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RESEARCH

Selection of the Most Appropriate Technology of Reparatory Hard Facing of Working Parts on Universal Construction Machinery

The aim of this work is to analyse the possibility to increase the service life of working parts on construction machinery exposed to intensive wear, such as steel blades of the rotary device for roadside vegetation maintenance and grass cutting. A special attention is paid to characteristic working conditions and complex wear mechanisms. In order to select the most appropriate reparation technology, both model and real investigations were conducted. The aim of the model investigations was to select the most appropriate procedure, filler materials and hard facing technology. Worn cutting edges of the blades were hard faced and sharpened by grinding to the shape and dimensions of new blades. Then, both new and repaired blades were alternately mounted on the rotor of the machine. Their wear was monitored under the same working and weather conditions. The repaired blades have proven more resistant to wear than the new ones, which is due to better properties of the hard faced layers.

Keywords: *hard facing, construction machinery, wear, hardness, microstructure.*

1. INTRODUCTION

Almost all working parts of construction machinery are exposed to complex tribological processes during operation. Sometimes, one type of wear is dominant, but in practice, combined wear is much more common. A typical example of combined wear is seen in blades of the device for roadside vegetation maintenance and grass cutting. These parts are exposed to abrasive, impact and fatigue wear as well as corrosion.

Working parts have relatively short service life, they increase machine downtime, it takes a long time to replace them, they decrease machine utilization rates, etc. However, reparatory hard facing can reduce or eliminate these problems. Hard facing also offers an opportunity to determine wear resistance of different filler materials.

Our investigations [1-12] and investigations of other authors [13-15, 20-24] have shown that worn and new parts can be successfully hard faced. However, both reparatory and production hard facing can be performed only in specialized facilities with expert staff and adequate equipment.

2. MACHINE AND DEVICE DESCRIPTION

The device for cutting grass and other vegetation is mounted on a universal machine Unimag (Fig. 1). This is a multipurpose vehicle on which thirty-two different devices can be mounted and operated. In addition to grass and vegetation cutting, it can be applied for snow clearing, aggregates spreading, land clearing and levelling, preparing soil or aggregate substrate for concrete or asphalt laying, digging holes in the ground, cutting and removal of trees, load lifting, trench digging for utility installation, etc.

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Figure 1. Machine and device for vegetation maintenance and grass cutting

The device for vegetation maintenance is powered by the vehicle. The torque is transferred through the output spline shaft connected to the hydraulic pump and hydro motor, and the device is controlled by hydraulic system. V-belt transmission protects the device allowing some slippage in order to prevent overloading and damages. The number of rotations of the output shafts is in the range from 540 to 1000 min^{-1}.

Forty blades (Fig. 2) are mounted in four rows on the holder of the output spline shaft. The blade mass is 0.30 kg, and all the blades are made of quenched and tempered (Q+T) steel Č4732 (JUS) – 42 CrMo4 (DIN). The connection between the rotary device and blades is mechanical, and blades are mounted on a special holder via screws. Whilst in operation the blades come into contact not only with grass, vegetation and soil, but also with rocks. In order to protect the blades, a protective roller is mounted. It rolls on the ground in front of the working part keeping the device at the same distance from the ground. Behind the working part, there is a curtain that prevents grass, vegetation and aggregates from sticking to the blades, which ensures safety of the vehicle operator and other participants in the traffic.

Figure 2. A new blade for vegetation and grass cutting

3. SELECTION OF THE MOST APPROPRIATE REPARATORY TECHNOLOGY

3.1 Introduction

In order to select the most appropriate reparatory technology, both model and real investigations were conducted. [1-6]. the models, made to be geometrically similar to the real parts, were used for trial hard facing with different filler materials and under different hard facing regimes. From these models, metallographic samples were prepared for hardness measurements, microstructure analysis and tribological investigations of wear resistance. The reparatory technology selected on the models was then applied to the real parts. New and differently hard faced blades were monitored under real working conditions with the aim to compare time in operation and degree of wear between the new and the hard faced blades and to provide final estimate of justification of reparatory hard facing.

The base material of the blades was Č4732 (JUS) – 42CrMo4 (DIN), while the following filler materials were used for hard facing: ABRADUR 58, E DUR 600, CrWC 600 and E Mn17Cr13 [1, 2, 4, 18]. Hard facing of the models and real parts was performed by manual metal arc welding method. Worn blades were hard faced in three passes to restore the lost - worn part, and then they were sharpened by grinding to restore the shape. The mass of the repaired blades was similar to the mass of new blades.

