



QUALITY OF WELD CLADS APPLIED BY SAW METHOD IN ADHESIVE WEAR CONDITIONS

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Resume

This contribution deals with the analysis of the renovation layer quality of continuous casting steel rolls, developed through the submerged arc surfacing method (SAW). The continuous casting roll was analysed via the degradation phenomena which act during the operation. Four kinds of filler materials were used for the renovation of the worn roll. Surfacing was carried out as a three-layer in order to eliminate the need for intermediate layer formation. The quality of weld deposits was evaluated in terms of the structure, hardness and wear resistance of weld deposits at 23 °C and 400 °C using pin-on-disc wear test. The best properties showed newly developed filler material W8-WLDC8 from the point of view of the hardness, together with wear resistance of the deposited layers in room and elevated temperatures.

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1. Introduction

Nowadays, continuous steel casting lines are widely used for casting steel. The steel casting line is the equipment for the continuous casting of steel with a slab crystallizer. The movement of the slab provides tens of rolls. Rolls are therefore one of the key elements of the line. The rolls operate under hard conditions leading to considerable wear of the rolls. The costs to change them are a very significant component of the total costs of ensuring the operation of the device.

Rolls are made of creep resistant low alloy C-Cr-Mo steel: 41CrMo4 EN 10083-1-91 or C-Cr-Mo-V: 1.7733 24CrMoV55, they are solid (forged, or cut), hollow, water-cooled inside and outside, alternately heated by a hot slab and cooled by water/steam/air cooling. The slab temperature at the beginning of the casting line is approximately 1250 °C and at the end of the line around 800 °C.

From the tribological point of view, rolls are stressed by an adhesive-abrasive and erosive

wear. Movement of the hot slab on the rolls causes adhesive-abrasive wear on the surface of the rolls and the abrasive present on the roll surface (residues of casting powder, corrosive products, scales), acts as an abrasive agent and grinds/cuts the roll surface. On the surface of the roll pitting corrosion arises as a likely centre of fatigue cracks. Continuous casting rolls are water-cooled inside and outside; the cooling water is sprayed onto the surface of the roll through nozzles [1].

Spraying water containing dust and small particles induces erosive wear. This aggressive environment causes a reaction between the free hydrogen ions with the fluorine-rich slag. If the cooling water has a high chlorine content, their interaction in the high temperature stress causes stress corrosion, primarily in the areas of fatigue cracks. The oxidative gases (oxygen, air, water vapor, carbon dioxide, sulphur dioxide etc.) react with the metal surface and create a "layer of corrosion products" (ionic compounds). Reductive gases (hydrogen, ammonia, methane,

hydrogen mixed with other gases, etc.) react with the metal or non-metallic component of the material, eventually penetrate into the metal and dissolve within them. [2]

The high number of built-in rollers and need for the replacement of nearly a thousand portions of rolls every year has led to the renovation of damaged rolls, which is an economically more advantageous solution than the replacement with a new roll [3-9]. One way as to how to repair rolls is the utilization of hard surfacing technology, where the deposition of special welding layers with specific properties can extend the roll lifespan and improve their technological properties [10, 11]. The decision as to whether to repair or disable the worn roll can be made only

after visual and ultrasonic checks of a turned roll surface based on the presence of defects, Fig. 1. A practical criterion for disabling the roll from operation is the development of main cracks exceeding the thickness of the weld. Maximum wear acceptable for renovation is 12 mm in diameter of the functional surface of the roll and 2 mm in diameter of the pin.

2. Materials and methods

In the experimental part of the work, a twice-renovated roller of continuous steel casting line was treated (USS Košice, Slovakia), diameter 180 mm, made of steel X20Cr13 EN 10088-3 from the top of the curved part of the line, see Fig. 2. The chemical composition of the roll is shown in Table 1.

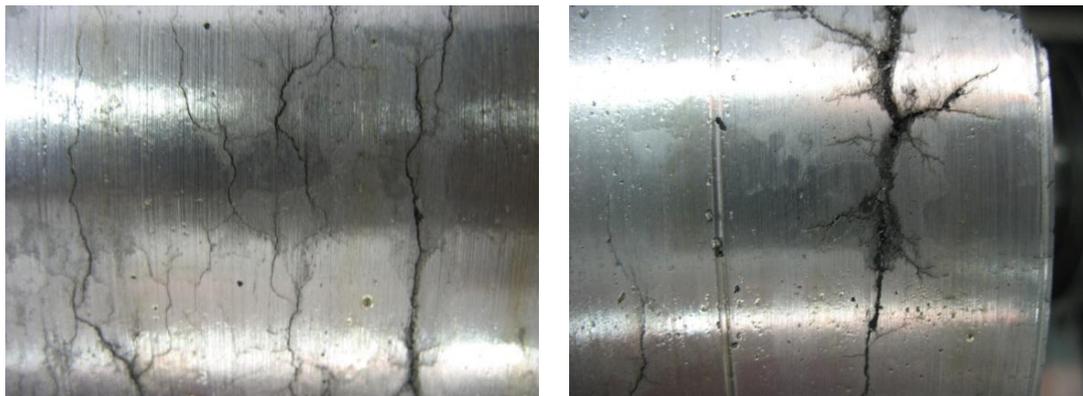


Fig. 1. Cracks on the surface of continuous steel casting roll caused by thermal fatigue

