Article

Possibilities for Renovation of Functional Surfaces of Backup Rolls Used during Steel Making

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Abstract: The paper presents the results of the research aimed at possibilities of renovation of functional surfaces of back-up rolls that are part of the hot strip rolling mill operating line using new types of additive materials. Experimentally, four melts of alloyed steel were produced in laboratory conditions from which four types of filler materials in the form of wires were made. They were made by pulling through dies to a diameter of 2.4 mm. The renovation of functional surfaces was performed on the batch of rolls with the outer diameter of 1000 mm and length 3000 mm. Cladding technology submerged arc welding (SAW) was applied for cladding of four spirals with 40 mm oscillation onto the base material of the 31CrMoV9 (EN 10085) sub-roll. The base flux marked WLDC 17-AWS A5.17-89 EM13K with basicity index 3 was used for cladding. The four-layer weld deposition was made to eliminate the effect of mixing the surfacing layers with the base material. The refurbished rolls were annealed after welding. Surface quality was assessed by visual inspection (VT) according to EN ISO 17637. The presence of internal errors was determined by ultrasound control (UT) in accordance with EN ISO 11666 and EN ISO 17640. The quality of the clad layers was analysed on metallographic sections using light microscopy. The microhardness of the individual clad layers was evaluated according to Vickers according to EN ISO 9015-2. Based on realized experiments it can be stated that the selected cladding parameter was suitable, and the overlay layers showed no surface or internal defects. Mechanical and tribological tests were carried out, but they showed significant influence of chemical composition of additive materials on mechanical properties, or wear resistance of the layers.

Keywords: cladding; renovation; backup rolls; surface; wear; microstructure; layer

1. Introduction

Steel making is a technologically demanding and complex process during which a significant wear occurs on the metallurgical primary operations technology and equipment. There are many factors influencing functional parts of this equipment. Namely direct external factors such as abrasive wear, adhesive wear, erosive wear, thermal fatigue, corrosion at high temperatures in combination with negative effect of fluxes and mould powders, as well as secondary indirect factors that originated during fabrication of the part, or during its previous renovation [1–4]. Diverse fabrication and inner defects are included, as well as residual stress. In order to provide for a continuous and trouble-free operation of the manufacturing process it is necessary to regularly inspect and maintain the parts and if needed replace them with new ones. Rolls play an essential role in the steel making processes with respect to steel-making on continuous strip rolling mills, processing of slabs on the hot strip rolling

