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Tribology in manufacturing processes

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IMPORTANCE OF TRIBOLOGICAL INVESTIGATIONS IN SELECTING THE TECHNOLOGY FOR REPARATION OF WORKING PARTS OF CONSTRUCTION MECHANIZATION

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Abstract: *The aim of this paper is to point out the importance of tribological testing in the procedure for choosing the proper technology for both reparatory and production hard facing technologies for some parts of construction mechanization exposed to intensive wear. The proposed procedure is shown on several examples of construction's equipment parts. Three filler materials were chosen and hard facing was conducted by applying it on specific samples. From hard faced layers and base materials of samples, blocks for tribological investigation were prepared. Wear resistance of the test blocks was monitored through the wear scar width. Results of tribological tests have shown that blocks which had been prepared from hard faced layers were more resistant to wear, than the blocks which have been prepared from base materials. Besides, the hard facing technology used on a samples was transferred to real working parts. Real parts were than mounted on construction equipment in order to test it in exploitation conditions. In these test geometry and weight loss were checked, as the parameters of wear resistance. For tested working parts, working conditions and used filler materials, tribological properties investigation had shown high correlation with investigation of parts properties, in real working conditions and also as one of the major criteria, tribological properties investigation can be used as a guideline in the process of choosing the hard facing technology.*

Keywords: *hard facing, filler material, tribogical test, wear, construction mechanization.*

1. INTRODUCTION

It is known that many working parts of construction mechanization after certain number of hours spent in exploitation, due to severe working conditions and complex wear mechanisms, need to be replaced or repaired. Due to high prices and long shipping times of new parts, alternative solutions could be found in repairing old or improving properties of new parts. In this case, by repair we mean that damaged working surfaces are renewed by applying new layers of appropriate filler material (FM) and by improving of properties of new parts we mean that additional layers of FM with special properties are applied on new surfaces. It is possible that appliance of this advance technology results in economic and many other benefits. Special attention needs to be paid on hard facing process, due to possibility of phase (structure) transformations, presence of residual stress and other unwanted effects that were caused as a consequence of input heat. For that reasons, to the problem of hard facing need to be approached as an important and complex technological issue.

2. PROCEDURES FOR CHOOSING HARD FACING TECHNOLOGY

According to many different authors, there are a few methods of approach to the problem of selecting the optimal hard facing technology, both reparatory and production [1-3]. Many of those approaches are similar to each other, but the most complete is one represented as an algorithm on Figure 1. Algorithm is composed from large number of steps, which cover many different tests. Number of steps and complexity of the algorithm are pointing out that only adequate technical approach to the problem can result in positive outcome (benefits) [2, 3]. All steps of the algorithm are equally important, but the aim of this paper is to emphasize the importance of tribological investigation.

Tribological investigation implies on using a special test device called tribometer. This device, allows the contact simulation of two samples. The contact between two samples, which geometry is predefined as blocks, pins, or disk, could be achieved in a point, along the line or on the surface. For the investigation of tribological properties of hard face layers, a block or pin is made and a hard material (e.g. tool steel) is used to make a disk whose rotation simulates movement of elements that are causing wear. Investigation could be realized with or without lubrication, with ability to precisely set up sliding velocity and normal load size. Using the results of tribological investigations an assumption on behaviour of material in real conditions can be made [2,3].

If the results of tribological investigation show adequate wear resistance, applied technology is transferred to real parts. Final decision on selected hard facing technology should be made after tests in working conditions.

