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CRACKING DUE TO REPAIR WELDING OF THE TREIBER ROLL

STVARANJE PRSLINA NAVARIVANJEM NA TRAJBER ROLNI

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Abstract

Repair welding has caused crack initiation in the upper Treiber roll in the steel works plant mill at Železara in Smederevo. The upper and lower Treiber rolls serve the purpose of folding and directing rolled metal strips, supplied by the output rollers to the coiling mandrel. The parent material of the upper Treiber roll is S235JO. Unsuccessful welding resulted in a series of further activities to remove cracks. In addition, the cracks are identified on the Treiber roll for easier designation and monitoring while machining. Hardness tests have been performed on specific locations within the welded hard layer. After machining and removal of the whole welded layer with defects, it is determined that the welding activities contributed to the occurrence of a number of cracks in the parent material, which did not exist prior to surfacing. Hence, steps that need to be taken in order to eliminate these cracks in the parent material are suggested at the end of this paper.

Izvod

Prikazan je uticaj navarivanja na stvaranje prslina u gornjoj trajber rolni pogona u Železari Smederevo. Gornja i donja trajber rolna imaju zadatak da izvaljanu metalnu traku koja se dovodi izlaznim rolganom u motalicu previju i usmere na trn za namotavanje. Osnovni materijal gornje trajber rolne je čelik S235JO. Neuspelo navarivanje je uslovilo čitav niz daljih aktivnosti radi eliminisanje prslina. Pored toga, izvršena je identifikacija prslina na trajber rolni u cilju lakšeg označavanja i praćenja ovih prslina tokom mašinske obrade. Urađena su ispitivanja tvrdoće na pojedinim mestima tvrdog navara. Nakon mašinske obrade i skidanja celokupnog navara sa greškama, utvrđeno je da su zavarivačke aktivnosti uslovile pojavu jednog broja prslina na osnovnom materijalu trajber rolne koje nisu postojale pre samog izvođenja zavarivanja. S toga su na kraju rada dati predloženi koraci za naknadno eliminisanje ovih prslina u osnovnom materijalu.

INTRODUCTION

Welding and related activities represent a process which requires special attention, starting from the design stage, through the development and technology up to the inspection stage, all in the purpose of putting the weld into exploitation, /1/. Deviations that occur during each of these stages may result in defects. Activities during repair welding that need to be undertaken are in accordance with the general repair weld algorithm. Prior to surfacing, the following group of activities should be performed:

- damage analysis,
- development of the repair welding procedure,
- welded joint control.

One of important activities during procedure development involves the analysis of the possibility of crack initiation and its prevention. Preheating prior to welding is one of those activities along with cooling or additional heat treatment where necessary. This requires solid knowledge from welders, and in particular, welding engineer. Welding must be performed entirely in accordance with the selected technology and procedure. Welders and welding coordinator should be thoroughly familiarized with these activities and are required to check if all of the predefined conditions have been met prior to welding. In order to provide the required level of quality, it is necessary to perform the welding in accordance with existing standards and regulations. Technological charts (WPS) must contain all of the necessary parameters (basic and additional) which provide insight into the welding technology, and as such can be individual entities, provided to the welder. There are cases in which welding is performed by personnel who are not experienced in the selection of welding technologies, or who are overconfident about their knowledge, which can lead to wrong results and unsuccessful welding.

REPAIR WELDING PROCEDURE BACKGROUND

Presented in this paper is the case of repair welding of the upper treiber roll within the ‘Topla Valjaonica’ facility at the Železara Smederevo mill plant with the influence of inadequately performed welding procedures on crack initiation as well as the activities necessary for their removal. Both lower and upper treiber rolls are driving rolls with their independent drive train placed in front of each strip winder. These rolls serve the purpose of folding and directing metal strips supplied by the output rollers to the coiling mandrel. The treiber roll also has the task of providing sufficient tensile force in the strip between the rolls and the coiling mandrel. The diameter of the upper Treiber roll is ∅900 mm, its calibrated length is 2280 mm, whereas the lower roll diameter is ∅400 mm. These driving rolls have the power of 0-420 kW, whereas their RPM can go up to 1150 min^{-1}. The position of the treiber rolls within production line is shown in Fig. 1.