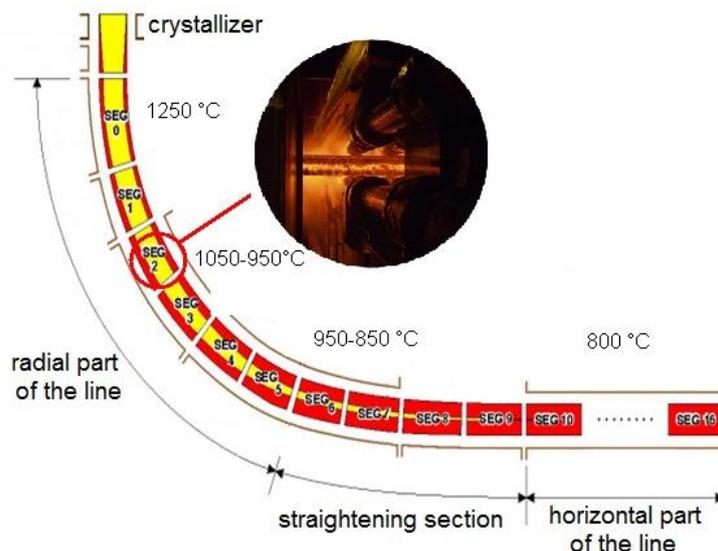


Fig. 2. Location of the roll in continuous steel casting line (full colour version available online)

Table 2

Chemical composition of welding wires used

| Wire | C | Si | Mn | S | P | Ni | Cr | Mo | Nb | V |
|--|------|-----|-----|------|------|------|------|------|------|------|
| WLDC 2 | 0.12 | 0.6 | 1.0 | 0.01 | 0.01 | 2.92 | 12.0 | - | - | - |
| Good resistance against thermal fatigue, corrosion and wear. | | | | | | | | | | |
| WLDC 3 | 0.1 | 0.6 | 1.0 | - | - | 2.5 | 12.2 | 0.8 | 0.15 | 0.15 |
| Cored wire for submerged arc welding of multilayer deposits on the functional surfaces. | | | | | | | | | | |
| WLDC 5Mod | 0.25 | 0.6 | 1.0 | - | - | 0.25 | 9.0 | 2.0 | - | - |
| Enhanced cored wire for submerged arc welding of multilayer deposits of hot rolling mills rolls. | | | | | | | | | | |
| WLDC 8 | 0.3 | 0.6 | 1.0 | - | - | - | 12.2 | 0.75 | - | 0.15 |
| Cored wire for submerged arc welding of multilayer deposition of hot rolling mill rolls. | | | | | | | | | | |

Table 3

Surfacing parameters

| wire | diameter | voltage | current | oscillation |
|-------------------|----------|---------|---------|-------------|
| W2-WLDC2 | 2,4 mm | 28 V | 350 A | 40 mm |
| W3-WLDC3 | 3,2 mm | 28 V | 450 A | 45 mm |
| W5HT-WLDC5 | 3,2 mm | 26 V | 600 A | 47 mm |
| W8-WLDC8 | 3,2 mm | 26 V | 450 A | 50 mm |

Mechanical properties of steel X20Cr13 [12]: tensile strength $R_m = 700 \div 850$ MPa, yield strength $R_{p0.2} > 500$ MPa.

The steel X20Cr13 is suitable for arc welding techniques and welding in a protective atmosphere. For hard surfacing of continuous steel casting roll flux-cored wires were used. Chemical compositions of welding wires are in Table 2.

For welding was used universal flux. Weld wires were manufactured by COREWIRE, Ltd. Wires W2-WLDC 2 and W3-WLDC 3 are commonly used for the surfacing of continuous steel casting rolls. Wires W8-WLDC 8 and W5HT-WLDC 5 have not yet been used for surfacing continuous casting rolls in practice. Surfacing parameters are given in Table 3.