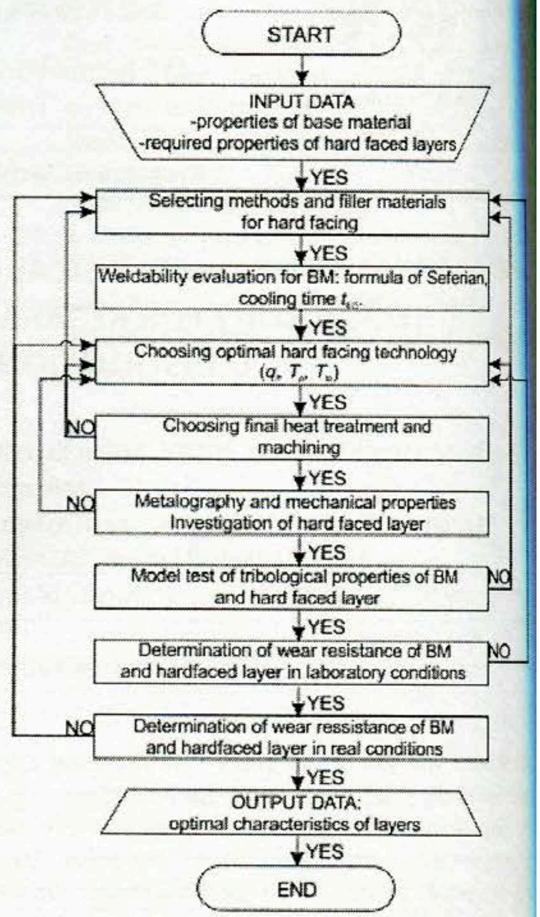


Figure 1. Algorithm for optimal hard facing technology selection

3. HARD FACING TECHNOLOGIES FOR DIFFERENT WORKING PARTS

In this section a brief description of applied hard facing technology for several characteristic parts of construction mechanization (methods, FM, parameters etc.) will be given. Knowing that working parts of construction mechanization are exposed to combined wear (especially abrasive), decision was made to use FM's with higher hardness. It is assumed that higher hardness is in correlation with better wear resistance [4].

3.1 Bucket teeth

The role of bucket teeth (Fig. 2) is in protecting the bucket during loading different materials [4, 5, 7]. In this case, dominant wear mechanism present is abrasive wear caused by different granulation of rock materials. Base material (BM) for bucket teeth manufacturing is ČL3134/GS-36Mn5 [4]. Based on the analysis of BM and working conditions, two FM for hard facing, were selected: INOX B 18/8/6 and ABRADUR 58 from producer SI JESENICE. All FMs are aimed for electric arc welding. FM INOX B 18/8/6 is used as interlayer, and layers made by ABRADUR 58 have high hardnes values, up to 58 HRC, so are used for covering layer. Chemical composition and mechanical properties of both BM and FM are shown in tables from 1 to 4.

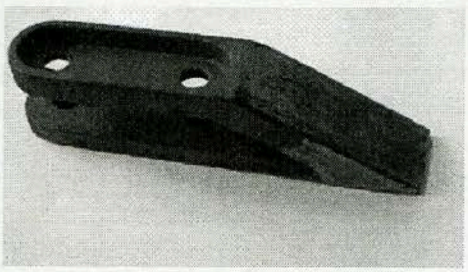


Figure 2. Tooth bucket [4]

Table 1 Chemical composition of BM [4, 5, 7]

Base material	Chemical composition [%]				
ČL3134	C	Si	Mn	P	S
Perscribed	0.45	0.50	1.80	0.04	0.040
Analysed	0.35	0.40	1.85	0.04	0.35

Table 2 Mechanical properties of BM [4, 5, 7]

Oznaka materijala	R_m [MPa]	R_{eH} [MPa]	A_5 [%]	[HB]
ČL3134	780-930	390	7	340-430

Table 3 Chemical composition of FM [4-8]

Filler material	Chemical composition [%]				
	C	Si	Mn	Cr	Ni
ABRADUR 58	3.60	-	-	32	-
INOX B 18/8/6	0.12	0.80	7	19	9

For experimental testing of tribological properties, two hard facing technologies were proposed. In the first technology, hard facing of BM has been done with preheating of BM samples up to temperature of 250°C, after that, two layers with FM ABRADUR 58 have been deposited. In the second technology no preheating has been done instead, interlayers of INOX B 18/8/6 have been deployed prior to layers of ABRADUR 58 [4,7]. Parameters for hard facing are shown in the Table 5.

After hard facing on models, tests were conducted, as well as preparation of blocks for investigation of their tribological properties.

