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RESEARCH

Carbide Type Influence on Tribological Properties of Hard Faced Steel Layer – Part II- Experimental Results

In this paper is presented a preceding procedure that should be conducted in order to successfully regenerate damaged forging dies by the hard facing process. After the tool damage types identification, as well as their causes, we have chosen the procedure and the parameters of hard facing that we further corrected by conducting the test hard facings on models. Thus, we were able to relate the experimental results outputs with the repair technology, taking as a criterion the quality of the surface layers wear resistance such as friction coefficient and width of hard faced zone, hardness and its distribution in cross section, then microstructure of characteristic of hard faced zones, etc. This research points out significancy of tribological properties of certain types of carbides and their effects on metal matrix, in which carbides are embedded. Our tribological investigations have shown that the working life of the hard faced tool can be longer than that of the new tool.

Keywords: *carbides, hard facing, forging dies, filler material, friction coefficient, microstructure, hardness.*

1. INTRODUCTION

Investigations on models suggest that, besides the applied technology, the type of filler material is of decisive importance for output properties of the hard-faced layer. Depending on all the working conditions of the part, the dominant type of wear, the most suitable filler material, the most suitable hard facing technology is chosen. The results of this paper point out the importance of the right choice of filler material and hard facing technology on which both type of microstructure, and type of carbides depend.

In previous paper [1] firstly is pointed out influence of the most important alloying elements in steel, then review of the most important kind of carbides developed during hard facing of steel parts with different filler materials, and finally it is pointed out their wear resistance in different circumstances.

In later sections it will be examined choice the most suitable filler materials and hard facing technologies, by examination of two the most frequently used alloy steels for work at elevated temperatures. To achieve it, number of experimental hard facings has been performed with two the most often used filler materials with variations of the most important technological parameters. Such hard faced samples are used to examine the most important wear resistance characteristics. These are foremost:

- hardness of hard faced zones and its distribution through cross sections,
- microstructure of hard facing zones and kind of carbides in those,
- coefficient of friction of corresponding contact surfaces of tribological pair, and
- width of wear zone.

Former models examinations, published elsewhere, were bases to prescribe starting hard facing technology of steels for working at elevated temperatures, which with small corrections may be applied for real working parts. Final decision, which hard facing technology should be accepted, should be made after analysis of results of

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experimental testing of real parts in real environments and verification of economical justification of applied technology. That is the most valid way to adopt proposed model of hard facing technology for examined working parts.

Here is given the complete technology of forging dies hard facing, made of alloyed steels, aimed for working at elevated temperatures. For estimates of weldability, the model tests were performed, in order to simulate the exploitation conditions. In this way, the output results were related to the chosen technology, i.e., the relationship was established between optimally determined hard facing parameters, corresponding thermal treatment and realized output results (tribological characteristics, microstructure, hardness, etc.). A reason for such a detailed investigation was the responsible function of the part and hard working conditions (high cyclic thermal fatigue, elevated temperatures, oxidation, corrosion, etc.).

2. MAIN CAUSES OF FORGING DIES DAMAGES

The forging dies are in exploitation subjected to numerous cyclic loads, thus, after certain operating time, the impression damages occur, and the tool has to be replaced or repaired [2-8, 16]. Statistical considerations of the damaged dies have shown that main causes of their removing from exploitation could be: change of dimensions and form of impressions due to friction and wear, cracks all over the die due to thermal fatigue, and micro cracks caused by action of the stress concentrators.
Wear, caused by action of impact-compressive loads, is characterized by appearance of deformation and friction, as well as cracks at certain depth at working surfaces. The fatigue cracks may also appear, also at certain depth beneath the surface.

Wear that appears at elevated temperatures is a consequence of oxidation, forming of oxide coating at high temperatures, decrease of mechanical characteristics at surface layers, what, together with effects of thermal fatigue, leads to increase of stresses and finally to destruction of surface. Accelerated wear of surface of dies that operate at elevated temperatures is usually in form of characteristic cracks and even crumbling caused by thermal fatigue. Factors that are leading to thermal fatigue are: material thermo-physical characteristics (thermal conductivity, specific heat and coefficient of thermal linear extension), the part geometry (size, shape, type of surface), and other material properties (mechanical, chemical, structural) [9-15]. Besides the thermal stresses, caused by temperature gradient, also appear the structural stresses, which depend on chemical composition of steel, kinetics of austenite transformation, namely the cooling speed. Due to influence of cyclic variation of thermal stresses, the initial cracks can also appear on the material surface.

