Application prospects of ASM 4603-SA surfacing material modified with hard-melting components for reconstruction of rollers for continuous casting machines

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Abstract. The results of researches aimed at studying the possibility of using ASM 4603-SA surfacing material modified with hard-melting components, namely tungsten carbide and boron nitride hexagonal, for reconstructing the rollers of continuous casting machines by electric arc surfacing are covered. It is shown that such material has higher wear resistance in comparison with the surfacing flux-cored wire 25Cr5VMoSi, as well as high resistance to cracks formation and net shaped marks as a result of cyclic high-temperature influences.

1. Introduction
Researches and developments aimed at production improvement and stability of steel casting process at continuous casting machines (CCM), one of the critical areas of which are rollers [1], hold an important place for steelmaking. In conditions of CCM [2] steel casting share growth the problem of roller resistance increase is actual.

At the present time the rebuilding of worn-out CCM rollers surfaces at steelmaking plants is carried out mainly with the use of arc surfacing technology with 20Cr13, 25Cr5VMoSi materials, etc.

It is known that abroad the actual resistance of rollers rebuilt by surfacing has been achieved equal to 3,000,000 tons of cast billet and in the domestic metallurgy – up to 500,000 tons. The difference is connected with high level of surfacing technology, surfacing material and the equipment used [3].

Increase of rebuilt CCM rollers resistance will reduce equipment downtime, direct and indirect repair costs.

Working surface of CCM rollers is an object of intense mechanical and cyclic heat influence as a result of cast billet movement along them. Abrasive and adhesion wear in combination with high-temperature oxidation as well as fatigue wear cause destruction of the working surface of the rollers, which requires restoration work.

Durability of CCM rollers depends on many factors – on materials used, technology of their manufacture, personnel qualification, heat treatment conditions, optimal modes of operation, cooling system efficiency, on design of both rollers and CCM strands, on working surface properties.

At steelmaking plants the worn-out CCM rollers are renewed by applying the surfacing technology. In most cases CCM rollers are made of heat resistant steel grades such as 20Cr13, 25CrMoV, etc., and
their reconstruction is carried out by electric arc surfacing with the use of wires of various compositions. Most commonly, for reconstruction of CCM rollers operating with metal friction a low carbon chromium stainless steels are used.

For surfacing the operating layer of CCM rollers the following alloying systems are mainly used: Fe-Cr (mostly for straight sections of CCM); Fe-Cr-Ni-Mo-N и Fe-Cr-Ni-Mo-V-Nb (mostly for curved sections of CCM) [4].

It is possible to improve metallurgical and technological properties of welding materials both by adding nickel in their composition and hard-melting nanodispersed components that contribute to the modification of the build-up metal [5].

Nowadays there is no single solution to the question of steel choice for production and reconstruction surfacing [6]. Conditions of real production are often individual and manufacturer-specific.

Previously, the authors [7] have conducted researches on the selection of optimal surfacing materials for the reconstruction of CCM rollers in order to reduce the wear of functional surfaces during operation and increase their service life. In the course of laboratory and industrial tests more than 30 surfacing materials of domestic and foreign origin were investigated. In terms of wear resistance, heat resistance and economic efficiency ASM 4603-SA surfacing material produced by LLC ASM Group, Cherepovets [8] showed high results. Surfacing of material was carried out under the layer of ASM BM-21flux. Wear resistance of rollers recovered with ASM 4603-SA material turned out to be 1.48 times higher than the wear resistance of the layer built-up with 25Cr5VMoSi wire, which is often used in repair shops of metallurgical plants.

Increasing the recovered CCM rollers durability by a factor of two or more is a relevant objective requiring the use of more wear-resistant materials capable of withstanding the abovementioned types of exposure over a longer period of time, provided that the economic viability of such materials is maintained.

To solve this problem, ASM 4603-SA flux-cored wire composition was modified together with the manufacturer by adding in its dry mixture hard-melting components – WC tungsten carbide powder in the amount of 3% (mass.) to increase wear resistance and BN hexagonal boron nitride in the amount of 0.2% (mass.) as a solid high-temperature grease.

The purpose of this work was to study the possibility of using flux-cored wire ASM 4603-SA, modified with hard-melting components for rebuilding the CCM rollers.

2. Research methodology

As surfacing base material the samples of steel 20Cr13 used for CCM rollers manufacture were applied. 25Cr5VMoSi, ASM 4603-SA, modified material ASM 4603-SA with 3%WC and 0.2%BN additives were surfaced on the bases in 2-3 layers depending on wire thickness.