Table 4 Mechanical properties of FM [4-8]

Filler material	Mechanical properties				
	R_m [MPa]	R_{eH} [*MPa*]	A_5 [%]	KV [J]	Hardness
ABRADUR 58	-	-	-	-	58 HRC
INOX B 18/8/6	590-690	> 350	> 40	> 80	200 HB

Table 5 Bucket teeth hard facing parameters

BM thickness [mm]	Filler material	Electrode diametar [mm]	Current [A]	Voltage [V]	Hard facing speed [cm/s]	Heat input [J/cm]
24-42	ABRADUR 58	3.25	130	25	0.124	20968
	ABRADUR 58	5.00	160	26	0.145	22952
	INOX B 18/8/6	3.25	100	24	0.136	14118
	INOX B 18/8/6	5.00	140	26	0.178	16360

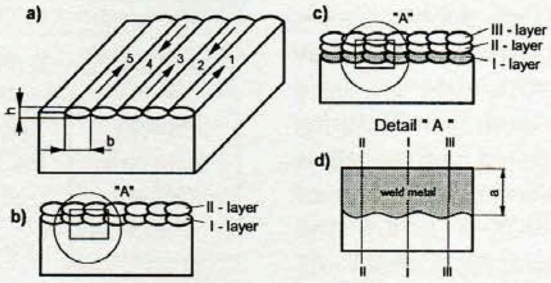


Figure 3. Schematic preview of two and three hard faced layers

3.2 Asphalt mixer blades

Mixer blades (Fig. 4) have very important role in preparing asphalt. They are exposed to aggressive abrasion of asphalt and aggregate particles at elevated temperature of 200°C [4, 6, 9]. Originally blades were made from ČL4150/G-X10Cr10 [4]. Poor weldability of this BM requires preheating of parts before hard facing (up to 500°C) and after hard facing parts need to be cooled down to room temperatures in furnace [4, 9]. Instead of reparatory hard facing the original BM surfaces, production hard facing was chosen. New low carbon construction steel Č0361/S235JR has been used. All samples were hard faced using 10 *mm* thick plates of BM. Chemical composition and mechanical properties of both BM are show in tables 6 and 7. Considering working conditions of the parts, filler materials that were selected are: ABRADUR 58, E DUR 600 and CrWC600. Two layers of each FM were deposited on interlayer deposited from INOX B 18/8/6, without preheating [4-6, 9]. Chemical composition and mechanical properties of new FM are shown in tables 8 and 9.

For new steel and selected FM, determined hard facing parameters are shown in table 10 [4, 5, 8, 9]. Using this parameters blocks for tribological investigations were prepared.

Table 6 Chemical composition of BM [4, 5, 9]

BM	Chemical composition [%]						
	C	Si	Mn	Cr	V	P	S
ČL4150	2.0	0.40	0.3	12	0.1	0.035	0.035
Č0361	0.17					0.035	0.035

Table 7 Mechanical properties of BM [4, 5, 9]

BM	R_m [MPa]	R_{eH} [MPa]	A_5 [%]	KV [J]	HB
ČL4150	-	-	-	-	552-555
Č0361	370-450	220-240	18-25	27	130-145

Table 8 Chemical composition of FM [4-6, 8, 9]

FM	Chemical composition [%]	
	C	Cr
E DUR 600	0.5	7.5
CrWC 600	4	26

Table 9 Mechanical properties of FM [4-6, 8, 9]

FM	Hardness
E DUR 600	57-62 HRC
CrWC 600	60 HRC

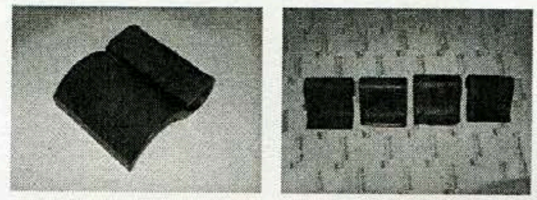
Table 10 Mixer blades hard facing parameters

BM thickness [mm]	FM	Electrode diemater [mm]	Current [A]	Voltage [V]	Hard facing speed [cm/s]	Drive energy [J/cm]