The worn turned roll was placed on roll surfacing equipment Weldclad GU125LZ, COREWIRE Ltd. after preheating in electric furnace at 350 - 400 °C. On the roll base materials were subsequently deposited three layers using automatic SAW technology (method

121 STN EN ISO 4063) without interlayer. After surfacing, the roll was cooled down in an electric furnace in isothermal cooling wrap (cooling rate 40 °C/h) to room temperature and subsequently was tempered at 500 °C/8 hours. After tempering, the roll slowly cooled in the furnace (cooling rate was 40 °C/h). When the roll reached a temperature of 150 °C, the roll was next cooled down to room temperature in the open air. After the deposition of weld layers and after turning the presence of surface defects in the weld deposits was checked using visual test and liquid penetrant test (STN EN ISO 23277). Subsequently, the internal defects were checked by an ultrasonic test (reflection method) according to STN EN ISO 11666. The test samples were cut from the roll mechanically, without heat affecting the use of the material (water jet technology). The microstructure of the weld deposits was evaluated on the metallographic sections [13]. The hardness of the weld deposits was measured according to the Vickers method (STN EN ISO 6507-1) on metallographic sections with a load of 294.2 N (HV 30), loading time 15 s.

The wear resistance of the weld layers was evaluated in terms of adhesive wear (pin-on-disc, test temperature 23 °C and 400 °C, relative humidity 21 %, normal load 5 N, the track radius 2.5 mm, sliding distance 100 m, linear speed 5 cm.s⁻¹, static partner: WC-Co ball, diameter 6 mm, surface roughness of the specimen before the wear test: 0.1 µm). The wear of the test samples was evaluated by the coefficient of friction and wear track profile using a confocal 3D microscope in accordance with ISO 20808: 2004. Next, the wear volume of the specimen V_{disk} [mm³] and specific wear rate of the specimen $W_{\text{s(disc)}} [\text{mm}^3 \cdot \text{N}^{-1} \cdot \text{m}^{-1}]$ was calculated after loads at specified temperatures [14, 15].

3. Results and discussion

The thickness of the individual layers of the weld deposit was determined by a macroscopic analysis of the samples. The thickness of the cover layer was 2 mm, the thickness of the first weld layer ranged from

2 to 7 mm, the thickness variation of the heat affected zone for W2-WLDC 2 and W8-WLDC 8 was 7 - 10 mm and for W3-WLDC 3 and W5HT-WLDC was 7 - 13 mm. The structure of the base material is low carbon martensite. The chemical analysis proved the presence of the Mn, Cr, Si in the base material. Mn content was 0.3 %, Cr 13.8 % and Si 0.3 %.

The microstructure of the cover layer of W2-WLDC 2 is low-carbon tempered martensite, Fig. 3a. The cover layer contains globular inclusions arising probably from the flux used; the acicular structure partially remains.

Fig. 3b shows the microstructure of the cover layer W3-WLDC 3, low-carbon high tempered martensite (or sorbite) with the remains of the grain boundaries. Fig. 4 shows the martensite structure of the weld W5HT WLDC-5 with ferrite islands.

Fig. 4b shows the structure of weld deposit W8-WLDC 8: tempered martensite with small carbide particles. The hardness of the weld

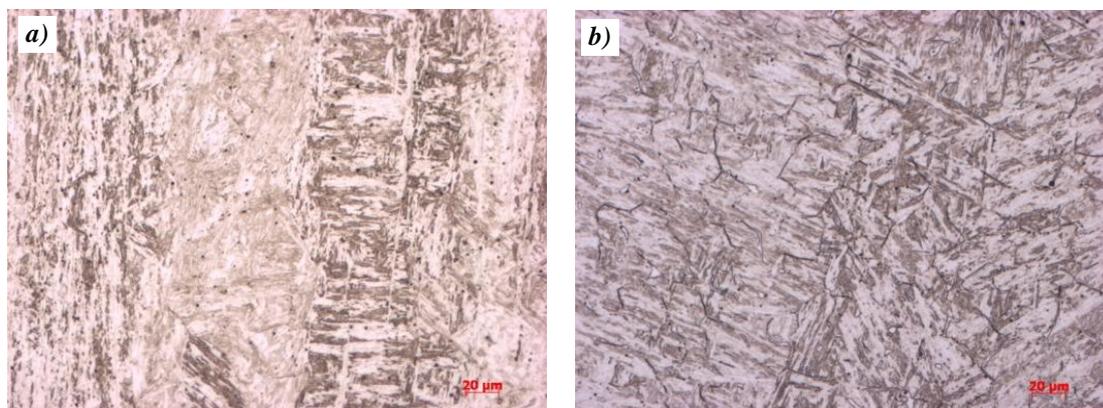


Fig. 3. Microstructure of cover layer of weld deposits a - W2-WLDC 2, b - W3-WLDC 3 (full colour version available online)