3.2 Base and filler materials

The spectrographic analysis of the base material revealed that the blades were made of low-alloy quenched and tempered steel Č4732. We used one worn blade to prepare metallographic samples for hardness measurements and microstructure analysis of the base material. The maximum measured hardness was 298 HB, while the microstructure was estimated as an interphase structure of the quenching and tempering. This microstructure is not especially resistant to intensive abrasive wear, so these parts become worn rather quickly [16, 17]. For this reason, we decided to try to extend their service life by hard facing. Tables 1 and 2 [18, 19] give the chemical composition and the most important mechanical properties of the steel Č4732.

Table 1. The chemical composition and applications of the steel Č4732

B. M.	Chemical composition, %							Application
Č4732	C	Si	Mn	Cr	Mo	P	S	For manufacturing of heavily loaded machine parts after heat treatment
Prescribed	0.38-0.45	0.15-0.40	0.50-0.80	0.90-1.20	0.15-0.30	0.035	0.035	
Analysed	0.45	0.40	0.80	1.20	0.30	0.035	0.035	

Table 2. Mechanical properties and microstructure of the steel Č4732

Notation		Mechanical properties and hardness						Microstructure
JUS	DIN	R_m, MPa	R_{eH}, MPa	A_5, %	Z, %	KV, J	Hardness, HB	Interphase tempered structure (mainly sorbite)
Č4732	42CrMo4	1100-1300	900	10	40	34 (20°C)	298*	

*Measured hardness of the sample after the thermal treatment of the Q+T

The following electrodes were chosen as filler materials: E DUR 600, CrWC 600, ABRADUR 58 and E Mn17Cr13 [1, 2, 4, 18]. Based on the manufacturer's recommendations, hard faced layers obtained using these electrodes have a high wear resistance, favourable toughness and can endure high impacts during operation. Hard faced layers can be mechanically treated only by grinding. These electrodes are especially recommended for hard facing of parts exposed to friction and metal-to-mineral wear, such as bulldozer blades, excavator bucket teeth, excavator shovels, conveyor elements, parts of crushing machines, blades and mixers in processing industry etc. For interlayer welding, a 3.25 mm diameter electrode INOX B 18/8/6 (JUS) - E 188 MnB10+ (DIN) [1-6, 9, 18] was used.

3.3 Estimate of basic material weldability

Due to its content of carbon and alloy elements, steel Č4732 belongs to conditionally weldable steels, which means that it requires a special technology of welding. However, it is possible to improve its weldability by preheating or depositing a plastic austenite interlayer. There are different methods to calculate the preheating temperature based on KH diagrams, but in this case, it was determined using the Seferian formula (Table 3.) [2, 11, 13].

Table 3. Determination of the preheating temperature using the Seferian formula

Applied method	Formula	Thickness, s, mm	Preheating temperature, Tp, °C	
			Calculating	Adopted
Seferian formula	$CE = CE_h + CE_s = CE_h \cdot (1 + 0.005 \cdot s), \%$ $CE_h = C + \frac{Mn + Cr}{9} + \frac{Ni + 7Mo}{18}, \%$ $T_p = 350 \cdot \sqrt{CE - 0.25},\ ^\circ C$	10	≈ 266	≈ 300

Preheating is recommended for hard facing with filler materials E DUR 600, ABRADUR 58 and CrWC 600, while it is not recommended for hard facing using the electrode E Mn17Cr13 because this filler material belongs to austenite steels which are well hard faced on materials with high potential hardness increase. Sometimes expensive preheating can be eliminated by application of interlayer austenite electrodes.

3.4 Model investigations

As mentioned before, we prepared physical models geometrically similar to real parts. The models were made of 10 mm thick low-carbon steel Č0361 (JUS) – S 235 JRG2 (EN 10025). The steel Č4732, of which the blades were made, was not used because Č0361 can be welded without preheating and it provides the same conditions for hard facing with different filler materials. In this way, hard faced layers obtained with different filler materials can be compared and analysed. The idea was to use Č0361 for manufacturing of new parts of construction machinery and to hard face the edges with layers resistant to wear [2, 4, 5, 14]. The models were hard faced by MMA procedure in the laboratory, and technological hard facing parameters were chosen in compliance with literature recommendations [1-9, 13, 18] (Table 4).

