Renovation of worn surfaces of equipment in the metallurgical industry

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Abstract: The paper presents the possibilities of renovation of worn functional surfaces of roll for continuous steel casting. The cylinder was made of steel 24CrMoV55 - DIN 17240. The lifetime of the continuous casting line roll is limited by the quality of their functional surface. The worn roll is decommissioned and the extent of its damage has been assessed. Cracks are a limiting factor in deciding on its renovation. Renovation of functional surfaces of roller from a diameter of ø 200 mm is realized by technology submerged arc welding (SAW). The article presents the results of research into the quality of newly formed cladding layers. Their quality was evaluated using non-destructive and destructive tests. Based on the performed experiments, it can be stated that the used surface renovation procedure is suitable for the renovation of functional surfaces of continuous steel casting rolls.

Keywords: RENOVATION, SURFACE, WEAR, STEEL PRODUCTION

1. Introduction

At present 92.8% of the world’s steel production is cast by the continuous casting machine. [1] For the steel production the rolls of the continuous casting play the primary role. Their role is to carry out the deformation of the casting steel and to guide the cooling steel strip from crystallizer in the route of the fluent casting. The rolls of the continuous casting lines are exposed to the combined wearing out. The abrasive wearing out is dominant which has the secondarily influence on the adhesive wearing out using the cycling exposing under the high temperatures in the corrosive conditions (Fig.1). These tribodegradation factors have a significant influence on the operating life of the rolls of the continuous steel casting installed in tracks of the fluent casting. [2,9,10] Several hundreds of the rolls are installed in the lines of the continuous steel casting there. Caster roll life can become the limiting factor for efficient long run slab caster operation. [3] With such a number of the rolls a 100% reliability is a must. The amount of the rolls itself presents the high part of the expenses for the operation, that’s because the rolls are renovated if it is possible. Not all of the rolls could be renovated. Choosing the rolls for the renovation has to undergo the strict control which approves or disproves the convenience of the roll. The renovations are mostly done with completing the absent material, where the material with better quality, compared to the original material, can be used. [4, 8] Then the operation life of the renovated component can be longer than the original one. It has been possible to renovate the rolls three times so far. Then the rolls are subsequently excluded from the operation. The criterion for the wearing out of the rolls is the wearing out of the surface more than 1 mm on the roll average or a development of the corrosive-fatigue cracks more than 4 mm deep where is a danger of later breaking of the casting steel and to guide the cooling out the deformation of the casting steel and to guide the cooling part. The roll did not give a sign of the trans-crystal cracks. [7] Consequently the worn-out roll was lathed with the diameter of 14 mm. After the turning, it was necessary to check the roll again, the surface of the roll was checked visually according to the norm EN 13018 and for the under-surface testing was used the ultrasonic method according to the norm EN ISO 11666. It was necessary to preheat the roll up to 200 °C during which the temperature must have been checked continuously even during the surfacing. The range of the surfacing temperatures was from max. 200°C up to 380°C (8).

The roll assigned for the fourth renovation was firstly visually tested with focus on the crack presence on the body of the roll or in its cooling part. The roll did not give a sign of the trans-crystal cracks. [7] Consequently the worn-out roll was lathed with the diameter of 14 mm. After the turning, it was necessary to check the roll again, the surface of the roll was checked visually according to the norm EN 13018 and for the under-surface testing was used the ultrasonic method according to the norm EN ISO 11666. It was necessary to preheat the roll up to 200 °C during which the temperature must have been checked continuously even during the surfacing. The range of the surfacing temperatures was from max. 200°C up to 380°C (8).
For the renovation, the surfacing SAW technology was used, the cladding was made in three layers (10). The first bottom layer was created in the combination of the tubular wire UP-5-200-CZ \( \phi \) 2.8mm and the addition F 56 with the aim of perfect connection of the basic material with the covering layer. The covering layers were made by combination of the wire UP-5-45-CZ \( \phi \) 3.2 mm and the addition F 56. The parameters of the surfacing are presented in the Table no. 3. The chemical composition of the additional materials is displayed in the Table no. 4. For the surfacing the addition F 56 has been used whose basicity is 1.4 and the basic chemical composition is in the Table no. 5. [6]