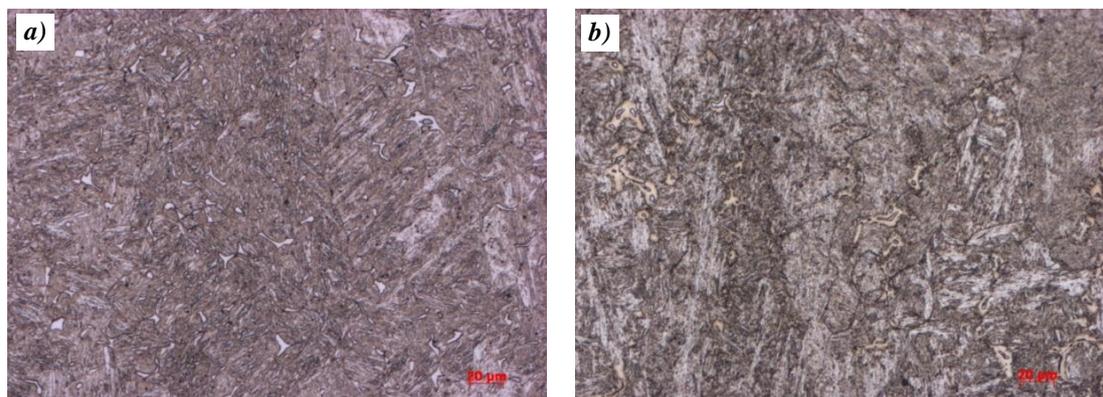


Fig. 4. Microstructure of cover layer of weld deposits a - W5HT-WLDC 5, b - W8-WLDC 8 (full colour version available online)

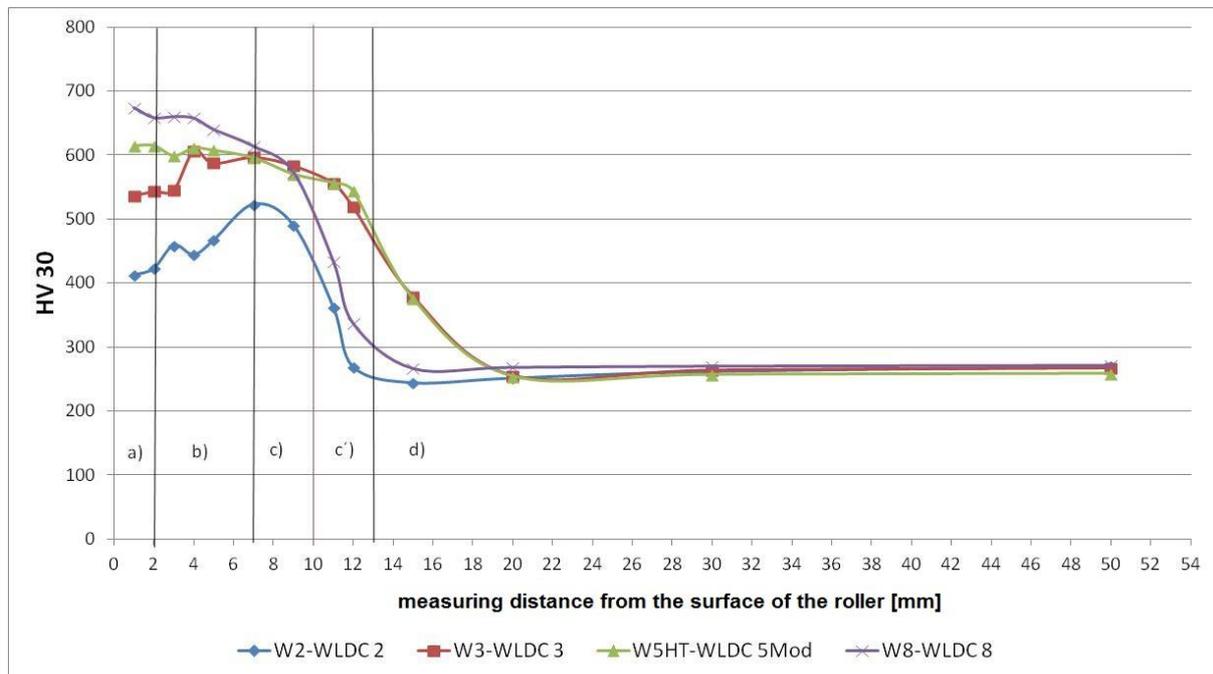


Fig. 5. Average values of surfacing layers hardness
(full colour version available online)

deposits was measured on metallographic sections from the functional surface of the roll to the base material, see Fig. 5.

The highest average hardness was found in the cover layer of weld W8-WLDC 8 at a distance of 1 mm below the roll surface, where it reached a value of 675 HV 30. The lowest hardness (412 HV 30) 1 mm below the surface was weld W2-WLDC. The hardness of the first surfacing layer varied in weld deposit W3-WLDC 3, W5HT-WLDC 5Mod and W8-WLDC 8 from 546 to 661 HV 30. The lowest hardness value was weld deposit W2-WLDC 2: 459 HV 30. During hard surfacing, heat affecting the base material occurred. It caused hardness increasing in HAZ approximately by 50 % compared to the unaffected base material. Hardness in HAZ at a distance of 7 mm from the surface was 520 to 614 HV30. Fig. 5 shows a decrease of the hardness values from the weld surface to the base material.