The width of one-pass hard faced layer was 6.0-10 mm, and its height ranged from 3.0 to 3.2 mm. The way of deposition, the order and number of the deposited layers and the model itself are shown in Figure 3. Prior to each pass, slag was removed with steel brush. The other layers were also deposited in this way (the second - Fig. 3b and the third - Fig. 3c). Figure 3d shows a sample for metallographic and tribological investigations, and Figure 3e shows hard faced sample models.

Table 4. Technological parameters of the model hard facing by MMA welding [2]

Thickness O.M. s, mm	Fiprom-Jesenice electrode	Electrode core diameter, d_e, mm	Hard facing current, I, A	Working voltage, U, V	Hard facing speed, v_z, cm/s	Input heat q_l, J/cm	Melting zone depth, mm
10	Sample 1: E DUR 600	3.25	120	25	0.124	19355	2.24-3.73
	Sample 2: CrWC 600	3.25	125	25	0.116	21552	2.36-3.94
	Sample 3: ABRADUR 58	3.25rup	130	25	0.124	20968	2.33-3.88
	Sample 4: E Mn17Cr13	3.25	130	25	0.152	17105	2.10-3.51

Hardness measurements (in direction I-I, Fig. 3d) and analysis of the newly formed structures in the characteristic hard faced layer zones were performed on metallographic samples shown in Figure 3. The most important results of hardness and microstructure distribution are given in Figures 4, 5, 6 and 7 [1-9].

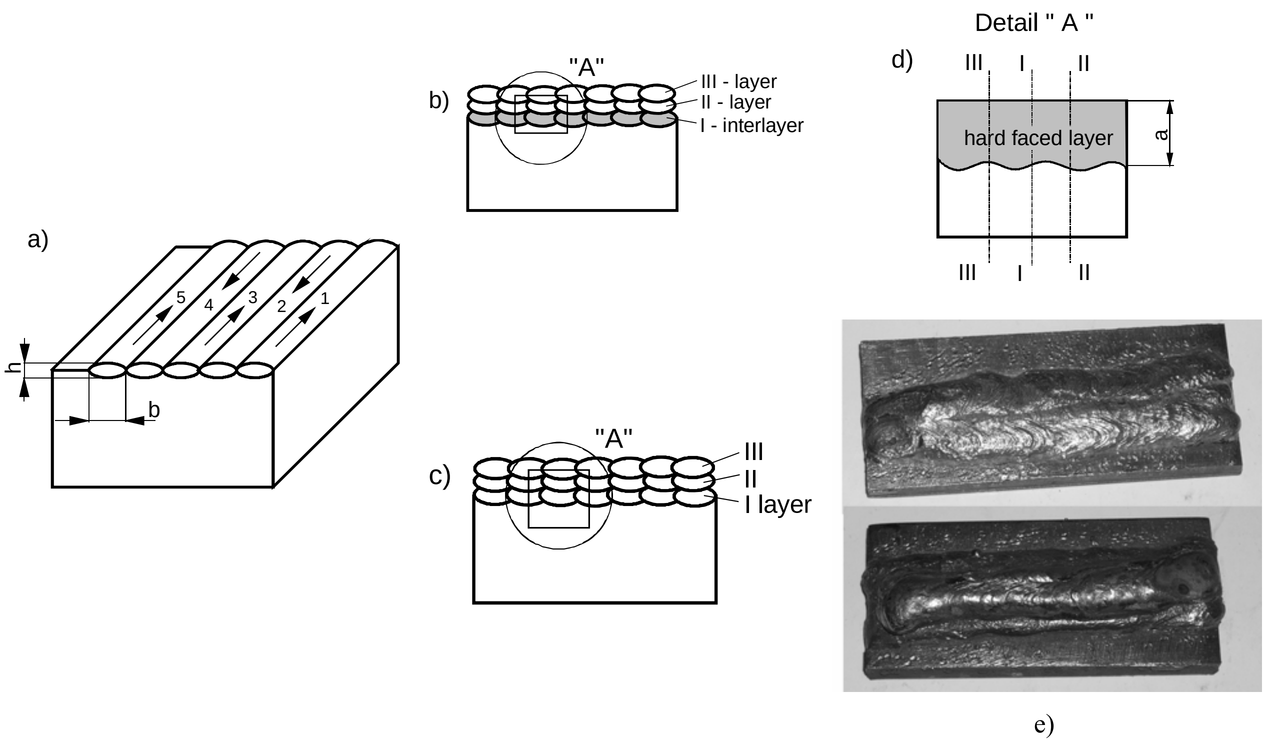


Figure 3. Order of hard faced layers deposition: a - 1st layer, b - 2nd layer, c - 3rd layer, d- metallographic block and e – hard faced sample models (model photos)