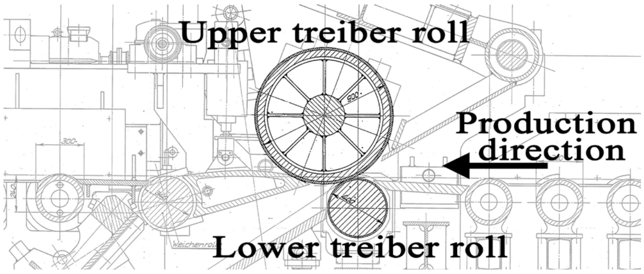


Figure 1. The position of Treiber rolls within the production line.

Regular maintenance in a form of repair welding of the upper treiber roll is necessary due to damage caused by exploitation conditions and wear, as predefined by the manufacturer (SIEMAG-SMS GROUP). The roll was premachined in the mechanical workshop within the Železara Smederevo to a diameter of ∅870 mm. Magnetic flux testing of the whole roll is performed after machining (including the branch and the work surface). No cracks were detected on the work surface of the roll. Cracks were detected in the branch, resulting in additional machining. After the additional machining and testing of the branch, it is determined that the cracks have been removed. From the above it can be concluded that the surfacing of the parent material is performed flawlessly. The thickness of the welded hard layer is defined at 40 mm within the repair welding procedure, including the intermediate layer, i.e. the diameter of the roll should be ∅910 mm. During the machining process, the upper roll diameter should be reduced to a diameter of ∅900 mm.

The performed repair welding was unsuccessful, resulting in the occurrence of cracks after the cooling process. This was followed by a series of other activities for the purpose of removing cracks in an inadequate way, causing even more problems (related to machining and damage in the parent material).

In the following section of this paper, a detailed overview of all activities performed during welding, as well as activities performed in order to remove cracks, are presented. Also shown in the conclusion is the overview of future activities related to repairing the roll damage due from welding activities.

PARENT MATERIAL

Steel S235JO (Č.0361), general structural steel with good weldability, is used as the parent material for the treiber roll. Its chemical composition is shown in Table 1, whereas its mechanical properties are given in Table 2.

Table 1. Chemical composition of the steel S235JO.

element	C	Si	Mn	Cr	Ni	Cu max.	P max.	S max.
wt. %	0.17	0.3	1.4	/	/	0.55	0.045	0.009

Table 2. Mechanical properties of the steel S235JO.

Tensile str. [N/mm^2]	Yield str. [N/mm^2]	Elongation [%]	Toughness [J]
400-490	245	22	27

Evaluation of steel weldability is determined using the carbon equivalent (C_{eq}) and taking into account the effects of chemical elements on the tendency of forming of brittle phases during the cooling of the welded joint. Considering that, of all elements, carbon has the highest influence, the influence of other elements is reduced to its equivalent.

Evaluation of this steel's weldability can be performed based on the total carbon equivalent according to the Seferian method, and its value is 0.33. The calculated value is within the range of $0.3 < C_{eq} < 0.5$, which suggests that welded joints of required quality can be obtained with the use of preheating or other technological measures.

One indicator of increased brittleness due to phase - structural changes, i.e. the tendency towards cold cracking, is the hardness (HV) of the heat affected zone. It is considered that, in the case of most structural steels, brittle phases will not form if the hardness does not exceed the value of 350 HV. Based on the chemical composition of the structural steel and the empirical formula shown in Eq.(1), the hardness value can be determined as

$$HV = 90 + 1050C + 47Si + 75Mn + 30Ni + 31Cr \quad (1)$$

Based on the value of HV = 317.6, it can be concluded that steel S235JO does not have a tendency towards cold cracking. For the purpose of analytical evaluation of the tendency towards hot cracking, the empirical coefficient HCS can be used, which it is given by Eq.(2) and it depends on the percentage of alloying elements. If HCS is less than 4, cold cracks probably will not form in the weld metal made of steels with $R_{eh} < 700$ MPa, whereas in the case of high strength steels ($R_m > 700$ MPa), the condition is more rigid, and HCS < 1.6.

$$HCS = \frac{C\left(S + P + \frac{Si}{25} + \frac{Ni}{100}\right)103}{3Mn + Cr + Mo + V} \quad (2)$$

Based on the obtained HCS value of 0.4 for steel S235JO, it can be concluded that this steel does not have tendencies towards hot cracking. It is concluded that steel S2325JO has good weldability and does not have tendency towards cold or hot cracking.