3.1 Evaluation of the weld deposits quality in terms of adhesive wear

At the start of the wear, the flattening of micro-peaks and the removal of material occur at the tribological contact place. Fig. 6

shows the appearance of the weld deposit wear track and profiles of the wear track.

Different wear track shapes were obtained with regard to the test temperature. In weld deposits W2 and W3 after the adhesive test at 23 °C in the bottom of the wear track, separating micro particles of material occurred and rolling up of material on the sides of the wear track. Due to the high temperature, the wear track was of equal width. Material loss at the temperature 400 °C is significantly higher compared with the material loss at 23 °C.

Evaluation of the weld deposits W5 and W8 showed a different wear track profile at both test temperatures, there has been registered a different wear mechanism. Due to the relative mutual movement of the static partner on the surface of the test sample at 23 °C, an adhesive micro-welds fracture occurred. Due to the higher test temperature, a wear track of equal width arose. Material loss at the test temperature 400 °C is significantly higher compared to material loss at 23 °C. Based on the measured data for the individual measured points for evaluated weld deposits, wear volume of disc specimen (V_{disc}) and specific wear rate was then calculated (W), Table 4.

Wear volume and specific wear rate of disc specimen

Table 4

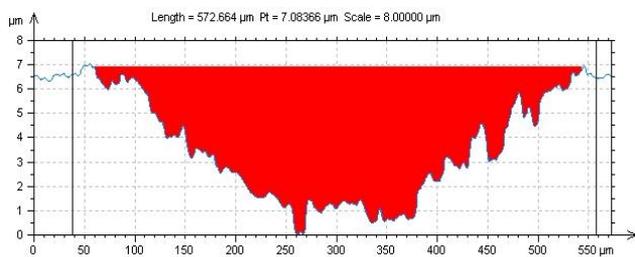
| Weld deposit | $V_{disc\ 23\ ^\circ C}^3$ [mm ³] | $V_{disc\ 400\ ^\circ C}^3$ [mm ³] | $W_{23\ ^\circ C}^{3\ -1\ -1}$ [mm ³ N ⁻¹ m ⁻¹] | $W_{400\ ^\circ C}^{3\ -1\ -1}$ [mm ³ N ⁻¹ m ⁻¹] |
|--------------|--|---|--|---|
| W2-WLDC 2 | 26,049 | 124,009 | 0,052 | 0,248 |
| W3-WLDC 3 | 15,997 | 123,132 | 0,032 | 0,246 |
| W5HT-WLDC 5 | 0,561 | 21,612 | 0,0011 | 0,0432 |
| W8-WLDC 8 | 0,688 | 19,186 | 0,0014 | 0,038 |

At test temperature of 400 °C higher material loss occurs compared to the material loss at 23 °C.

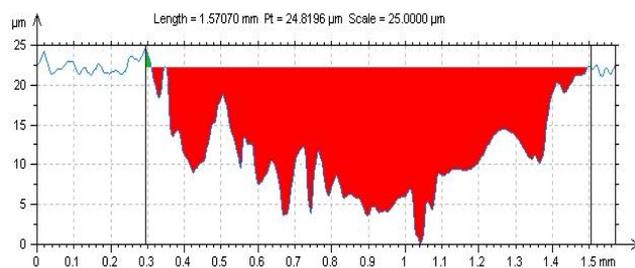
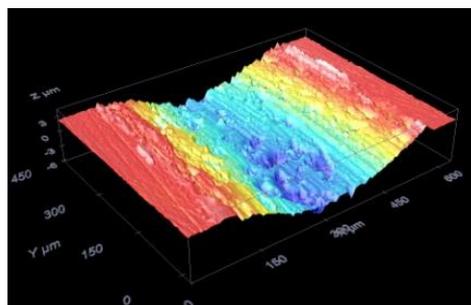
Weld deposits W2 and W3 showed a higher-order wear compared to W5 and W8. Weld deposit W8-WLDC 8 proved the highest wear resistance at the temperature of 23 °C and also at 400 °C. The lowest wear resistance was demonstrated by weld deposit W2-WLDC 2, today commercially used for the repair of the continuous steel casting rolls. The results

of the wear test can be explained by the hardness, structural characteristics and chemical composition of weld wires.