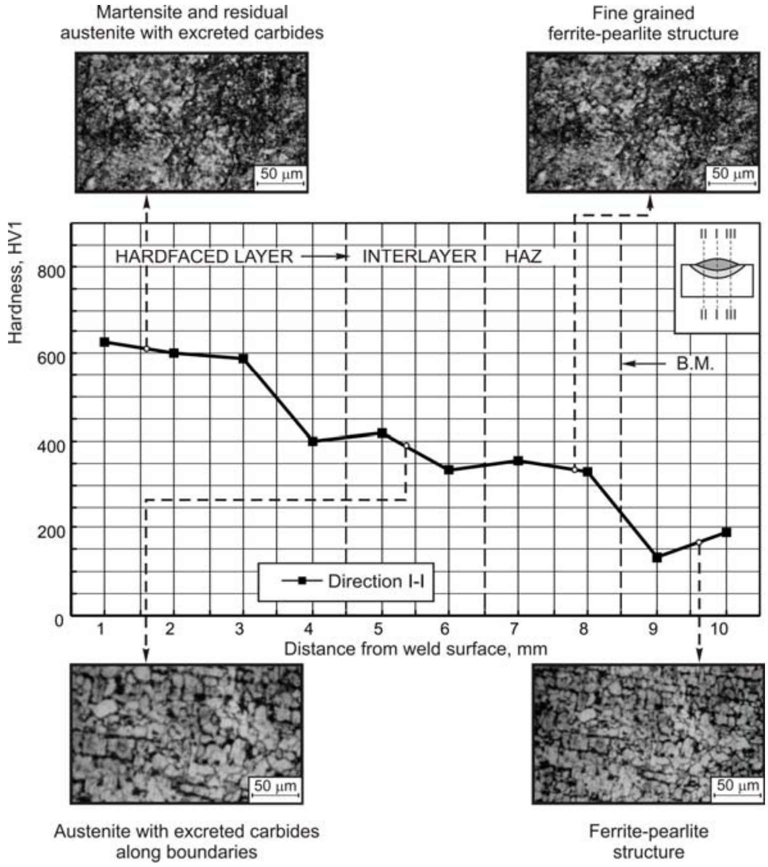


Figure 4. Microstructure of the hard faced metal zones: B.M. - Č0361, interlayer - INOX B 18/8/6 and hard faced layer - E DUR 600

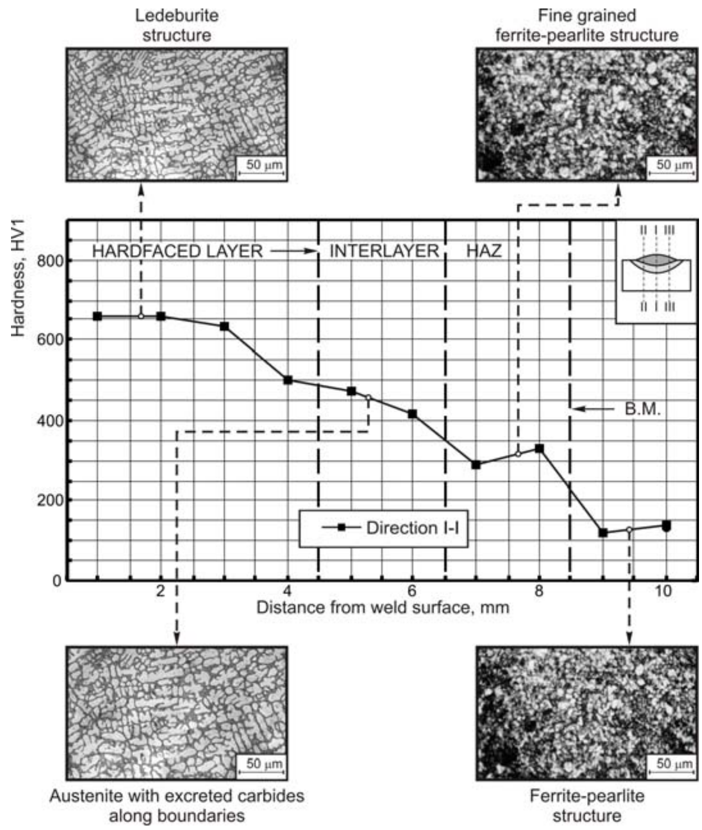


Figure 5. Microstructure of hard faced layer zones: B. M. - Č0361, interlayer - INOX B 18/8/6 and hard faced layer - CrWC 600