For manufacture of test composition of ASM 4603-SA + 3%WC + 0.2%BN wire with a diameter of 2.4 mm for electric arc surfacing the following materials were used:

- tungsten carbide powder (tungsten carbide powder WC3, produced by the company Volfram, FSSS = 2.53);
- boron nitride BN hexagonal (grade A, produced by LLC Platina);
- ASM 4603-SA (Fe – base, C 0.30%, Si 0.7%, Mn 1.8%, Cr 5.0%, Ni 0.1%, Mo 1.4%, V 0.7%, W 1.1%).

Dry mixture concentrate was obtained by mechanical mixing of powders in the Fritsch Pulverisette 5 planetary mill. Then the concentrate was mixed with the rest of the dry mixture in the required proportions under the conditions of LLC ASM Group. The mass ratio of the dry mixture to the mass of the coat is 30:70. The effective mixing of components inside the mixer bowl was due to its complex spatial motion. Figure 1 shows the distribution of chemical elements in the wire mixture.

X-ray structure phase analysis of the samples with surfaced layers was performed on the DRON-4 diffractometer using monochromatic CoKα radiation (wavelength 1.79021 Å) and Cu-Kα radiation.
(wavelength 1.54178 Å). Survey was carried out in step scanning mode in the interval of angles $2\theta = 10^\circ...130^\circ$, survey step was 0.1°, exposure – 2...4 sec.

Spectrum processing was performed using qualitative PHAN and quantitative PHAN% analysis programs developed in NUST MISIS.

Figure 1. Distribution of chemical elements in the wire mixture.

Hardness of the samples with surfaced layers was measured according to GOST 9013-59 Metals. Rockwell Hardness Measurement Method on hardness measuring instrument TR 5006.

Metallographic samples were prepared on polishing machine StruersRotoPol-21 in automatic mode. Struers papers with a grain of silicon carbide SiC 120, 220, 500, 800, 1200, 4000 were used consistently in the process of grinding.

The samples were polished using a suspension of colloidal silicon oxide O-PS (grain size 0.04 μm).

Microstructure of surfaced layers was studied with the Neophot-32 optical microscope and the Hitachi S-3400N scanning electronic microscope equipped with the NORAN X-ray energy dispersion spectrometer.

Tribological properties of the samples with surfaced layers were estimated in accordance with international standards ASTMG 99-959 and DIN 50324 at high temperature friction machine High-temperature Tribometer CSM Instruments as per the pin-on-disk plan.

The ball made of Al$_2$O$_3$ with diameter of 6 mm was used as counterbody. The linear sliding speed of the samples is selected as 10 cm/s, the load is 5 N. The dependence of the friction coefficient of the interacting pair on the run length of the counterbody, equal to 500 m, was built on a computer using the InstrumX software.

Wear track profile was studied on optical profilometer Veeco Wyco NT 1100.

The rate of wear was determined by the equation:

$$W = \frac{sL}{Nl}$$  \hspace{1cm} (1)

where $W$ – ware rate, mm$^3$·N$^{-1}$·m$^{-1}$; $L$ – perimeter of circle, mm; $s$ – groove wear section area, mm$^2$; $N$ – load, N; $l$ – sliding distance, m.

Tribological tests were carried out at a temperature of 700 °C. The choice of the experiment temperature was due to the results of temperature measurements of the CCM No.2 withdrawal-straightening machine rollers at JSC Oskol Electrometallurgical Plant (figure 2) [5]. The measurements
were performed by thermovisor SDS HotFind-DXT. The measurement results showed that the surface temperature of the roller in contact with the cast billet is up to 462 °C (point P02 in figure 2). Thus, the tests were conducted under more severe temperature conditions than the production ones.

Figure 2. CCM withdrawal and straightening machine roller temperature measurement results at the moment of its contact with cast billet.

CCM rollers in the process of their operation are under thermal-cycle loads as it can be seen from figure 2, the surface temperature of rotating rollers with a frequency of 0.4 rpm varies from 462 ºC (point P02) to 282 ºC (point P01). ASM 4603-SA and 25Cr5VMoSi surfacing materials show high resistance to such temperature fluctuations in production conditions. To test the ability of the modified surfacing material to withstand thermal cyclic loads, heat resistance tests were conducted on the specimens.

Heat resistance tests were carried out in a muffle laboratory furnace of the EKPS-10 brand. Samples with 20×20×20 mm surfaced layers were soaked for 30 minutes in a furnace at 900 °C and then cooled in 20 °C water for 30 seconds. The number of heating-cooling cycles was equal to 30.

Cracks after cooling were a criterion for the thermal resistance of samples with surfaced layers.