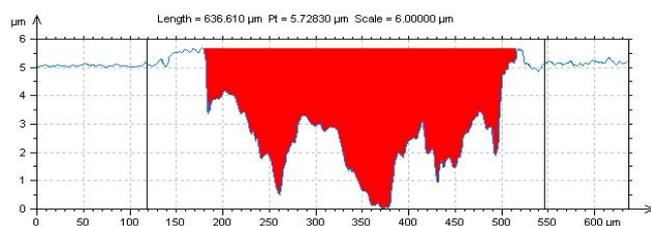
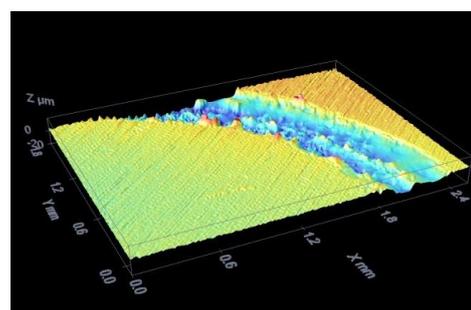
The influence of the test temperature on the friction coefficient is not evident, Fig. 7. The highest friction coefficient was on weld deposits W2-WLDC 2 and W3-WLDC 3. Weld deposits W5HT-WLDC 5 and W8-WLDC8 showed a continuous increase of the friction coefficient depending on the sliding distance.