**Table 3: The parameters of the surfacing of the fourth cladding**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Filler material</th>
<th>Diameter of wire [mm]</th>
<th>Cladding current [A]</th>
<th>Cladding voltage [V]</th>
<th>Cladding speed [m/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>UP-5-200-CZ</td>
<td>2.8</td>
<td>310</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Covering</td>
<td>UP-5-45-CZ</td>
<td>3.2</td>
<td>390-450</td>
<td>30-32</td>
<td>25</td>
</tr>
</tbody>
</table>

**Table 4: The basic chemical composition of the filler material (in wt. %)**

<table>
<thead>
<tr>
<th>DIN 8555</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>Nb</th>
<th>N2</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP-5-200-CZ</td>
<td>0.05</td>
<td>0.8</td>
<td>0.6</td>
<td>16.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>UP-5-45-CZ</td>
<td>0.07</td>
<td>0.7</td>
<td>0.6</td>
<td>13.0</td>
<td>0.7</td>
<td>0.2</td>
<td>0.12</td>
</tr>
</tbody>
</table>

**Table 5: The basic chemical composition of the addition F 56 (in wt. %)**

<table>
<thead>
<tr>
<th>SiO2</th>
<th>MnO</th>
<th>FeO3</th>
<th>Al2O3</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-16</td>
<td>max.1</td>
<td>max.1</td>
<td>42-48</td>
<td>8-13</td>
<td>max.1</td>
</tr>
<tr>
<td>CaF2</td>
<td>NaO</td>
<td>K2O</td>
<td>BaF2</td>
<td>P</td>
<td>S</td>
</tr>
<tr>
<td>24-30</td>
<td>max.0.5</td>
<td>max.2.5</td>
<td>max.1</td>
<td>max.0.6</td>
<td>max.0.6</td>
</tr>
</tbody>
</table>

Immediately after the surfacing it was necessary to temper the roll. The tempering temperature reached 540 °C with the maximum heat speed 50 °C per hour and the residence to this temperature lasted for 6 hours. Subsequently the cooling of the roll was 40 °C per hour up to 210 °C followed by the free cooling in the air. [6,7]

After the surfacing and heat treating the roll has been chip machined with the diameter of \( \phi \) 300h10 for the active part. Within the final testing of the surfacing the visual testing of the roll has been carried out according to the norm EN ISO 17637 as well as the penetration testing according to the norm EN ISO 23277 which has been supposed to reveal the surface and undersurface defects. For detecting the inner defects, the ultrasonic testing has been used according to the norm EN ISO 11666. Based on the NDT tests the roll has been classified as convenient.

After the successful surfacing creation, the destructive tests were done. To carry out the already mentioned tests it was necessary to take the example samples from the roll. In the Fig. 2 are shown the places where the samples for the destructive testing were taken. The samples from the cut roll have to be removed without the heat influence on the samples.

**EDX analysis**

For the EDX analysis the samples were taken from the covering layer and the observation was done with the microscope JEOL JSM-35CF. The EDX analysis itself was carried out on the analyzer LINK AN10/855.

**The metallographic analysis**

On the cross cuts the macro and microstructure were evaluated according to the norm EN 1321. The examined samples were taken from the basic material (BM), the transition part and the surfacing metal. The samples were cast into the dentacyl, metallographically refined, polished and finally etched with the etcher Villela-Bain. The evaluation of microstructure was done with the light microscope Olympus TH4-200.

The hardness testing HV

The hardening of the cladding, heat-affected zone (HAZ) and BM was realized on the cross cut of the roll according to the norm EN ISO 9015-1 using the Vickers’ method and the engine HPO 250 with the load 100 N and the temperature 20°C and the indentor’s operation lasted for 15 seconds. In the Fig. 3 the points of the incisions are depicted.

**The tensile testing**

The testing followed the norm EN ISO 6892-1. During the sample taking for the tensile testing the material were removed from the edge of the underclad layer, the Fig. 2 (D). The testing was carried out with the test engine TIRA test 2300 with the temperature 20°C. In the Fig. 4 is displayed the used example of the round shape.