10	INOX 18/8/6	3.25	100	24	0.136	14118
	ABRADUR 58	3.25	130	25	0.124	20968
	E DUR 600	3.25	120	25	0.119	20168
	CrWC 600	3.25	125	25	0.116	21552

3.3 Knives for terrain levelling

Main purpose of this working parts is to cut grass and level different terrains [3, 5, 10]. This working parts are subjected to intensive wear, thus, damage of this part often occurs. The blades were made from Č4830/51CrV4 steel and they have a specific geomtry. Chemical composition and mechanical properties of BM are shown in table 11 and 12. As in prevous cases, same FM were used, for which, hard facing parameters are shown in precous tables 5 and 10. On figure 5 new and worn parts are shown.



a) b)

Figure 5. Appearance of new (a) and worn (b) blades

Table 11 Chemical composition of BM [3, 10]

BM	Chemical composition [%]						
	C	Si	Mn	Cr	V	P	S
Č4830	0.47-0.55	0.4	0.7-1.1	0.9-1.2	0.1-0.25	0.025	0.025

Table 12 Mechanical properties of BM [3, 10]

BM	R_m [MPa]	R_{Eh} [MPa]	A_5 [%]	KV [J]	HB
ČL4830	700	550	13	-	248

4. TRIBOLOGICAL TESTING OF BASE AND FILLER MATERIALS

After hard facing, from deployed layers blocks for tribological investigations with dimensions 6.3×10×15 *mm* were prepared. Disk with standard dimensions was made from tool steel Č5430/36CrNiMo4 hardened to approximately 46-50 HRC [4]. To exclude the influence of surface quality, all elements were fine grinded and polished. Figure 6 shows scheme of conducted tests.

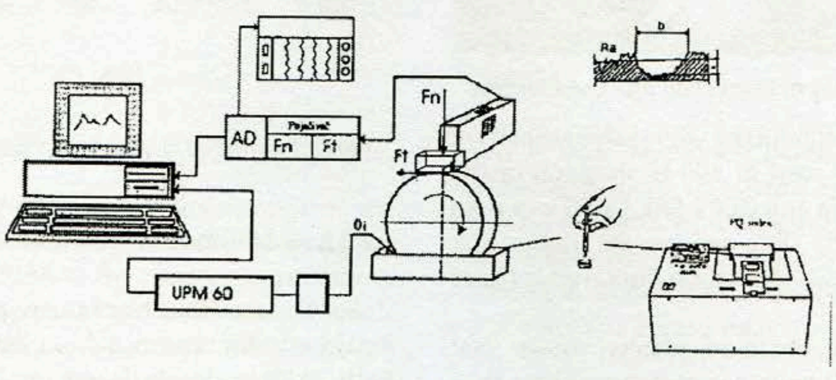
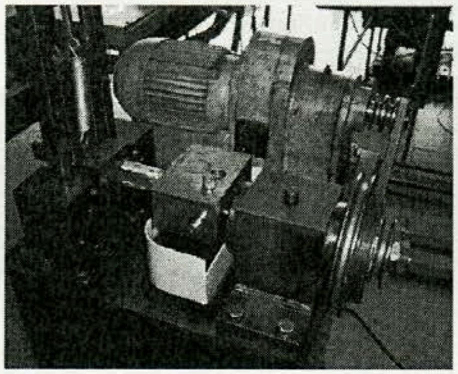


Figure 6 Scheme of tribological properties investigation

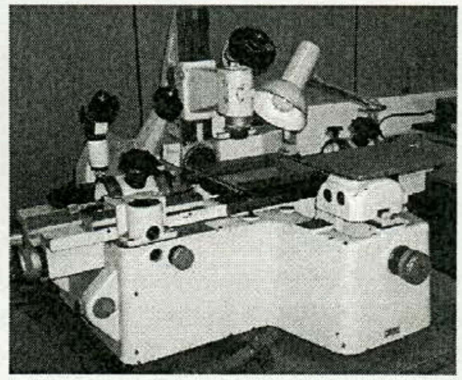
The investigations have been completed on TPD-93 tribometer (fig. 7a) developed by Faculty of Engineering's center for system revitalisation. After the tests were finished, using microscope UIM 21 (fig. 7b) width of wear scars were measured. Width of wear scar served as criteria for determination wear resistance of tested block [4-7, 9-11].