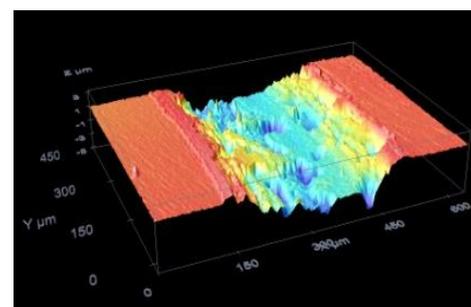
a) W2-WLDC 2, 23°C

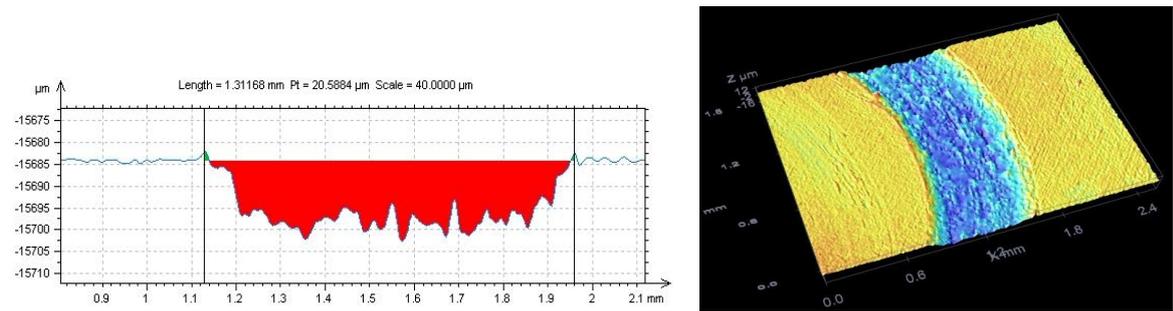


b) W2-WLDC 2, 400°C

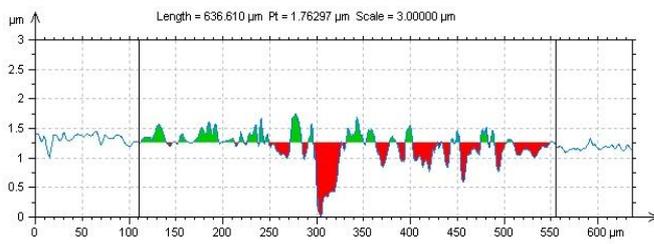


c) W3-WLDC 3, 23°C

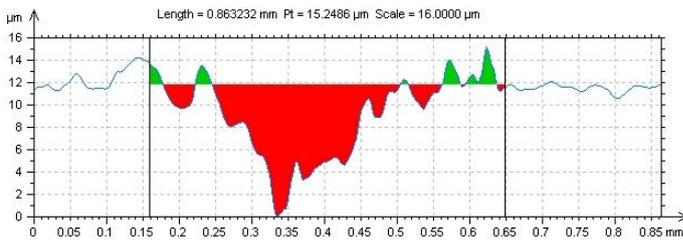




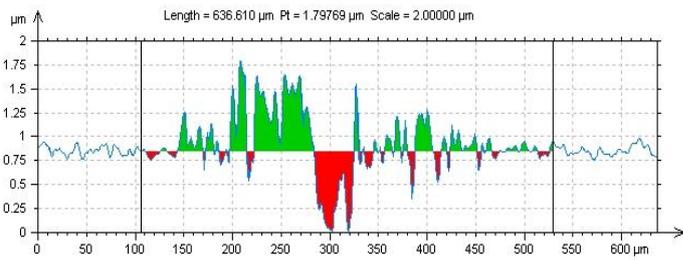
d) W3-WLDC 3, 400°C



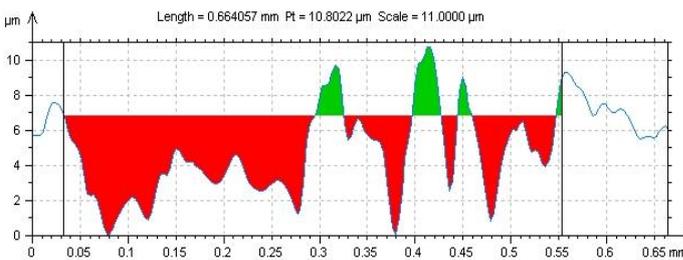
e) W5HT-WLDC 5Mod, 23°C



f) W5HT-WLDC 5Mod, 400°C

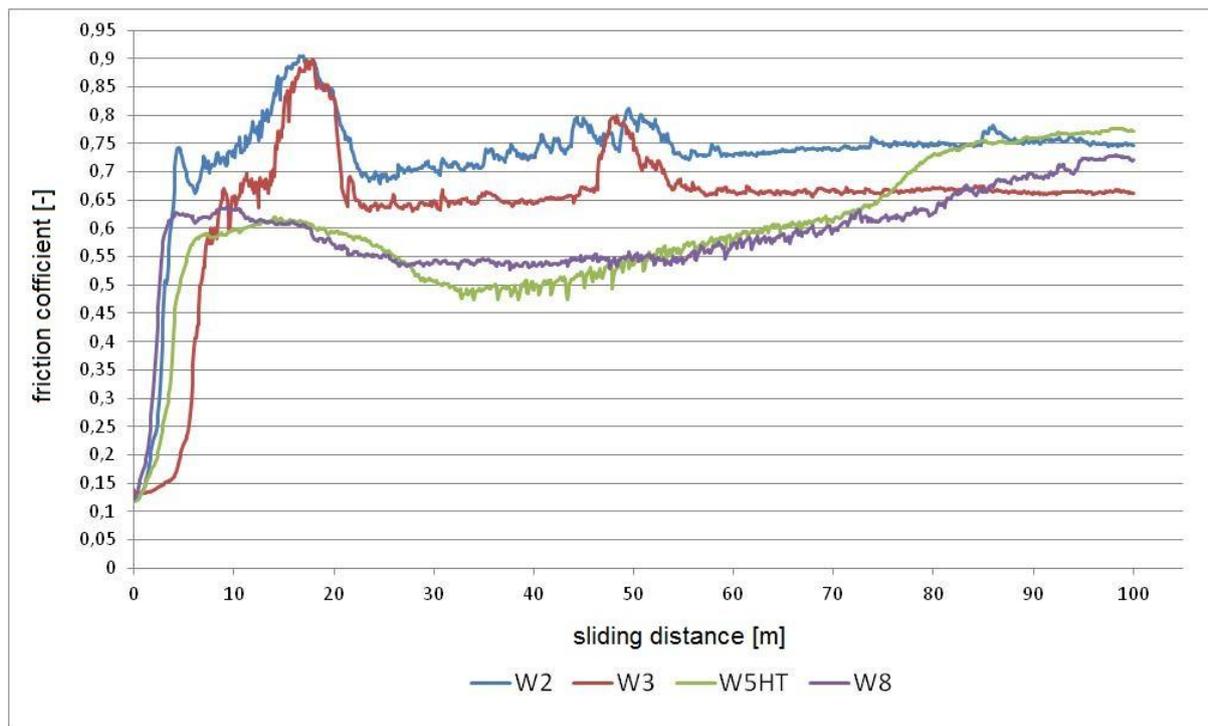


g) W8-WLDC 8, 23°C

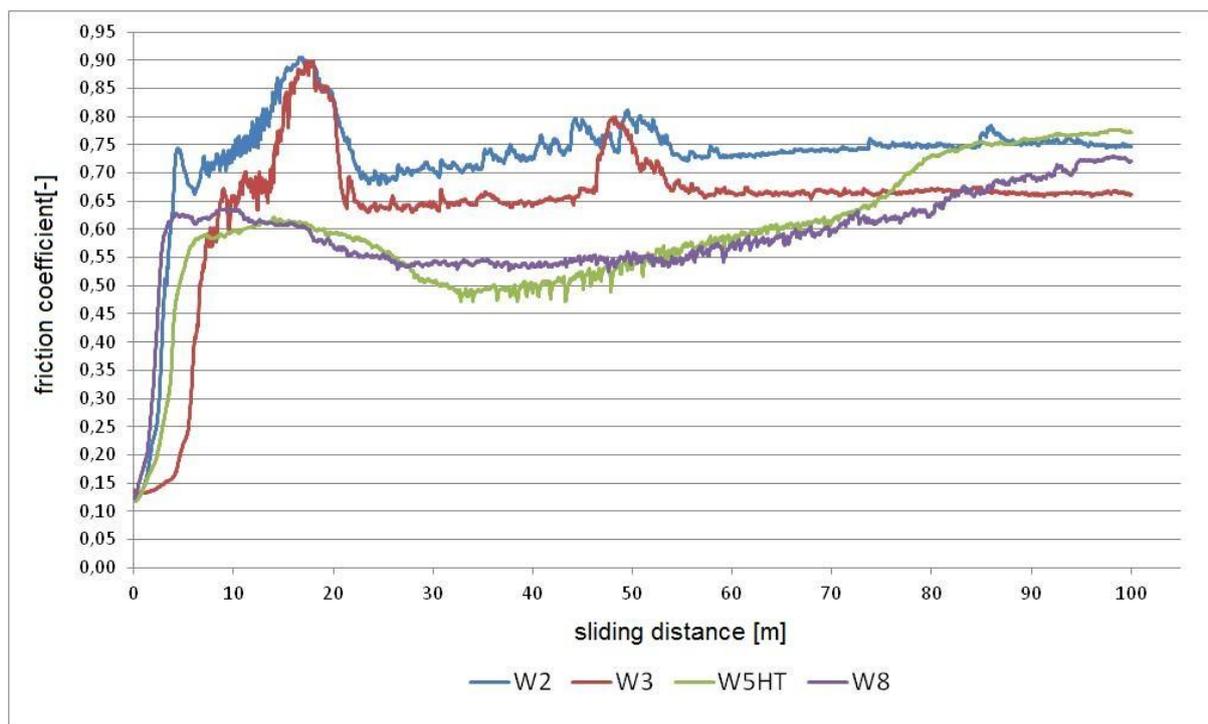


h) W8-WLDC 8, 400°C

Fig. 6. Wear track profiles and 3D views of the wear track after adhesion test at 23°C and 400°C
(full colour version available online)



a) at the temperature of 23 °C



b) at the temperature of 400 °C

Fig. 7. Friction coefficient of the weld deposits
(full colour version available online)

4. Conclusions

This paper analyzes the application capabilities of cladding layers and their resistance against degradation phenomena at the restoration of functional surfaces of rolls for

continuous casting line. Hard surfacing was realized by the method 121 STN EN ISO 4063 – SAW, without interlayer. Efforts are currently aimed at the realization of surfacing without interlayer mainly for economic reasons.

In the work, the quality of the claddings, made of four types of welding wires produced by COREWIRE, Ltd. was assessed using experimental techniques. Two of them have been used commercially for number of years for the restoration of continuous casting rolls: W2-WLDC 2 and W3 WLDC 3. In the experiment the newly developed welding wires W5HT-WLDC5 and W8-WLDC 8 were also used, which have not yet been used commercially for the restoration of functional surfaces of continuous casting rolls. The completed experiments were aimed at the evaluation of the microstructure of claddings and the change in their hardness. The adhesive resistance of claddings was evaluated at 23 °C and 400 °C. The temperature of 400 °C was selected for wear resistance tests of claddings because it is a temperature of normal operation of continuous casting rollers. Adhesive wear of rolls for continuous casting process was simulated in the contact load (pin-on-disc).