REPAIR WELDING TECHNOLOGY

Welding is performed up to the outermost rings on both sides of the work surface. The first two layers represent the intermediate (puffer) layer. The following three layers represent the hard weld. Repair welding is performed using the automated Flux-Cored Arc Welding procedure (FCAW) with the use of the following consumable materials:

- WLDC 9 wire, along with the universal Weldclad powder is used for the intermediate layer. The wire is low-alloyed flux-cored, used for submerged-arc welding for build-up, maintenance and repair. WLDC 9 has excellent hot slag release, especially suitable for continuous welding operations. Universal Flux is suitable for single and multi-pass welding using single- or twin wire technique, /4/.

- WLDC 17 wire is used for the hard weld. This wire is fully basic, all mineral, non-alloying agglomerate flux for submerged arc welding wire, used for multilayer surfacing of hot strip mill process rolls including wrapper rolls and has a martensitic matrix, /4/.

Layers are applied using the oscillation technique, with weld overlap of 30-35%. Welding parameters are given in Table 3. Cooling of the welded joint is performed at room temperature.

Table 3. Welding parameters.

Layer	Electrode	Temperature max	Current	Polarity
1	WLDC 9	420°C	500-550 A	-
2	WLDC 9	420°C	500-550 A	+
3	WLDC 17	420°C	500-550 A	-
4	WLDC 17	420°C	500-550 A	+
5	WLDC 17	420°C	500-550 A	+

The diameter of the roll after welding is between ∅910 and ∅912 mm. The roll was not annealed after the welding process. Cracks have occurred in certain zones of the roll. The detected cracks were grooved by grinding. It is determined that the cracks cannot be eliminated and is assumed that they have propagated into the pre-machined parent material. One part of the grooved cracks with designated fields is shown in Fig. 2.

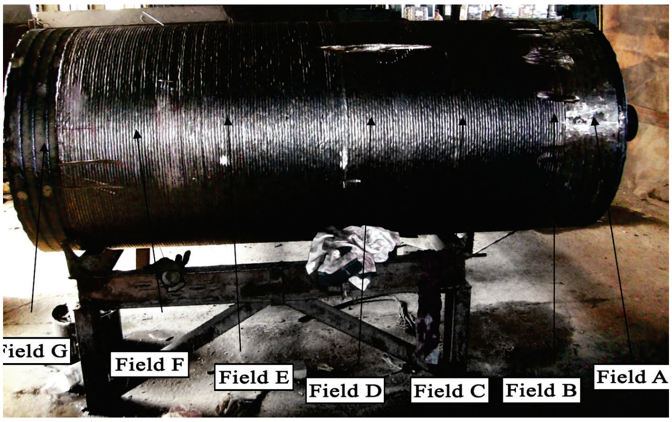


Figure 2. The Treiber roll after welding and grooving.

IDENTIFICATION OF CRACKS

A total of 46 cracks are detected in the roll along with small mesh cracks in field A along the circumference. For the purpose of easier identification, the cracks are divided according to zones.

Field A is ground with a width of 300 mm along the circumference. Magnetic flux testing in this field detected small mesh cracks (Fig. 3a).

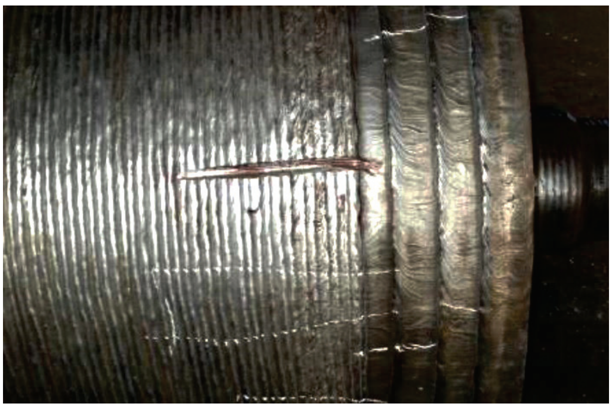
Field B is 200 mm wide and grooved along the circumference. A total of 19 cracks are detected in this field. Two of the cracks are eliminated by grooving, with the groove depth of 20 mm. The depth to which the cracks have propagated could not be accurately determined, since there is no documentation about it (Fig. 3b).