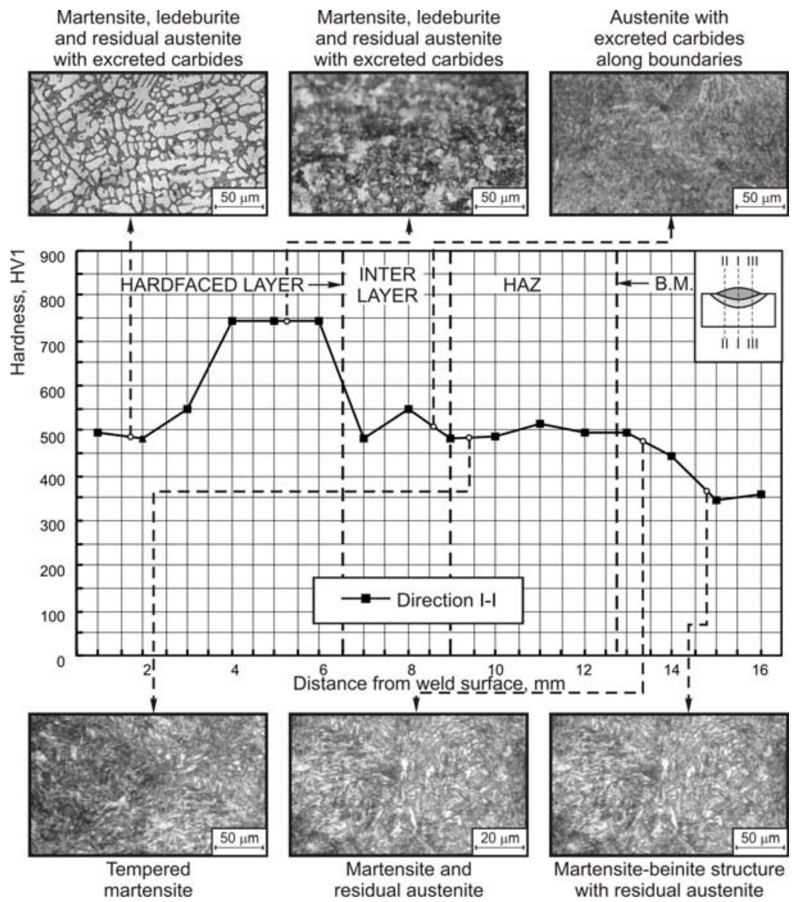
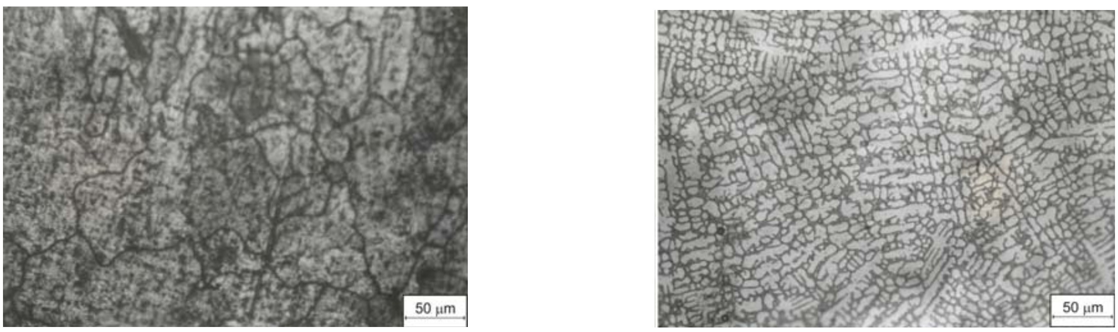


Figure 6. Microstructure of hard faced layer zones: B. M. - Č0361, interlayer - INOX B 18/8/6 and layer - ABRADUR 58



a) b)

Figure 7. Microstructure of the hard faced layer: (a) E Mn17Cr13 and (b) INOX B 18/8/6

3.5 Tribological investigations

For tribological investigations, it was necessary to prepare blocks whose dimensions were compatible with the tribometer installed at the Faculty of Mechanical Engineering. Five blocks were prepared - four of them from the hard faced layer (E DUR 600, CrWC 600, ABRADUR 58 and E Mn17Cr13) and one from the base material (Č4732). The blocks were grinded until their dimensions were 6.3×15×10 mm so that they could be placed on the tribometer holder and come into contact with the disc of standard dimensions [2]. During the investigation, a line contact "block on disk" was realized. Outer variables were: contact force, slide speed and lubricant.