mill stands or rolls on the cold strip rolling mill. The task of rolls on the steel continuous casting line is apart from steel guiding, i.e., guiding continuous slab during its cooling, to shape the slab during deformation of its solidifying skin. As result of high temperatures ranging from 1250 °C to 800 °C thermal fatigue occurs on the roll surface [5,6]. During steel rolling process the cooling with water spray is applied in the curve section of the rolling mill. A negative factor having effect on the overall service life of rolls is also high portion of chlorine ions that contribute to origination of the so-called corrosion fatigue. The surface quality of these rolls directly influences also the quality of the rolled steel surface. Surface defects that originate on the rolls are also reflected on the surface of cast and rolled steel. In the next phase, slabs are processed on the hot strip rolling mill stands. The roll configuration in the finishing stands of hot strip rolling mills consist of two relatively small work rolls supported by two larger backup rolls [7,8]. Work rolls are responsible for the direct contact of the roll surface with slab during its rolling. Work rolls are exposed during service to thermal fatigue, mechanical fatigue, wear, impacts so that good thermal, mechanical and tribological properties are required for the materials employed for their fabrication [1]. Backup rolls fall in the second group of rolls. These are the rolls with diameters of more than 1000 mm and the length range up to 3000 mm [9]. The task of backup rolls is to support work rolls and thus prevent their bending or even breaking. Whereas temperature is not a problem (HSM backup roll surface temperature typically is 150 °C in service), mechanical stresses have a fundamental effect on roll service life. No water cooling of rolls is required, the corrosion fatigue influencing the quality of their surfaces is only small and, therefore, the corrosion fatigue is much lower. During service, backup rolls are subjected to intense compressive stresses (of the order of 1–5 GPa at the surface) while cyclic shear stresses, sometimes in excess of 500 MPa, are generated below the surface of the rolls, as presented in analyses Hertz and Belyaev [10,11]. In addition to mechanical stresses, backup rolls are subjected to wear, however, unlike for work rolls, the nature of the wear mechanisms is not well documented [12,13]. Nevertheless, two body abrasive wear from carbides and three-body abrasive wear from hard strip oxide transfer (between the work and backup roll) are believed to be the predominant mechanisms [14–16]. Uneven roll surface finish leads to a heterogeneous load distribution on the barrel length, which causes localized plastic yielding and eventually induces cracking and spalling [17–21]. On the basis of service conditions, the ideal back-up roll material should exhibit high resistance to fatigue crack initiation and propagation, high resistance to burst cracking, a uniform microstructure and properties, low strain hardening behaviour and finally, good wear resistance. Previous work [1–3,14] in the field of continuous casting as well as on hot rolling rolls produced exceptional results. In this particular study a fundamental approach has been adopted, which includes an investigation of back-up roll failure and the possibility of restoring its surfaces by cladding [22]. The research in the area of renovation of backup rolls and work rolls has developed in several directions. One was to apply additive materials with higher level of plasticity and toughness during restoration by cladding using arc methods even at the cost of lower abrasive resistance and another direction was the possibility of layer hardening by precipitation. Carbide precipitation is the main strengthening mechanism and each type of carbides play different kind of roles. As well known, the fine dispersed strengthening MC carbide retards the microstructural recovery and is important for improving the creep rupture strength of steel. The popular Cr-Fe-rich carbide M_7C_3 grows easily and usually precipitates on the lath or block boundaries, which caused the migration of grain boundary and, therefore, shortened the time to the onset of acceleration creep. Here $M = Fe, Cr, Mo, V$, etc. Recently, Janovec [23,24], Bhadeshia [25] and Pigrova et al. [26] have attributed considerable attention to the precipitation behaviours of carbide during long-term aging. However, there is seldom detailed investigation on the carbide evolution behaviours of low-alloyed Cr-Mo-V steels during heat treatment, such as mass fraction, chemical composition and particle size. It usually plays a key role on the stability and resistance to creep and to hydrogen damage [27–31]. The disadvantage of backup rolls is their difficult restoration after they are worn out and with respect to their dimensions the cost of new rolls requires a significant investment for the mill restoration [5,6,8,9,12–16,22,32].

The paper presents the results of the research focused on the evaluation of the quality of the four types of weld deposits of the backup rolls of the cold rolling mill. The microstructure of the clad layers, their mechanical properties and the lifetime were evaluated in rolling fatigue conditions.

2. Experimental Materials and Methods

The test clad layers were applied to the base material (BM)-31CrMoV9 (EN 10085) as its chemical composition is identical to the chemical composition and mechanical properties of the backup rolls. As a base material the roll with diameter of 120 mm and length of 2000 mm was used which was subsequently coated with a 35 mm thick clad using the submerged arc cladding technology. The chemical composition of the steel is shown in Table 1 and mechanical properties of the steel are shown in Table 2.

Table 1. Chemical composition of steel 31CrMoV9 (wt%), Fe Bal.

C	Mn	Si	P	S	Cr	Ni	Cu	V	Mo	Al	Ti	Sn
0.30	0.49	0.23	0.015	0.028	2.40	0.11	0.18	0.12	0.20	0.032	0.017	0.012

Table 2. Mechanical properties of steel 31CrMoV9.

Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Contraction (%)
802	939	19.6	65.8

Four experimental filled tubular wires with a diameter of 2.4 mm (designed as 1–4) and chemical composition as given in Table 1 were used for surfacing of samples. The flux used for the cladding was specially developed for surfacing with experimental filled tubular wires. The working designation of the flux is WLDC 17 and its chemical composition is shown in Table 3. Basicity index 3. Filled tubular wires and flux were developed by CoreWire Ltd. Company, (Ash Vale, Aldershot, Hampshire, UK).

