higher Mn-buildup resistance characteristics than that of the conventional material and has put it into practical use. HG-360M2 is a thermal spray material intended to suppress the reaction of the roll material with Mn sticking to the roll surface. **Figure 10** shows the result of evaluation of the reactivity of the thermal spray material coating to Mn. In the conventional material, Mn sticks to the surface of a thermal spray coating and reacts to the coating and partial enriched concentration of Mn is observed. Contrarily to this, enriched concentration of Mn is not observed on the surface of the thermal spray coating of HG-360M2, displaying better result as compared to the conventional material. By putting the thermal spray coating of HG-360M2 into practical use, development of buildup on a hearth roll surface has become suppressed and the service lifetime longer that of the conventional material has become realized.

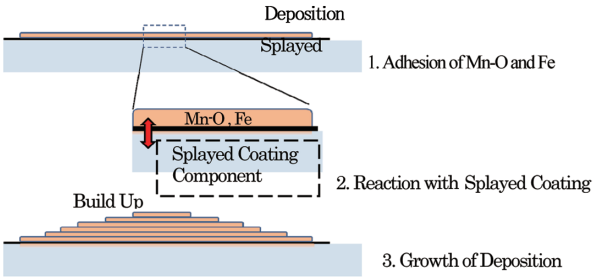

Fig. 9 Problem of build up for hearth roll

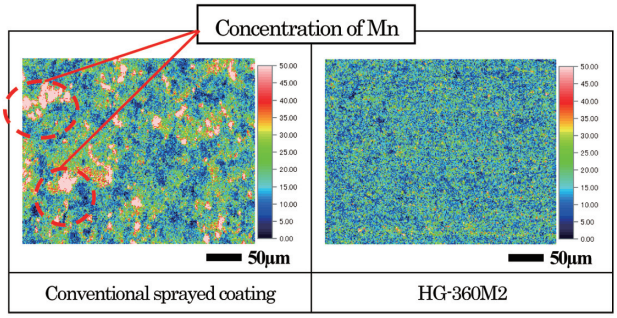

Fig. 10 Result of Mn reaction test

Hereafter, for a hearth roll of a CAPL, further improvement in buildup resistance performance is sought for along with the increase in tensile strength to ultrahigh strength and change in operating environments and therefore improvement in thermal spray coating performance is being sought for. In order to suppress the development of buildup to cope with these needs, thermal spray coating is required to have the characteristics that does not allow reaction to sticking Fe, Mn, or easy sticking, or suppressing the growth even if sticking takes place and exfoliating. For this purpose, precise analysis of buildup phenomenon becomes important. Presently, development of further excellent cermet thermal spray material is underway from the viewpoint of suppressing reactivity to Mn.

2.5 Thermal spray coating of hot dip galvanizing coating roll

CGL is a manufacturing line to enhance the corrosion resistance of a steel sheet by producing a zinc coating on the surface of a steel sheet. Thermal spray technology of Nippon Steel & Sumikin Hardfacing is contributing to the manufacturing of high quality continuously galvanized steel sheets. A sink roll in a zinc bath exerts great influence on the quality of hot dip galvanized steel sheets (**Fig. 11** shows a sink roll and support rolls). Since after 1980s, as a roll coated with thermal spray of WC-Co system showed excellent abrasion resistance and corrosion resistance as compared to those of rolls with corrosion resistant material such as SUS316, have come to be used for most of rolls operated in the zinc bath in domestic lines.

In the rolls with thermal spray coating of WC-Co system of conventional specification, such problems as elution of Co and formation of brittle Co_3W_3C (η phase) and W_2C hamper the use of the rolls for a long period.[1] To solve the problem, cermet thermal spray coating "HG-204" of boride system has been developed. HG-204 is a thermal spray coating material composed of compound boride system, and has been successfully developed as a material having coating characteristics of zinc corrosion resistance, high-temperature cracking resistance and abrasion resistance superior to those of conventional thermal spray material of WC-Co system. **Figure 12** shows the results of zinc emersion tests of cermet thermal spray coatings of WC-Co system and HG-204N. In seventy two hours zinc immersion, in the thermal spray coating of WC-Co system, erosion developed in the area about half of the dipped area is observed; however, in case of HG-204, the thermal spray coating got uniformly molten-zinc-wet and the thermal spray coating maintained a sound state.

On the other hand, as to the problem of dross built up[2] which frequently takes place in zinc coating process, HG-204N is designed

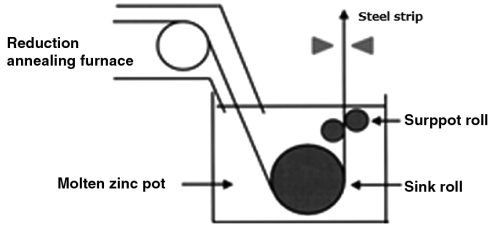

Fig. 11 Position of sink roll and support roll in the molten zinc pot

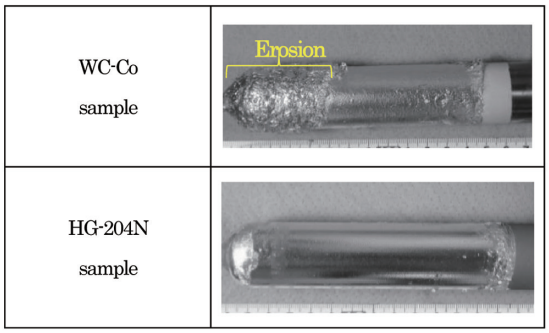

Fig. 12 Result of molten zinc corrosion test (723K, 100%Zn, 72 hours)

and developed to suppress the erosion of thermal spray coating to minimum extent, and to prevent the change in bath composition at the interface between the thermal spray coating and molten zinc, and to maintain the fluidity of molten zinc in neighborhood area of the roll surface. Accordingly, HG-204 has the characteristic of hampering dross sticking to thermal spray coating in the zinc bath together with the characteristics enabling easy mechanical removal even when dross sticks to the thermal spray coating.

Authors are determined to develop hereafter the thermal spray coating of rolls aiming at further improvement in quality and pursuing the possibility of longer continuous operation durability under joint development work with respective steel works.

3. Conclusion

Along with the technological innovation of iron- and steel-making technologies, characteristics demanded by iron- and steel-making equipment including rolls are changing incessantly. Surface modification technologies are becoming increasingly necessary to comply with the change such as sophistication of function and quality of iron and steel products, such as growing tensile strength of thin steel sheets, needless to mention of contribution to maintenance cost reduction by prolonging lifetime, there is no termination to the development of new materials.

To grasp accurately the phenomena that arise from the change in operation and to develop new materials matching the change in a speedy manner are becoming important. In view of the cases in which prolonged cycle of development can't catch up the change in custom needs and newly developed and productized materials maybe obsolete, authors are determined to promote establishment of efficient material development system and development method.

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