**3. Results**

After the analysis of the cladding quality done by the visual, penetrant and ultrasonic method, the cladding of the roll was evaluated as convenient. Consequently, the destructive testing was carried out on the samples taken from the roll using the already mentioned method.

The chemical composition of the covering layer was identified by EDX analysis which is presented in the Table 6.

**Table 6: Chemical composition of the covering cladding layer (in wt. %)**

<table>
<thead>
<tr>
<th>C</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Nb</th>
<th>N2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05-0.07</td>
<td>12.5-13.5</td>
<td>0.7-1.1</td>
<td>3.5-4</td>
<td>max. 0.02</td>
<td>0.08-0.12</td>
</tr>
</tbody>
</table>

The macroscopic analysis

The macroscopic and microscopic structure was evaluated on the cross cuts of the roll. The macroscopic structure is seen in the Fig. 5. For better observation of HAZ it was necessary to etch the sample with the etcher Villela-Bain. The width of HAZ respects the amount of the input heat for the surfacing under the addition and duplicates the shape of the surfacing layers. In the macrostructure
the defects were not present. Martensitic microstructure of base material is in Fig.6.

The transition between the basic material and HAZ was fluent. By the influence of the added heat the transformation from the coarse texture bainitic forms to finegrained martensit was made. The place of mixture of the cladding with HAZ is narrow. The first layer of the clad metal is created by the coarse structure in the transit part. The microstructure of the welded layers is in the Fig. 7.

![Fig. 5: The macrostructure of the cladding](image)

![Fig. 6: The microstructure of the base material](image)

The cladding is made of the martensitic structure where carbides parts are found. The interlayer has been made of the structure without strong lines of the grain’s despite of the covering layer with intensive precipitates. While identifying, for more exact identification we have chosen the Schaeffler diagram.

Hardness testing HV
On the crosscut of the roll, the hardness of the cladding has been measured, HAZ and BM shown in the graph, on Fig. 8. So, the result is that the maximum average hardness was measured in the covering welded layer in the depth of 1 mm from the surface 405 HV10. Because of the growing distance of measuring from the surface, the decline of the hardness was depicted. In HAZ, the average measured hardness was 258 HV10. The basic material was measured with the average hardness 247 HV10.

Tensile testing
From the results we can say that HAZ shows the average value Rm 939.4 MPa what refers to the increase of 42.3% compared to the heat non-influenced BM. Elongation (A5) has already been increased to the value of 17.3% compared to BM.

![Fig. 7: Microstructure of the covering layer of the cladding](image)

![Fig. 8: Measured value of hardness](image)

4. Conclusion
The article presents the results from the analysis of the welded layers on the roll of the continuous steel casting with the average ø300mm from the material 24CrMoV55 – DIN 17420. The evaluated roll has been renovated by the technology SAW four times. The rolls of the continuous casting line are usually renovated 3-times maximum and then decapitated from the process of renovating the active plates. Because of the financial savings in the metallurgy, the possibility of the prolonging the operating life with one more cycle has been tested. The quality of the renovated roll has been evaluated by non-destructive and destructive testing. The visual, penetrant and ultrasonic testing of the welded roll has not confirmed the presence of the surface and under-surface defects. The destructive tests have been aimed on the analysis of the quality mainly in the heat influenced area which is the most defect sensitive. The defects found in this place are the most frequent reasons for the destruction of the welded layers on the rolls. The experiments have been carried out:

- the static tensile testing done according to EN ISO 6892-1 has confirmed the increase of the hardness material property in HAZ with the measured average values Tensile Strength = 939.4MPa, Yield Strength = 783 MPa and elongation A5 = 17.3%.

- in the welds the metallographic analysis of the cross cuts has not identified the presence of the inner defects. The structure of the basic material of the roll is created by the low temperature martensite.

The structure of the interlayer and the covering layer has been formed by the low-carbon martensite. For increasing the resistance against the abrasive wearing the welded metal is alloyed with Cr and N whose main role is to strengthen the structure precipitally with carbides and nitrides.

This contribution has brought the useful information about the renovations of the continuous casting lines which are consequently applied in the operation of steel production using the continuous casting lines. Based on the experimental results we can state that the
evaluated roll fulfils the criteria of the renovation quality for reusing it in the continuous casting line.

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5. References:

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