In the present case, it is analyzed the forging dies aimed for manufacturing parts in car and trucks producing industry. During the excessive monitoring of dies in exploitation, it was noticed that failures (removing dies form exploitation) could be due to following reasons:

- increase of the forged pieces dimensions due to worn die,
- deformation of the thin-walled portions of the die (ribs, mandrels),
- appearance of cracks at certain parts of the die, and
- local fractures.

The aforementioned damages are remedied primarily by application of the manual arc welding (MMA) procedure, and machining is mainly done by grinding (occasionally by milling), depending on the application of the filler material. In order to select the optimum technology of forging dies hard facing, numerous tests were conducted at the model whose sizes were determined according to the similarity theory principle, namely the non-dimensional analysis.

For the quality criterion of the performed hard facing was adopted the change of hardness and structure in the zones of the hard faced layer, namely in the heat affected zone beneath it, as well as the resistance of the deposited layers to wear.

Hard facing of dies aimed for operation at elevated temperatures as an objective has generally their repairing by compensating losses caused by friction or crumbling. Manufacturing of new dies made of construction carbon steels with working surfaces hard faced by tool steel presents an exception. In the case of tool aimed to work at room temperature, the reparatory hard facing is also very popular, as well as manufacturing of alternative dies with hard-faced blades.

3. MATERIALS FOR FORGING DIES MANUFACTURING AND THEIR CHARACTERISTICS

Refractory steels are used for temperatures above 300°C. Here are considered small, eventually medium and large dies, for hot forming, tools for pressing and extrusion of non-ferrous metals at elevated temperatures, tools for hot trimming, dies for pressurized casting of pure Al, Zn and Mg. In the considered case, all experiments were conducted on forging dies made of steel Č5742 (DIN 17350 56NiCrMoV7) and Č4751 (DIN 17350 X38CrMoV51). Chemical composition, mechanical characteristics and microstructure of these steels are given in Tables 1 and 2 [2, 3, 16].

Table 1. Chemical composition and comparative marks of steels Č5742 and Č4751 [2, 3, 14, 18]

No.	Mark by YUS	Chemical composition, %									Relation to other standards	
		C	Si	Mn	P	S	Cr	Ni	Mo	V	DIN	UNI
1.	Č5742	0.55	0.3	0.7	0.035	0.035	1.1	1.7	0.5	0.12	56NiCrMoV7	U52NiCrMo6KU
2.	Č4751	0.40	1.0	0.4	0.025	0.025	5.0	-	1.3	0.4	X38CrMoV51	UX35CrMo05KU

Table 2. Mechanical characteristics and microstructure of steels Č5742 and Č4751 [2, 3, 14, 18]

No.	Mark by YUS	Soft annealing			Quenching and tempering			Preheating temperature (Seferian formula)	Microstructure Base metal - B.M.
		t, °C	HV_{max}	R_m , MPa	t, °C	HRC	R_m, MPa		
1.	Č5742	670-700	250	850	400-700	50-30	1700-1100	≈ 300	M + B (Interphase structure)
2.	Č4751	800-830	250	850	550-700	50-30	1700-1100	≈ 300	M + B (Interphase structure)

Since blacksmith workshops use forging dies in thermally tempered state (quenching and high tempering), we subjected all the samples to that treatment, to come as close as possible to real (exploitation) conditions. On selected samples (models) we measured hardness after thermal treatment and it was 40-42 HRC for Č5742 and 41-49 HRC for Č4751. The softening annealing was not performed (though HV>350) since mainly grinding was used for machining.

Since the samples of thicker cross sections were also hard faced (s = 40-45 mm), made of steels prone to self-hardening (C>0.35%), the preheating was necessary. The preheating temperature was determined according to Seferian formula [2, 12, 16, 17], leading to $T_p \approx 300°C$.