4.1 Bucket teeth

For this case three blocks were prepared. One block from BM, and one for each applied hard facing technology (with and without preheating). In table 13 information for each prepared block were given and on figure 8 test blocks and disk are given.



a)



b)

Figure 7. Appearance of TPD-93 and UIM 21 devices

Table 13. Test blocks properties

Block no.	BM	FM	Number of deployed layers	Layer height [mm]
Blok 1	ČL3134	INOX B 18/8/6 ABRADUR 58	3	8.2-9.5
Blok 2	ČL3134	ABRADUR 58	2	6.3-8.5
Blok 3	ČL3134	-	-	-

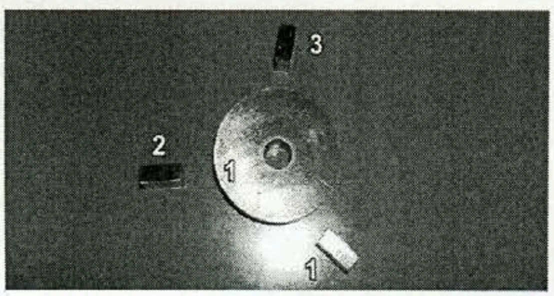


Figure 8 Display of blocks and disk used for test

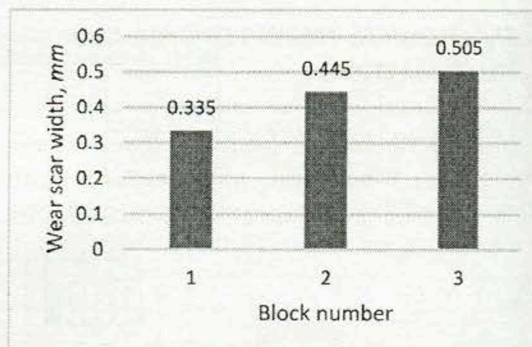


Figure 9. Graphic display of obtained results [4]

Tests were conducted with sliding velocity of 1 m/s, normal load of 300 N, duration of the test was 60 min and GLX 2 SAE 15-40 was used for lubrication. Obtained results (wear scar width) are shown on a graph displayed in figure 9.

Analysis of obtained results shows that blocks 1 and 2 have narrower wear scar than the block 3, thus according to tribological investigations they are more resistant to wear. Comparing the two hard faced blocks, block 1 showed greater wear resistance, so it has been decided to transfer its hard facing technology to real parts [4].

4.2 Mixer blades used in asphalt bases

For this case four blocks were prepared, two from both BM, and two from FM (fig. 10) [4]. Both FM's were deployed on interlayers of INOX B 18/8/6. In the table 14 information for each prepared block were given and in figure 11 the obtained results are presented. For better comparison, properties of block 1 were also shown. Disk for this investigation was prepared the same way as the first one.

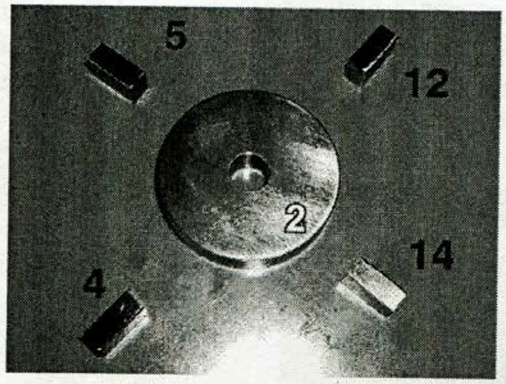


Figure 10. Display of prepared blocks and disk

Table 14. Test blocks properties

Block no.	BM	FM	Number of hard faced layers	Layer height [mm]
Blok 1	ČL3134	INOX B 18/8/6 ABRADUR 58	3	8.2-9.5
Blok 4	Č0361	INOX B 18/8/6 CrWC 600	3	4.5-6.0
Blok 5	Č0361	INOX B 18/8/6 E DUR 600	3	4.2-5.6
Blok 6	ČL4150			
Blok 7	Č0361			