Field C is 400 mm wide, and no cracks are detected along the circumference. Field D, with a width of 300 mm, contained 13 cracks along its circumference. One of the cracks shown in this field (Fig. 3c), is eliminated by grooving to 25 mm depth. Field E is 600 mm wide, and no cracks are detected along the circumference. Field F is 200 mm wide, and 14 cracks are detected along the circumference (Fig. 3d). Field G, with a width of 280 mm has not been ground on the opposite side and no cracks are detected in it.

Cracks in field A

Cracks in field B

Cracks in field D



Cracks in field F

Figure 3. Cracks on the roll after surfacing of fields A, B, D and F.

TESTING AND ADDITIONAL MACHINING OF THE TREIBER ROLL

The Treiber roll with defects could not be put into service, hence a plan for machining the welded roll for the purpose of removing cracks and defects is developed. Before the direct removal of the hard weld, hardness testing is performed along the treiber roll. Shown in Fig. 4 are the fields and measuring locations where hardness tests are performed. Hardness values are shown in Table 4. After hardness measurements, the Treiber roll is machined in order to remove the whole hard weld. It is decided to machine the roll (lathe machining) and to remove layer by layer up to the puffer layer in order to determine the extent of crack propagation. This is followed by removing of the layers up to the parent material for the purpose of complete removal of cracks which have occurred due to grooving. Removing of the whole welded layer could not be completed in a single pass due to its thickness, thus it had to be done in 5 passes.

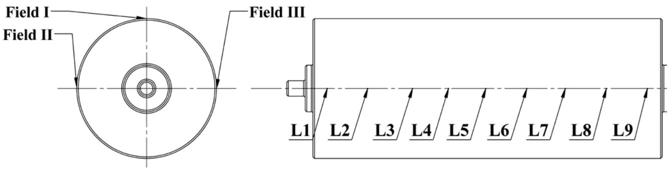


Figure 4. Fields and locations (L1 to L9) of hardness measurements.

Table 4. Measured hardness.

Measuring location	Field 1	Field 2	Field 3
1	48 HRC	50 HRC	46 HRC
2	47 HRC	48 HRC	47 HRC
3	46 HRC	48 HRC	46 HRC
4	48 HRC	49 HRC	46 HRC
5	49 HRC	48 HRC	46 HRC
6	47 HRC	47 HRC	46 HRC
7	47 HRC	48 HRC	45 HRC
8	46 HRC	47 HRC	44 HRC
9	47 HRC		

Due to the hardness of the welded layer and the presence of grooves it was not possible to perform machining, i.e. the lathe knives broke. After this, the grooved parts were filled for the purpose of easier machining.

After filling of the grooves, the Treiber roll is machined to a diameter ∅905 mm, thus 5 mm are removed per circumference. Visual control is performed along with magnetic flux testing. Cracks have remained, and new ones occurred as well. Namely, cracks have occurred in locations where additional surfacing was performed (filling of grooves with a depth approximately 20 mm), and where there were none previously, along the whole circumference and depth, which suggests that this part was simply ‘glued on’ (Fig. 5). It can be seen in the figures that cracks are continuous along the welded surface circumference. Cracks have occurred as the consequence of the lack- or inadequate preheating in these locations, i.e. filling of grooved locations is performed in cold conditions. Parts with thickness greater than 20 mm need to be preheated and they cannot be adequately welded without preheating, /2, 5-9/.