4. SELECTION OF TECHNOLOGY AND FILLER MATERIAL

Hard facing of chosen samples was performed in Laboratory of ZA[1], by application of cored electrodes. Technological parameters of hard facing were determined according to [2, 16, 17], and hard-facing was performed in two and three passes to decrease the degree of mixing (dilution), i.e., to obtained declared characteristics supplied by the manufacturer of electrodes. It has been measured the velocity of hard facing during each pass, and also, prior to applying another layer, checked the preheating temperature, i.e., the interpass temperature. The digital-measuring device Tastotherm D1200 was used for measurements, which is supplied with a thermocouple NiCr-NiAl with a measuring range from - 50°C to 1200°C.

As a filler material were applied highly alloyed basic electrodes UTOP 38 (DIN 8555 E3-UM-40T) ∅3.25 *mm* and UTOP 55 (DIN 8555 E6-UM-60T) ∅5.00 *mm*. The filler materials were aimed for hard facing of dies that are used for forming of steels and other metals both in hot and cold state, like ingot mold, steel molds, dies and pressing mandrels. Hard-faced layers are tough, resistant to wear and impact. The hard faced layers hardness is constant up to temperature of 600°C. These basic electrodes were dried prior to application according to the following regime: heating up together with the furnace up to temperature of 350-400°C, keeping for two hours at the drying temperature, and cooling in

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[1] ZA - Zastava cars, Kragujevac, Serbia.

the furnace for one hour, while the temperature did not fall below 150°C. Thus heated electrodes were used for hard facing of the preheated samples, with what we decreased the level of diffusive hydrogen and eliminated the possibility appearance of hydrogen induced cracks.

In Tables 3 and 4 are presented the hard facing parameters (hard facing current was for about 10% lower than at welding), as well as properties of the filler material.

Table 3. Parameters of the hard facing process [2]

No.	Electrode mark		Core diameter, mm	Hard facing current, A	Voltage, V	Hard facing velocity, cm/s	Heat input energy, J/cm
	Iron plant "Jesenice"	DIN 8555					
1.	UTOP 38	E3-UM-40T	3.25	115	26	≈ 0.28	8543
2.	UTOP 55	E6-UM-60T	5.00	190	29	≈ 0.25	17632

Table 4. Filler material properties [2, 18]

No.	Electrode mark		Chemical composition, %					Type of current	Hard faced layer hardness, HRC	Application
	Iron plant "Jesenice"	DIN 8555	C	Cr	Mo	V	W			
1.	UTOP 38	E3-UM-40T	0.13	5.0	4.0	0.20	+	= (+)	36-42	Hard facing of dies for operation at elevated and normal temperatures
2.	UTOP 55	E6-UM-60T	0.50	5.0	5.0	0.60	+	= (+)	55-60	- II -

Order of hard faced layers deposition is given in Figure 1a, where prior to each pass, the layer of slag was removed with a steel brush. The following layers were also applied according to this scheme (the second - Figure 1b and the third - Figure 1c).

The width of a pass hard faced with the ∅3.5 mm electrode was b ≈ 10-12 mm, the height of the faced layer was h ≈ 1.5 mm, and with the ∅5.00 mm electrode measures were b ≈ 16-18 mm and h ≈ 2.1 mm.