Prior to each investigation, the contact surfaces of the discs were grinded to remove the wear traces so that their roughness could be measured and compared to the contact surface roughness of the tested blocks. Table 5 shows the technology of the sample preparation for tribological investigations of the hard faced layers and base materials. The coupled pairs “disc- block” were lubricated with the motor oil GLX 2 SAE 15 W-40.

Table 5. Technology of the sample preparation for tribological investigations (blocks and disks) [2]

Sample number	Substrate material	Hard faced layer material	Number of the hard faced layers	Height of the hard faced layer, mm	Blocks and discs
1.	Č0361	Interlayer-INOX B 18/8/6 Hard faced layer -E DUR 600	3*	4.2-5.6	
2.	Č0361	Interlayer -INOX B 18/8/6 Hard faced layer -CrWC 600	3*	4.5-6.0	
3.	Č0361	Interlayer -INOX B 18/8/6 Hard faced layer -ABRADUR 58	3*	3.0-3.5	
4.	Č0361	Hard faced layer -E Mn17Cr13	3	6.2-8.0	
5.	Č4732	-	-	-	

*) The first layer is a plastic interlayer of F. M. - INOX B 18/8/6, while the second and the third layers are made of F. M.–ABRADUR 58, E DUR 600 and CrWC 600.

The aim of these investigations is to determine the wear resistance of the base and filler materials and to estimate how appropriate these filler materials are for reparatory hard facing of blades and other parts of construction machinery exposed to combined wear.

Prior to investigations, topography of the disc and block surfaces was measured on the computer measuring system Talysarf 6. Then, the contact was realized. The normal force of F_N = 300 N and the sliding speed of v_{kl} = 1 m/s were adopted. During the contact of ≈ 60 min, a change of the friction coefficient was registered (Fig. 8, 9, 10, 11 and 12). When the contact was terminated the topography of the disc and block surfaces was studied i.e., the wear scare area of the block was measured (Fig. 13). In this way, tribological characteristics were determined. The wear scare width was measured using a universal microscope UIM-21, with magnification of 50 times.