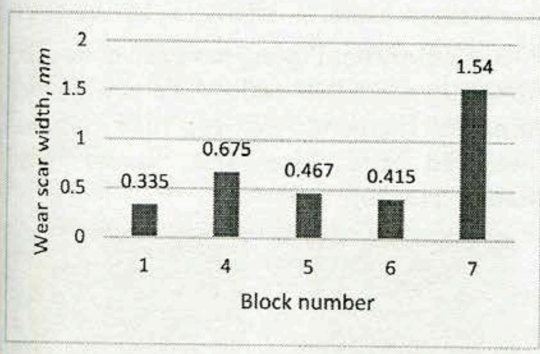


Figure 11. Graphic display of obtained results [4, 9]

Analysis of obtained results shows that the worse wear resistance has block prepared from steel Č0361/S235JR. Greatest wear resistance are displaying block prepared from models hard faced with combination of INOX B 18/8/6 and ABRADUR 58 block from ČL4150 and last blocks from E DUR 600 and CrWC600. Due to good wear resitance of all hard faced blocks, technologies were transfered to hard facing of real parts. Final selection of hard facing technology is obtained after investigation of parts properties in working conditions [4, 9].

4.3 Knives for terrain leveling

According to results obtained in previous sections, it has been decided to use same FM and parameters for hard facing of worn surfaces on real parts.

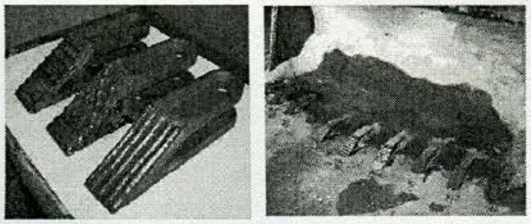
5. HARD FACING AND MONITORING OF REAL PARTS

As it was mentioned before, hard facing technologies were transfered from blocks on real working parts. After that, mass of each part was measured. Parts were mounted and released in exploitation. Periodically, working parts mass was measured.

5.1 Bucket teeth

During the repair procedure, it has been concluded that used technologies are giving great results. Partial production of hard facing has been done, due to obtained conclusions.

From nine teeth, three were partialy hard faced. Each tooth had different layout of hard faced layers (Fig. 12). Hard faced teeth were mounted on the middle position of bucket (teeth 4, 5, 6), where greatest loads were expected.



a) b)

Figure 12. Display of hard faced samples (a) and mounted on bucket (b)

As mentioned, each teeth's mass was measured before mounting on the bucket. After 3200 working hours mass measurments were done [4]. The obtained results are shown in Figure 13.

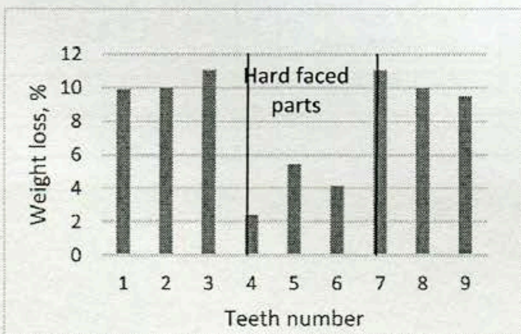


Figure 13. Weight loss of new and production hard faced teeth

Obtained results show that hard faced parts have 2-3 times longer life span. Additional conclusion could me made, that longitudal layout of hard faced layers has shown the greatest wear resistant of all hard faced teeht.

5.2 Mixer blades used in asphalt bases

Hard facing technologies from models were transfered to real working parts (fig. 14), which mass was then measured. In the Figure 15 obtained results from investigation in real conditions after 720 working hours were shown.