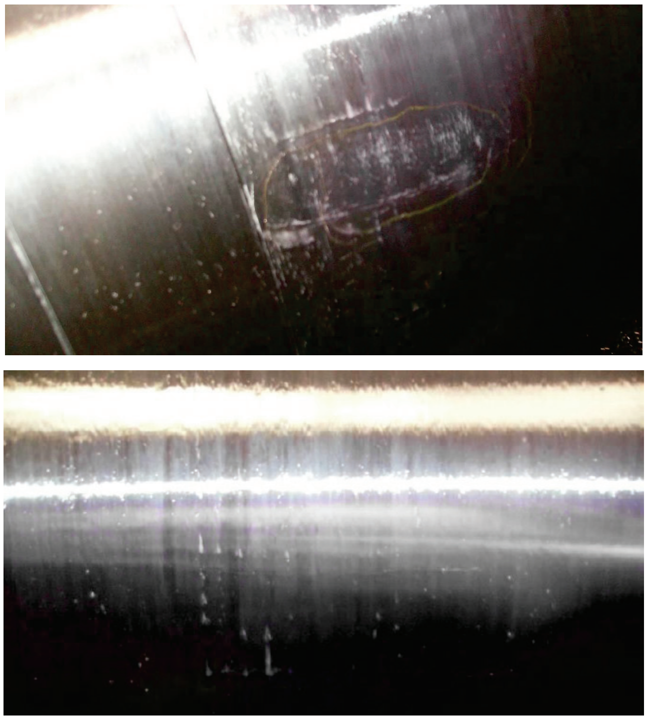


Figure 5. Cracks in grooves of fields B (top) and D (bottom) after additional welding, caused by the lack of preheating.

It was decided to continue machining the roll to a diameter of ∅900 mm, followed by additional magnetic flux and ultrasound tests. After machining, magnetic flux tests are performed and it is determined that the cracks remained the same as after the first machining, whereas they could now be visually detected as well (Fig. 6 top). Ultrasonic tests determined that the current depth of cracks is 17 mm (Fig. 6 bottom).

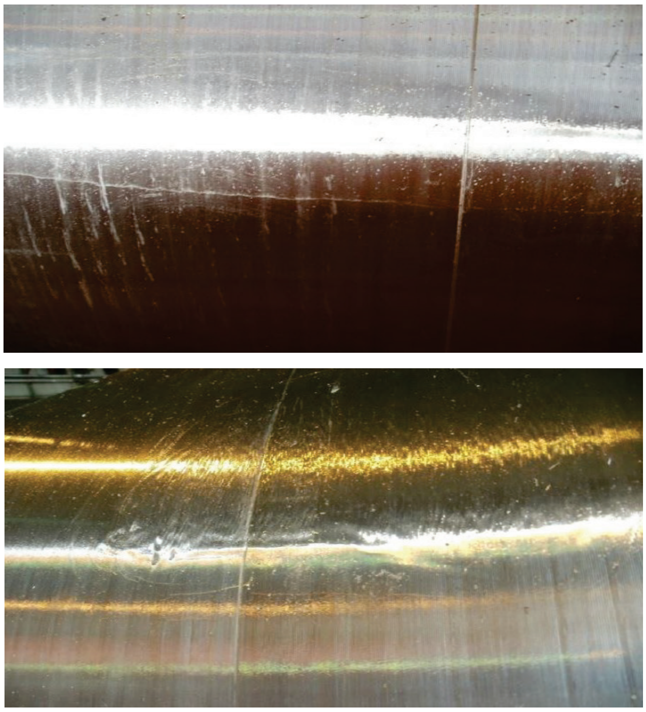


Figure 6. Cracks in grooves, fields B and D after additional welding due to lack of preheating, which can be detected visually.

It was decided to continue with further machining for the purpose of removing cracks and determining their depths. After machining to a diameter of ∅882 mm, magnetic flux tests determined that small mesh cracks in field A, shown on Fig. 2, were eliminated. As for field B, the cracks were positioned in the layer that was additionally welded. Crack depth was around 10 mm. Weld separation from the parent material was also determined (Fig. 7). Within the remaining area of field B, a number of cracks remained. No cracks are detected in field C, whereas one crack remained in the additional weld in field D, with a depth of 10 mm. Within the remaining area of field D, as well as in fields F and G, a number of cracks had remained.