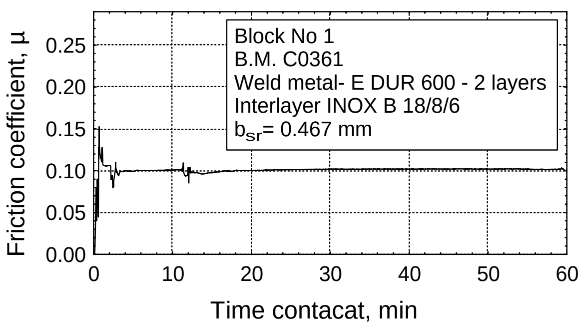


Figure 8. Change of the friction coefficient during the contact of 60 min

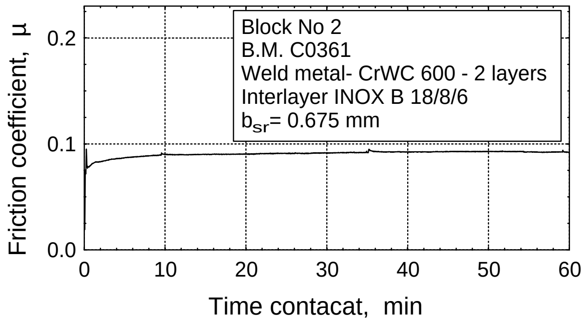


Figure 9. Change of the friction coefficient during the contact of 60 min

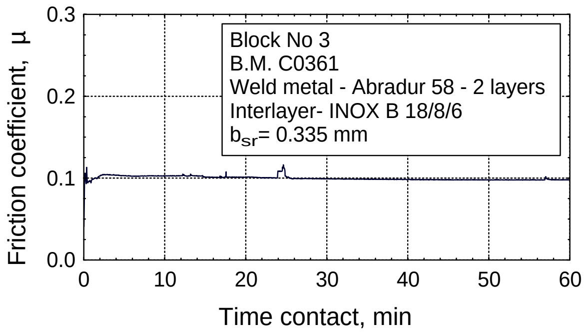


Figure 10. Change of the friction coefficient during the contact of 60 min

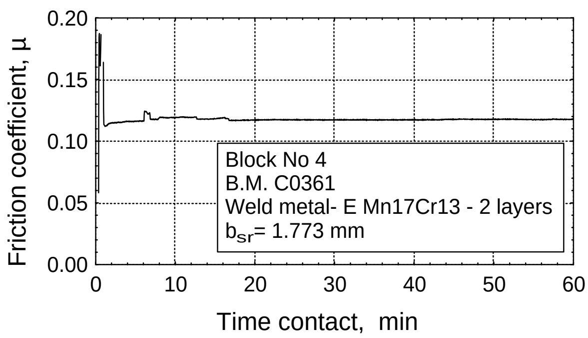


Figure 11. Change of the friction coefficient during the contact of 60 min

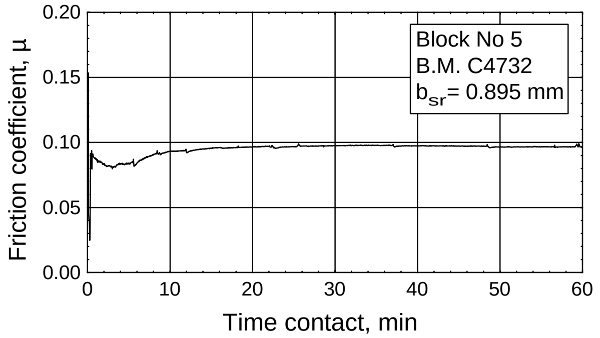


Figure 12. Change of the friction coefficient during the contact of 60 min

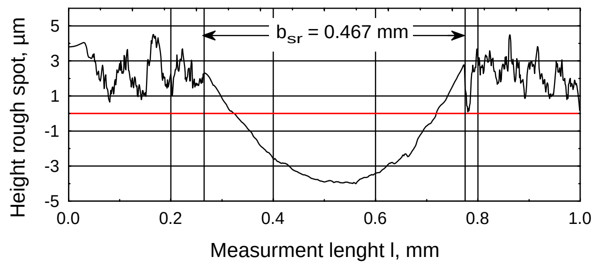
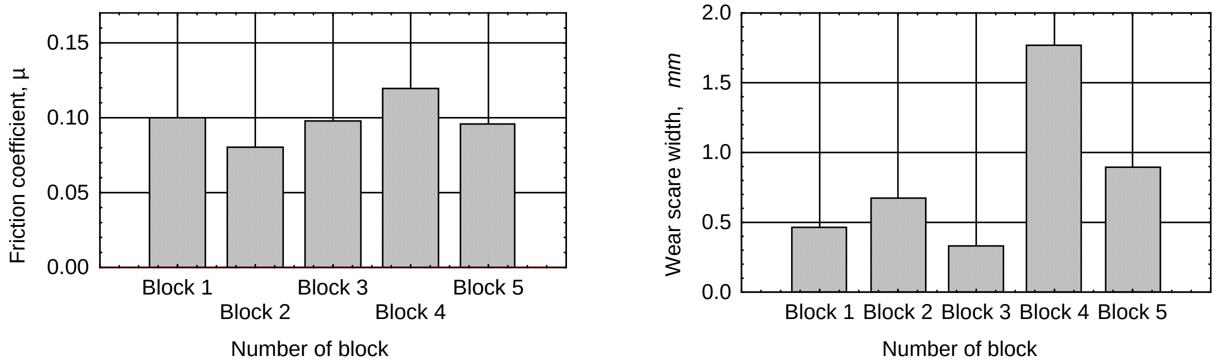


Figure 13. Layout of the wear scare - block No 1 (after the contact of 60 min)



a) b)

Block 1-E DUR 600, Block 2-CrWC 600, Block 3-ABRADUR 58, Block 4- E Mn17Cr13, Block 5-Č4732

Figure 14. Histograms of the mean values of friction coefficients (a), and wear scare widths (b) after the contact of 60 min

Figure 14a gives a graphical presentation of mean values of the friction coefficient, and Figure 14b shows mean wear scare area widths of the investigated blocks.