Table 3. Chemical composition of the flux (wt%).

Flux	C	Mn	Si	Cr	P	Cr	Mo
WLDC 17	0.32	1.01	0.54	0.006	0.007	5.0	3.05

2.1. Cladding Technology and Used Equipment

Arc cladding technology under the flux method 121-EN ISO 4063 SAW was used for cladding. The samples were clamped into a dedicated Weldclad GU125LZ, manufactured by CoreWire Ltd. (Ash Vale, Aldershot, Hampshire, UK). There were deposited four spirals with 40 mm oscillation onto the base material of the 31CrMoV9 (EN 10085) sub-roll. Five layers of a total thickness of 35 mm from each type of experimental wire were gradually welded to the cylindrical sample.

2.2. Cladding Parameters

Prior to cladding, the base material was preheated to 280 °C. Cladding parameters have been chosen based on the procedures used to renovate the work rollers in practice. During process, a constant voltage cladding system was implemented. The cladding voltage and wire feed are controlled. The current size during cladding was 300 A. Table 4 shows the cladding parameters used for all types of welds. The samples were tempered at two temperatures, 280 °C and 480 °C for 5 h, cooled in an electric furnace. Visual inspection according to EN ISO 17637, capillary test according to EN ISO 23277. and ultrasonic inspection according to EN ISO 11666.

Table 4. Used cladding parameters.

Preheating	280 °C
Roller rotation speed	270 mm·min ^{−1}
Spiral climb	11 mm
Voltage	29 V
Wire feed speed	6 m·min ^{−1}

2.3. Filler Materials

Four types of experimentally new developed filler materials were used in the experiment, whose chemical composition in the four-overlay layer is in Table 5. Chemical analysis of the clad layers was carried out in the fourth surfacing layer, as the aim was to determine the chemical composition of the surfacing itself, without mixing with the base material. The analysis of the welds showed that the chemical composition of coatings differs significantly only in three components. The highest percentage of Cr contains layer with wire B1, the highest percentage of C contains layer with wire B2. In the layers made of filler materials B3 and B4, the Cr content was reduced to about 2.88%.

Table 5. Chemical composition of clad layers (wt%), Fe Bal.

Weld Deposit	C	Mn	Si	P	S	Al	Cu	Ni	Cr	Ti	V	Nb	Zr
B1	0.27	1.01	0.55	0.02	0.01	0.02	0.05	0.21	5.2	0.02	0.02	<0.01	<0.005
B2	0.46	1.05	0.54	0.02	0.01	0.03	0.04	0.2	4.81	-	0.26	0.003	-
B3	0.24	0.95	0.49	0.02	0.01	0.02	0.05	0.19	2.88	-	0.01	0.002	1.174
B4	0.41	1.00	0.23	0.01	0.01	0.04	0.04	0.02	2.89	-	0.01	<0.002	-

2.4. Methodology of Chemical Composition Assessment and Structural Analysis of Clad Layers

Chemical analysis was performed on transverse metallographic sections in individual weld layers. An electron microscope JEOL JSM-7000F (JEOL Ltd., Tokyo, Japan) was used for the analysis, which was supplemented with a device for energy dispersive microanalysis, allowing elemental analysis.

2.5. Methodology of the Hardness Test

The hardness test was carried using Vickers pyramid indenter, test load of 10 kgf (98.07 N), dwell time 15 s, measuring device WOLPERT 930 (Wilson Wolpert Instruments, Aachen, Germany).

2.6. Methodology of the Evaluation of Welds by Static Tensile Testing

The static tensile test was performed on the ZWICK Z 400 (ZwickRoell GmbH and Co. KG, Ulm, Deutschland), according to EN ISO 6892-1. The test specimens were removed from the cylinder without heat treatment under intensive cooling. The test was performed on a RoellAmsler RKP 450 (ZwickRoell GmbH and Co. KG, Ulm, Germany) according to EN ISO 148-1.