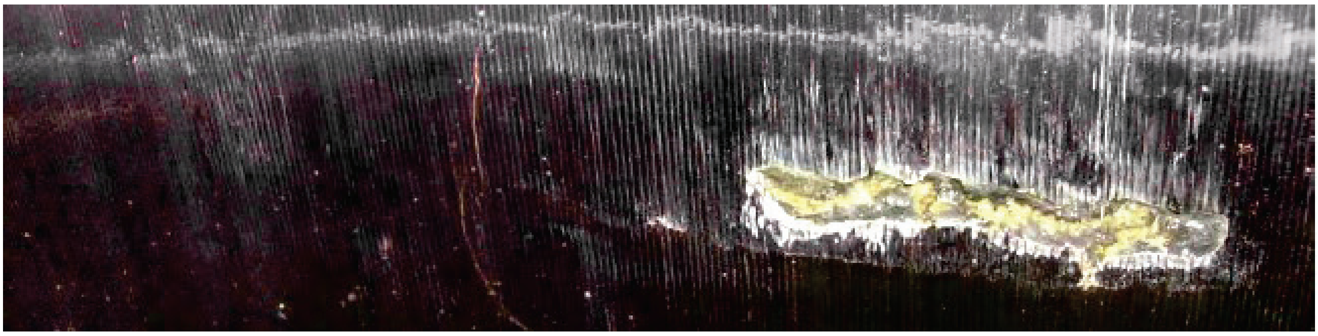


Figure 7. Location in field B where the weld is separated from the parent material.

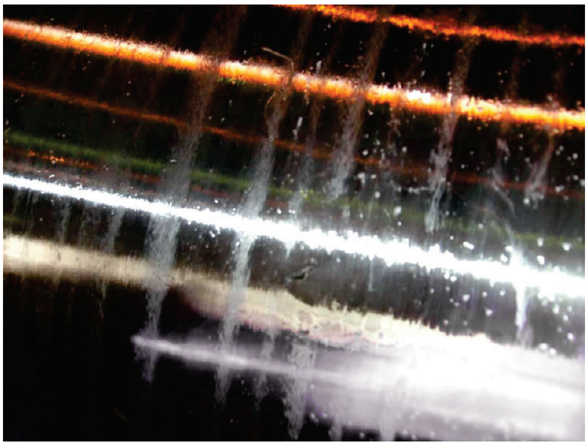
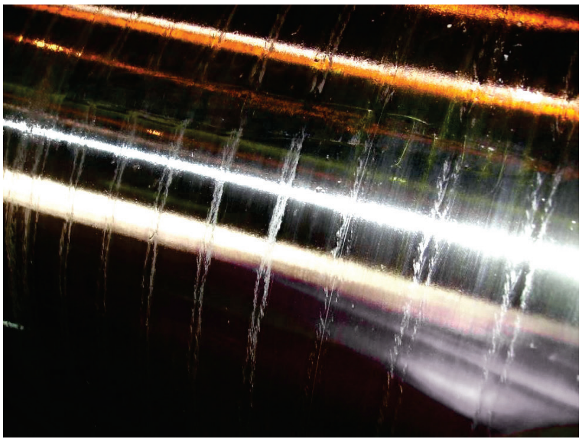
(a)  (b) 

Figure 8. a) Holes in field B as a result of additional surfacing; b) crack in field D, with a depth of around 8 mm.

It is obvious that the number of cracks decreased, but they were not completely eliminated, thus it was concluded that there is a need for further machining.

After the fourth machining of the roll to a diameter of ∅873 mm, additional magnetic flux and ultrasonic tests were performed. These tests determined that the small mesh cracks in field A have been completely eliminated, as well as in field B, although 2 mm deep holes remained (Fig. 8a). As for field D, a crack with depth of 8 mm remained in the additionally welded layer used for filling of grooves (Fig. 8b). Other cracks in this field have been completely removed. No cracks are detected in field E, whereas three cracks with depth of 20 mm remained in the field F.

After the fourth machining, the number of cracks has reduced to 3+1 (caused by inadequate additional grooves filling). It is determined that three remaining cracks have propagated into the parent material not because of reduced stress but because of inadequately performed grooving and welding. For the purpose of complete removal of the weld up to the parent material, the fifth final machining is performed. It is decided to machine the roll to a diameter of ∅870 mm. After this, additional magnetic flux and ultrasonic tests were performed. Shown in Fig. 9 is the appearance of the Treiber roll after the fifth machining.