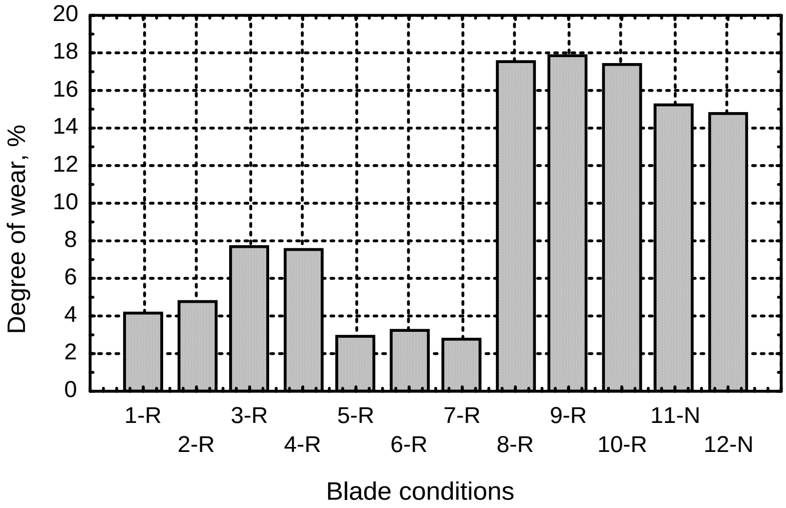
Measurements of the wear scare width have revealed that the hard faced layers have a significantly higher resistance to wear compared to base material of the blades. This particularly applies to the hard faced layers obtained using the electrode ABRADUR 58, with application of the interlayer electrode and without preheating. It illustrates how complicated it is to select hard facing technology and filler materials for real technological working conditions of the construction machinery.

4. HARD FACING OF REAL PARTS

The technology selected on model investigations was applied to the real parts. For investigations under real conditions, 10 blades were hard faced. Two blades were hard faced with electrodes E DUR 600 and E Mn17Cr13, and three blades were hard faced using the electrodes ABRADUR 58 and CrWC 600. Cutting blade edges were hard faced along the back and front angle sides of the blade, lengthwise. The width of the hard faced layer was about 25 mm. The hard faced blades (Fig. 15) were sharpened by grinding and then they were finally ready.

Figure 15. Blades repaired with different filler materials

Thus repaired and sharpened blades were mounted together with new blades on the device and their performance was monitored under real working conditions. The mass of the blades before mounting was 0.30 kg. The wear process was monitored during 120 hours of effective work. Then the devices were cleaned and washed and all the blades were dismounted. Figure 16 shows the mass losses of new and hard faced blades.



1-R and 2-R – ABRADUR 58; 3-R and 4-R – CrWC 600; 5-R, 6-R and 7-R – E DUR 600; 8-R, 9-R and 10-R – E Mn17Cr13; 11-N and 12-N – NEW BLADES (B. M.)

Figure 16. Graphical presentation of the degree of wear of the blades after 120 hours of effective work

Based on the material mass losses of the studied samples, it can be concluded that, under the same working conditions, the hard faced blades have in general shown better resistance to wear compared to new, not hard faced blades. The same conclusion can be drawn for the blades hard faced with ABRADUR 58, CrWC 600 and in particular with E DUR 600, while the blades hard faced with E Mn17Cr13 exhibited significantly less resistance to wear, even compared to new blades. This is the result of the working conditions and impossibility of austenite to transform into martensite in shallow surface layers of the hard faced metal. Therefore, it can be concluded that manganese austenite steel or Hadfield steel is not suitable for the given working conditions [2, 6, 9].

5. CONCLUSION

Having conducted investigations on models and real working parts, the following important conclusions have been drawn:

- Blades can be successfully repaired by hard facing with or without preheating but with application of austenite interphase filler materials;
- Results obtained in tribological model investigations are in good compliance with the results obtained in investigations on real parts;
- Reparatory hard facing of blades with hard electrodes can significantly extend their service life;
- The most suitable filler material for reparatory hard facing of blades is E DUR 600, with service life of 1200 h of effective work compared to 240 h of new blades,
- The costs of reparatory hard facing are lower than the cost of new blades;
- Multiple reparations of worn blades have been proven possible;
- These methods of reparation can also be applied to other types of construction machinery operating under similar working condition.

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