2.7. Methodology of the Impact Bending Test

Impact bending test was performed according to standard ISO 148-1:2016 “Metallic materials—Charpy pendulum impact test” using V-notch samples, 25 samples were tested within every assessed type of clad layer, at temperature of 21 ± 1 °C. The notch was made perpendicular to the axis of the backup roll, in direction from the surface to the core of the roll. Charpy pendulum used HIT450P (ZwickRoell GmbH and Co. KG, Ulm, Germany).

2.8. Methodology of the Evaluation of the Fatigue Wear of Clad Layers

Rolling fatigue was evaluated on the R-MAT. The layout of the test samples and their dimensions are shown in Figure 1a,b. The disc dimensions used were: $R_{11} = 72.5$ mm; $R_{12} = 4.5$ mm; $r_{21} = 4.8$ mm. The discs are made of 100CrMnSi6-4 bearing steel. They are hardened to a hardness of 722–775 HV.

The effect of cyclically repeating contact stresses on the surface layer of the material is manifested as “pitting”. Test specimens made of weld deposits were stored in ball bearings. They were rotated by the effect of friction. The test device indicates the occurrence of pitting by sensing the vibration of the test samples by acoustic emission. Acoustic emission (AE): This method can be used for detection of very small energy loss processes, e.g., friction, cavitation, and the contact of rolling bearing parts. AE arises in irreversible dislocation and degradation processes in both the macro- and micro-structure of material. In such cases, energy is released; it is changed into a mechanical stress impulse spreading in the material in the form of a crosswise or lengthwise stress wave which, when reaching the interface of the surface and air, partially bounces and partially transforms and spreads by so called Rayleigh waves and is partially transformed into Lamb waves. The released energy is very small, which requires very sensitive sensors. Piezoelectric sensors are usually used. The waves are detected by piezoelectric sensors with frequency zone from 100 kHz to 4 MHz with resonance frequency above measured scale or by resonance sensors with more resonances and adjustable sensitivity depending on frequency in case of narrow measured zones [33–36]. The test samples were subjected to 13, 16, and 19 kg weights during the experiment. The maximum test time was 3000 min.

Figure 1. Fatigue contact testing (a) scheme of the friction element arrangement during the test on R-MAT. (b) An evaluated sample in R-MAT.

3. Results and Discussion

3.1. Non-Destructive Testing of the Cladded Layers

The visual inspection performed according to EN ISO 17637 standard confirmed the good quality of the weld deposits. No surface defects were found on the evaluated surfaces. The quality of the overlay was also confirmed capillary test according to EN ISO 23277. The presence of internal errors was not recorded with realized ultrasonic inspection according to EN ISO 11666. The quality of the cladded layers can be classified in the highest class, B—EN ISO 5817.

3.2. Structural Analysis of Clad Deposit B1

The microstructure of surfacing layers made by wire B1 is shown on Figure 2. On the metallographic section it was after etching with 3% HNO₃ solution possible to observe a clad made in five layers. Additionally, the heat-affected region with the thickness of 3.4 mm was quite visible. The area of mixing clad layer metal with the base material is narrow. In addition to the grain size change, the concentration of the dark pearlite phase can be observed at the boundary, and the troostite was also observed. Figure 2 shows the microstructure of the clad boundary. The microstructure of the first layer is formed by tempered martensite. The microstructure of the second surfacing layer is formed by sorbitol, Figure 2b. Carbide phases were observed. The third surfacing layer has a structure formed by heterogeneous tempered martensite, Figure 2c. The microstructure of the fourth surfacing layer is

formed by partially tempered martensite with preserved subeutectoid ferrites deposited in light bands at the boundaries of the original austenitic grains, Figure 2d. The cover layer of the clad has a structure consisting of tempered martensite and troostite, Figure 2e,f.

Figure 2. Microstructure of surfacing layer B1.