3. Results and their discussion
The phase composition of the surfaced layers is shown in table 1.

| Surfacing material   | Phase            | Structure type | Pearson symbol | Mass fraction (%) | Periods (Å) |
|----------------------|------------------|----------------|----------------|------------------|-------------|
| 25Cr5VMoSi           | α-Fe             | type A2        | cI2            | 98               | a = 2.872   |
|                      | γ-Fe             | type A1        | cF4            | 2                | a = 3.587   |
| ASM 4603-SA          | γ-(Fe-Cr-C)      | type A1        | cF4            | 12               | a = 3.601   |
|                      | α-(Fe-Cr)        | type A2        | cI2            | 88               | a = 2.880   |

It was found that the main phase in the samples surfaced with 25Cr5VMoSi and ASM 4603-SA materials is α-Fe (martensite) – 98 and 88% respectively. In the layer surfaced with ASM 4603-SA wire the content of austenite is 12% (γ-Fe), in the sample surfaced with 25Cr5VMoSi – 2 %. The structure of the layer surfaced with flux-cored wire ASM 4603-SA + 3%WC + 0.2%BN is shown on the figure 3. The border between the base and the surfaced layer is characterized by the absence of defects (figure 3a). Figure 3b shows that there are inclusions in the surfaced layer, which are manganese sulfide MnS.

Figure 4a shows a fragment of a surfaced layer, figure 4b shows its diffractogram, and table 2 shows the chemical composition. It is apparent that the tungsten content is 2.3%.

The results of tribological studies (coefficient of friction $C_f$, rate of wear $W$) and hardness measurements of surfaced layers are given in table 3.

Figure 5 shows the correlation of the frictional coefficient of the samples with surfaced layers from the counterbody run length. Figure 6 contains the samples wear track profiles and their 3D images.
Figure 3. Structure of surfaced layer ASM 4603-SA + 3%WC + 0.2%BN.

Figure 4. Fragment of surfaced layer ASM 4603-SA + 3%WC + 0.2%BN (a) and its diffractogram (b)

Table 2. Chemical composition of surfaced layer ASM 4603-SA + 3%WC + 0.2%BN, %.

| Zone at figure 4a | Si-K | V-K | Cr-K | Mn-K | Fe-K | Mo-L | W-M |
|------------------|------|-----|------|------|------|------|-----|
| 1                | 0.4  | 1.1 | 4.4  | 2.2  | 88.6 | 1.1  | 2.2 |

Table 3. Characteristics of surfaced layers

| Surfaced layer | Hardness HRC | Frictional coefficient $C_f$ | Wear rate $W$ ($\times 10^{-6}$ mm$^3$·N$^{-1}$·m$^{-1}$) |
|----------------|--------------|------------------------------|---------------------------------------------------|
| 25Cr5VMoSi     | 50.04±1.05   | 0.54                         | 44.6                                              |
| ASM 4603-SA    | 52.45±1.77   | 0.56                         | 31.7                                              |
| ASM 4603-SA +3%WC +0.2%BN | 57.37±0.64 | 0.52                         | 21.5                                              |

The samples with surfaced layers of ASM 4603-SA materials are characterized by a lower rate of wear (1.48 times) compared to the sample surfaced with 25Cr5VMoSi flux-cored wire.

Wear rate of modified wire ASM 4603-SA + 3%WC + 0.2%BN is 21.5$\times 10^{-6}$ mm$^3$·N$^{-1}$·m$^{-1}$, which is 1.5 times lower than the material ASM 4603-SA and 2 times lower than 25Cr5VMoSi.
Figure 5. Dependence of friction coefficient of the samples Cfr on the counterbody run length l:
1 – sample surfaced with ASM 4603-SA wire; 2 – sample surfaced with 25Cr5VMoSi wire;
3 – sample surface with modified ASM 4603-SA + 3%WC + 0.2%BN wire.

Figure 6. Wear track profiles of samples (a, c, e) and their 3D-images (b, d, f): a, b – sample surfaced with 25Cr5VMoSi wire; c, d – sample surfaced with ASM 4603-SA wire; e, f – sample surfaced with modified ASM 4603-SA + 3%WC + 0.2%BN wire.

As a test results of the surfaced material ASM 4603-SA + 3%WC + 0.2%BN it was found that after 30 heating-cooling cycles the cracks on the samples surfaces were not observed (figure 7).

Thus, modification with hard-melting components of ASM 4603-SA surfacing wire made it possible
to reduce friction coefficient and increase wear resistance.

4. Conclusion
It was revealed that the use of ASM 4603-SA flux-cored wire with added hard-melting components is promising for the reconstruction of CCN rollers by surfacing. In the result of arc surfacing of this material the wear-resistant layer with hardness up to 57 HRC is formed on the surface of CCM rollers, resistant to crack formation and net shaped marks as a result of cyclic high-temperature effects, characterized by a lower coefficient of friction compared to the layer surfaced with the base material.

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