Obtained results, once again show that hard faced parts are more wear resistant than new parts. Blade hard faced with E DUR 600 has proven the most resistant. Blades hard faced with ABRADUR 58 also show good resistant. The least resistant FM has proven to be the CrWC600, but comparing it to resistance of BM it still represents an improvment. Conclusion can be made that hard faced parts have longer working life in the given conditions, and that results of triblogical investigations show great corellation with results obtained in real investigation.

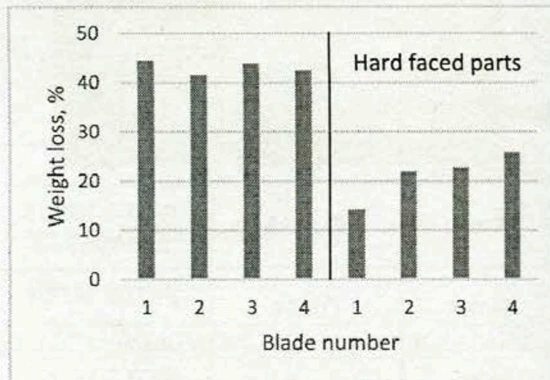
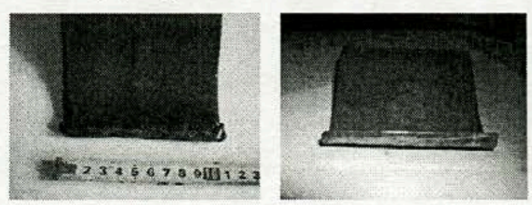


Figure 15. Graphical display of weight loss on diffrent mixer blades

5.3 Knives for terrain levelling

Reparatory hard facing has been done using ABRADUR and E DUR 600 FM. Parts were hard faced and sharpened (Fig. 16). Their mass was measured and afterwards knives were mounted [3, 10].



a) b)

Figure 16. Display of hard faced and sharpened blades

Again, the same conclusions have been obtained from the results (fig. 18). Hard faced parts show greater wear ressistance than the new parts. FM E DUR 600 after all investigations proves as the most wear ressitant, specially in conditions where during the work impacts occurs. All investigations are showing great corellation with tribological investigations.

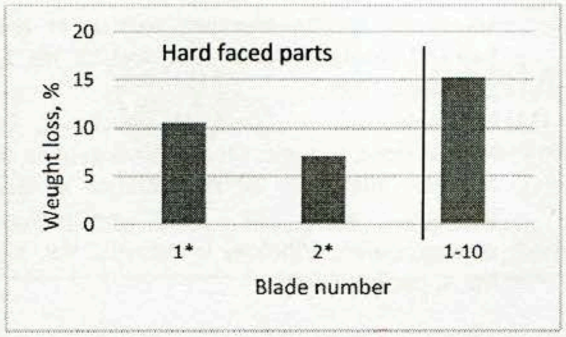


Figure 18. Graph display of weight loss on different blades for terrain leveling

6. CONCLUSION

Today, technology of hard facing represents an advanced technology whose correct application could result in many benefits. For result of hard facing to be good, correct technical approach, adequate knowledge and equipment are required. The aim of this paper is to establish a corellation between tribological investigation and real working conditions for working parts of construction mechanization. Primarly, experimental tests were conducted and blocks from hard faced layers and BM were prepared. As a criteria of wear ressistance, wear scar widht has been used. After the analysis of the obtained results, applied technologies were transfered to real parts. as a parameter of wear resistance in real investigation the working life and geometry change. Based on that results final hard facing technology has been chosen.

Results obtained from tribological investigations, show that the most resistant FM was ABRADUR 58 which had the narrowest wear scar of 0.335 mm. Second most resistant filler material was E DUR 600, whose wear scar width was 0.467 mm. Least wear resistant FM proves to be CrWC600. Its width of wear scar was 0.675 mm.

Investigation in real working conditions showed similar results. Most resitant FM proves to be E DUR 600 followed by ABRADUR 58 and CrWC 600. ABRADUR 58 is the most resistant in the static conditions (without impacts) whereas E DUR 600 proves to be the most resistant in conditions with slight imapacts. Still great corellation of real and tribological investigations exsists, and the results of tribological investigation could be used as guidelines for choosing technology of hard facing.

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