3.3. Structural Analysis of Clad Deposit B2

The microstructure of a clad with five surfacing layers made by additive material B2 is shown on Figure 3. The microstructure of the transitional area is documented on Figure 3a. At the fusion boundary, there was acicular ferrite on the base material, pearlite and troostite were found in the dark region. The narrow melting region is followed by the original massive austenitic grains of the layer containing needle-like, partially thickened martensite. The grain boundaries are lined with the pearlite phase, as well as the troostite. The grains are oriented in the direction of cooling of the clad layer metal. The microstructure in the first surfacing layer is shown on Figure 3b. It is formed by a needle-like,

partially-tempered martensite. At the boundaries of the original grains, troostite is excluded and perlite exists in a small volume. The microstructure of the transit of first and second surfacing layer is shown on Figure 3c. It is a partially preserved primary dendritic structure. At the boundaries of the original grains, troostite is excluded. The microstructure of the third surfacing layer is formed by arranged martensite dendrites, Figure 3d. The microstructure of the fourth surfacing layer is formed by tempered martensite at lower temperatures. The microstructure of the cover layer is documented on Figure 3e,f. It is a partially preserved primary dendritic structure with nucleus of tempered needle like martensite. Inclusions are also observed.

(a) Interface detail between the heat-affected region and the first surfacing layer.

(b) Microstructure of the first surfacing layer.

(c) Transit of the first surfacing layer to second surfacing layer.

(d) Detail of the dendritic structure of the third surfacing layer.

(e) Microstructure of tempered martensite in the clad layer.

(f) Primary dendritic microstructure with tempered martensite.

Figure 3. Microstructure of surfacing layer B2.

3.4. Structural Analysis of Clad Deposit B3

The area of mixing the clad and base material in the transitional area was very narrow, and the concentration of the pearlite phase and the acicular ferrite can be observed at the fusion boundary. In the area of mixing, the structure is composed of fine-grained sorbite and troostite. The detail of this thermally-influenced structure of the first clad metal layer is shown on Figure 4a. The structure is formed by sorbite and tempered martensite. The transition of the first and second layer is shown on Figure 4b. The structure is formed by needle martensite. The original austenitic grains are well visible on the structure. The microstructure of the first surfacing layer is formed by tempered fine-grained martensite and troostite. The transitional area of the second and third surfacing layer is shown on Figure 4d. A significant difference in the composition of structures in the transitional area of the second and third surfacing layer was recorded. Due to the heat introduced into the third layer, the structure in the second layer was annealed, where the sorbite and martensitic structure is present. The fine layer of heterogeneous martensite (it is also shown on Figure 4c) is documented in the third layer. The sorbite structure was observed in the fourth layer, Figure 4e. The microstructure of the cover surfacing layer is formed by tempered low carbon martensite and troostite, Figure 4d.

(a) Microstructure in the first surfacing layer of the sample.

(b) Microstructure on the surface of the first surfacing layer of the sample.

(c) Fine-grained tempered martensite in the third surfacing layer of the sample.

(d) Microstructure of the transition of the second and third surfacing layer.

Figure 4. Cont.

Figure 4. Microstructure of surfacing layer B3.

3.5. Structural Analysis of Clad Deposit B4

The microstructure of the clad made using the additive material B 4 is shown on Figure 5. It is a clad deposit made of five layers. Figure 5a shows the microstructure of the transitional area of base material in heat affected region onto the welding layer metal. In the heat-affected region, the structure is formed by acicular ferrite. In the area of mixing the clad layer metal and first surfacing layer the structure is formed by finely divided sorbite and troostite for the reason of multiple annealing, as result of depositing the clad passes and following heat treatment. On Figure 5b the structure is in the middle of the first surfacing layer formed by sorbite and troostite. The microstructure of the second surfacing layer is shown on Figure 5c. It is a fine-grained sorbite; a troostite structure with significant boundaries of the original grains. The detail of the second surfacing layer formed by troostite is shown on Figure 5c. The transition of the third and fourth surfacing layer is shown on Figure 5d. The weld clad is formed by the mixture of sorbite and troostite, especially for the reason of annealing by two another covers layers. The fourth layer has a distinctly different structure consisting of tempered martensite with well-defined boundaries of the original austenite grains. The presence of fine dispersed precipitates was noted in the structure. The microstructure of the fourth surfacing layer is formed by tempered low carbon martensite, Figure 5e. The structure of the fifth (cover) surfacing layer formed by fine-grained needle martensite is shown on Figure 5f.