The structural analysis showed a low-carbon tempered martensite structure in the cladding layers. The hardness of cladding decreases from the surface to the base material of the roll. At a distance of 7 mm below the surface, the hardness of the material increased due to the influence of heat introduced into the material from an electric arc during cladding. At a distance of 13 mm below the surface, hardness values nearly the same as in the base material were found. In the course of surfacing, heat affection of the base material occurred, resulting in an average increase in hardness HV30 in HAZ approx. by 50 % compared to the unaffected base material. Claddings made using welding wires W3 and W5HT have a wider HAZ. The highest hardness in the cover layer was cladding W8 WLDC-8, the lowest was W2-WLDC 2.

Based on the analysis of the results obtained by simulation of the tribological phenomena operating in the continuous casting rolls during their operation, a newly developed

welding wire WLDC W8-8 can be identified as the most suitable for the restoration of rolls of continuous steel casting line. The slightly lower wear resistance exhibited cladding made by welding wire W3-WLDC 3. This commercially used type of welding wire can also be recommended for the restoration of continuous casting rolls. Cladding made by commercially used wire W2-WLDC 2 showed the lowest tribodegradation resistance and in experimental conditions of thermal stress the weld deposit failed. This clad showed the lowest hardness and adhesive wear resistance. Based on the measured results it can be stated that the cladding W8-WLDC 8 showed the lowest wear volume and the specific wear rate. The elevated temperature led to a higher specific wear rate and wear volume of materials for all types of weld claddings. The effect of the elevated temperature is more pronounced in the weld claddings WLDC 5Mod and W8-WLDC 8.

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