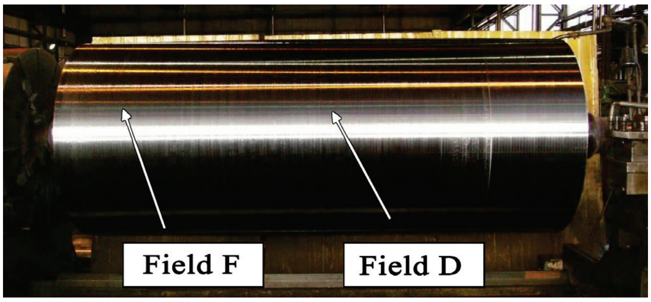


Figure 9. The Treiber rolls after fifth final machining, with designated fields F and D.

The overview of the number of cracks in the non-machined ∅910 mm, as well as after the fifth machining to a diameter of ∅870 mm, is shown in table 5. In the field D, an 8 mm deep crack remained in the welded layer after additional welding and grooving. Other cracks have been completely eliminated. As for field F, three cracks with a depth of 20 mm remained. In this part, the roll has greater thickness and due to increased mass, sudden temperature output and inadequate (non-uniform) preheating, the hard welded layer cracked and the cracks propagated to the parent material.

Table 5. Overview of the number of cracks per field before and after machining.

Field	A	B	C	D	E	F	G
Non-machined roll ∅910 mm	small mesh	19	0	13	0	14	0
After 5th machining to ∅870 mm	0	0	0	1	0	3	0

DISCUSSION AND CONCLUSIONS

Presented in this paper is the significance of adequate preheating in order to avoid the occurrence of cracks and other deformation. Preheating reduces the cooling rate, thus reducing the temperature difference between the parent material (which is cold) and the welded layer (which transforms from a hot liquid state to a solid state, until it reaches environmental temperature). Preheating enables more time for contraction stresses to equalize, since both the welded layer and the parent material contract due to cooling.

Out of 46 detected cracks, 42 are eliminated during 5 stages of machining. These could not have originated in the parent material, since they disappeared during the machining.

The reason behind the occurrence of cracks lies in inadequate preheating, improper performing of the process and sudden and non-uniform cooling after welding.

Preheating is performed for the puffer layer, although its documentation is incomplete. Due to a time and material restriction, there was a brake in the manufacturing process before the hard welded layer was applied. During the manufacture shutdown, temperature control was not performed.

The cracks are the consequence of applying of a hard weld to an insufficiently preheated surface (or a completely cold one), even though the welding technology specified preheating to be necessary. Most of the cracks are located in the reinforced part of the roll, as well as in its vicinity. Cracks are assumed to reach the depth of up to 20 mm, corresponding to the roll diameter of ∅880 mm, under the condition that the puffer layer is applied up to this diameter.

Out of 4 cracks that could not be removed, three have propagated into the parent material, whereas one occurred due to additional groove filling performed for the purpose of easier machining. Cracks are located in the part of the roll where the thickness is increased due to inner reinforcements, resulting in increased mass as well. Due to this, the heat output in this area is significantly greater and faster, which in turn caused the resulting cracks to propagate into the parent material. As for the non-reinforced part of the roll (no increase in mass), cracks are removed by machining.

Future activities recommended for the purpose of removing these four cracks include grooving crack locations and additional repair welding in order to fill the parent material, along with mandatory inspection using NDT methods. Only after it would be concluded that there are no cracks or other defects, the whole treiber roll can be repair welded again to a diameter of ∅910 mm.

In addition to this, direct cause-and-effect relation which resulted in the occurrence of cracks is the human factor, i.e. oversights and lack of knowledge from either the welding engineer or welders. This further resulted in economic loss in addition to the technical one, due to the need for additional machining of the Treiber roll after welding in order to remove the defects, as from the need for additional welding. All of the above operations resulted in additional costs, downtime, indirect and direct costs, all of which could have been avoided by adequate performing of the welding process.

The roll is once again surfaced, in accordance with the welding technology. There are no surface cracks on the roll, and it is put back into exploitation as such.

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