Figure 5. Cont.

Figure 5. Microstructure of surfacing layer B4.

Figure 6 shows the course of average hardness values on flat specimen from base material up to the surface layer. The greatest hardness was measured on the deposit B2 in the layer 3. The layers 1–2 are the layers of material mixing, thus layer 3 stands for the actual clad hardness. From layers 3–7 the hardness values are very similar. The hardness values at B2 was 767 HV10. The lowest hardness values were measured on the deposit B3, 425 HV10. The deposits B1 and B4 showed identical hardness values of an average of 530 HV10 from the third layer.

Figure 6. Course of average hardness values from BM, through HAZ to weld clad on samples B1–B4.

3.6. Results of Static Tensile Test Measurements

Average mechanical properties of clad layers are shown in Table 6. Sample B3 showed the greatest average values of tensile strength. The lowest average values of tensile strength were measured on sample B2.

Table 6. Average mechanical properties of the clad layers.

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Contraction (%)
B1	981 ± 4	1033 ± 6	0.9 ± 0.2	4.54 ± 0.2
B2	744 ± 6	784 ± 8	1.0 ± 0.2	3.1 ± 0.2
B3	767 ± 8	1155 ± 11	5.2 ± 0.4	9.06 ± 0.3
B4	755 ± 4	888 ± 6	1.7 ± 0.2	3.8 ± 0.2

3.7. Results of Impact Bending Test Measurements

The test was performed three times from each clad deposit. Figure 7 shows the average values of the energy absorption and Figure 8 shows the values of the notch toughness. The B3 deposit showed the greatest absorption and notch toughness ability. On B2 the lowest values were recorded.

Figure 7. Measured values of energy absorption for individual clad layers.

Figure 8. Measured values of notch toughness for individual clad layers.

Clad layers must resist intense tribodegradation. Tests of rolling fatigue resistance of surfaces were performed in experiments. This type of phenomenon together with the adhesive wear of the surfaces, is one of the dominant types of degradation. In Figure 9 surfaces after exposure on a test experimental device are documented. The clad deposits were tested at three loads, 13, 16 and 19 kg. Defects were divided to three groups: A—small defect; B—medium-sized defect; C—large defect; and X—no defect. The tests on respective clad deposits were performed until a defect on the test specimen originated, yet the test lasted for the period of 3000 min as maximum. Details of the surfaces after wear are shown in Figure 10.

Figure 9. Surface of clad layers after rolling fatigue.

Figure 10. Macrostructure of surfacing layers at the wear point (19 kg).

Figure 9 shows some images of the defects and their onset time at different loads. Deposit B2 showed the best rolling fatigue results and it had the best resistance from all clad deposits. At the load of 13 kg for the duration of 3000 min no defect originated. When increasing the load to 16 kg small defects were formed and at the repetitive increase to 19 kg defects were formed that belonged to the B defect group. In both cases it was the pitting. Deposit B3 showed the worst results of rolling fatigue, where defects, developed pitting (Figure 9-B3) of a rather big size were formed already at the lowest load of 13 kg. At the load of 16 and 19 kg pitting was formed with cracks propagation. Such defects could cause major accidents in operations and mill delays. The deposits B1 and B4 showed minimum differences in the initial testing phase, even though at the load of 19 kg B4 showed a significantly higher wear. Figure 10 presents macroscopic defects images of respective clad deposits. The summary results of the evaluation of rolling fatigue by acoustic emission at a load of 13 kg are shown in Figure 11. When using the load (16 kg and 19 kg) there was a significant decrease in the pitting resistance times of the surfaces, which is documented in Figure 9. The simplest is the record of the total number of counts in the course of the test. An example of this “summation” curve can be seen in Figure 11. It is quite easy to identify time areas in which the mechanism of damage is strongly changed. In place marked X, the stage of running-in is finished and strong pitting appears in place Y. The standard test system is switched off, by means of vibration sensors, in place Z.

Figure 11. Summation of records of the number of AE overshoots (counts) in the course of contact fatigue tests of clad deposits.

4. Conclusions

Based on realized experiments it is possible to define the following conclusions on the suitability of application of individual filler materials for welding of functional surfaces of cylinders by SAW method. Deposit B1—the cover surfacing layer has a structure formed by tempered martensite and troostite. Deposit B2 has, on the cover surfacing layer, a well-preserved dendritic structure with nucleus of tempered needle like martensite. Occurrence of inclusions was also recorded. B3 has a cover surfacing layer structure formed by tempered low carbon martensite and troostite. B4 cover surfacing layer structure is formed by fine-grained needle martensite. B1 appears from among all structures as the most suitable structure since it has a sorbite structure, eventually tempered martensite in all its layers.

Hardness measurement was performed from the base material to surface layer, the respective indentations were at the distance of 1 mm from each other. When testing flat samples, the biggest hardness was recorded on the deposit B2 (in average the value HV10 was 767). The lowest value was measured on the deposit B3 where the average values were at about 425 HV10. Deposits B1 and B4 showed almost identical values, they were at about 530 HV10.

When measuring the hardness on circular samples the biggest hardness was recorded on the deposit B2, (767 HV10). In the depth of 3 mm below the surface the hardness decreased to the value of 756 HV10, whereas in the depth of 6 mm the hardness increased to 408 HV10. This deposit type represented the greatest values. Deposit B3, 425 HV10 showed the lowest average values on surface. From these results dependences of residual stress and hardness by respective layers were formed.

The static tensile test showed the highest values of strength, strain and taper limit in deposit B3. The average tensile strength was 1155 MPa, the average elongation reached 5.2% and the average contraction value was 9.06%. The lowest values were measured on the deposit B4.

The impact bending test revealed that the deposit B3 has the biggest absorption and notch toughness values, the absorption values were at 35 J and the notch toughness value was 50 J/cm². Deposit B2 showed the lowest values. Here the absorption values were at the limit of 5.2 J and the notch toughness was 8 J/cm².

The rolling fatigue was analysed at three loads, 13, 16 and 19 kg. For these loads, the area of the specimen and start of the defect formation were observed. Defects were divided into three groups, A—small defects; B—medium-sized defects; and C—large defects. Deposit B2 showed for all loads the lowest wear values. At the load of 13 kg and for the period of 3000 min no defect originated. A small defect originated only at the load value of 16 kg. At the load of 19 kg the defects increased and reached the medium-sized defect values.

From the complex assessment of analysed deposit properties (strength, hardness, plastic properties, toughness and wear) and their structure it can be stated that the deposit B 1 is the most suitable clad material for cladding of backup rolls, namely for the following reasons:

Based on these requirements the use of the deposits B2 and B3 seems to be less suitable than B 1 and B4, whereas the deposit B1 has better mechanical properties.

The highest rolling fatigue resistance was shown by the weld metal designated as B2. Only the surfaces of this weld metal resisted the damage (pitting) for the specified time of 3000 min. Lower resistance to rolling fatigue was shown by the weld B1. The B3 and B4 welds did not withstand the specified time of 3000 min even at the lowest applied load of 13 kg. As rolling fatigue is one of the primary tribodegradation factors in working and auxiliary rolls of the hot rolling mill, these indicators need to be taken into an account in the final evaluation of the chemical composition of the filler material for cladding. From the viewpoint of the structure of the clad surfacing layers the B1 deposit is also more suitable, since it has sorbitic structure or tempered martensite in all layers, with minimum differences in hardness, the transfer of base material and clad layer is continuous, and the mixing area is very low.

Based on comparison of all results from respective tests it can be observed that the B1 deposit is based on the structure analysis, hardness, adhesive wear, mechanical properties, rolling fatigue and residual stress the best suited clad layer. Based on the performed experimental work, in order to assess the suitability of the clad surfacing layers it is necessary to consider not only the mechanical properties of clad layers, but mainly the mutual relation between them, while considering also the tribological properties of clad layers for specific conditions of their wear in operation [37–41].

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