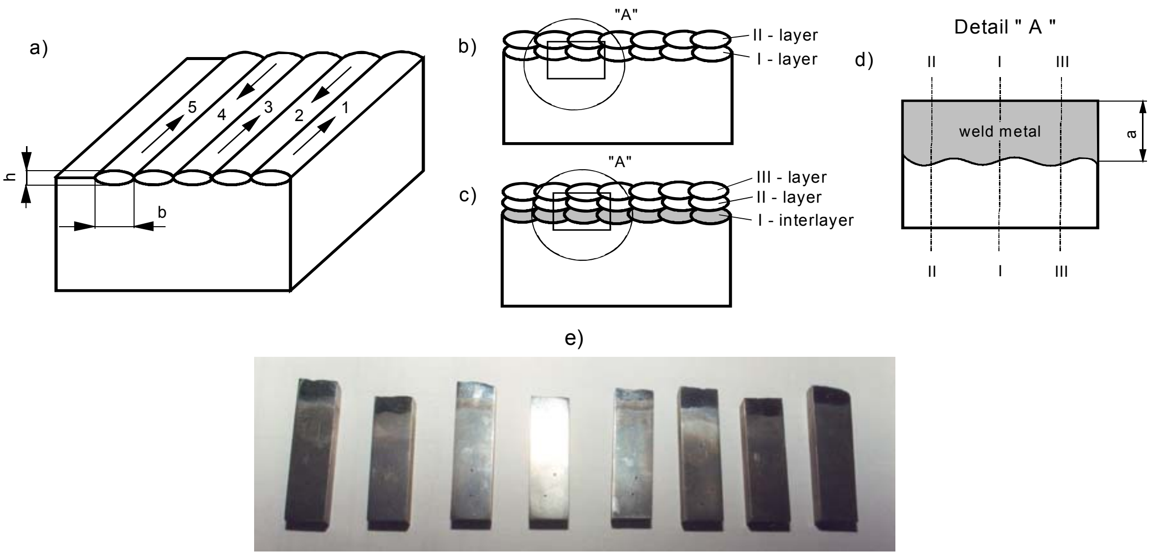


Figure 1. Order of hard faced layers deposition: a) 1st layer, b) 2nd layer, c) 3rd layer, d) metallographic block, and pin appearance, and e) samples prepared for metallographic testing

5. TRIBOLOGICAL INVESTIGATIONS

5.a Preparation of pin and disk

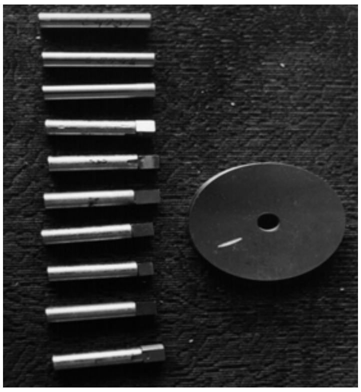
In order to determine the tribological characteristics of the hard faced layers, the hard facing was performed on different materials (Č5742 and Č4751), with different filler materials (UTOP 38 and UTOP 55), and in two and three layers, (see Fig. 1 and Tab. 5).

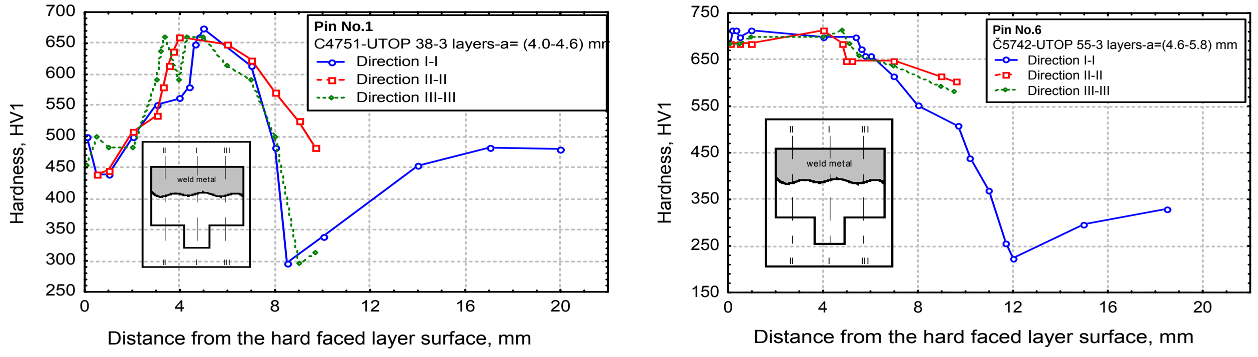
According to presented technology of hard facing, and Figure 1d, the preparation of pins was done by grinding, to examine the tribological characteristics. Two pins were also prepared from Č5742 and Č4751 (∅10 x 50) tempered to (380-410) HB. Disks were made of Č3840 – JUS (145V33-EN 10027) with dimensions ∅75 × 10 mm. Disk hardness was within limits 61.8 to 65.3 HRC, namely 742-839 HV1.

5.b Hardness distribution and microstructure of pins and disks

After preparation of samples-pins, the hardness HV1 was measured on them in directions I-I, II-II and III-III (Figs. 1d and 1e), starting from the hard faced layer surface at different distances. In Figure 2 are presented only the characteristic diagrams of some pins hardness variation [2, 3, 14].

Table 5. Technology of pins preparation

Number of sample-pin	Substrate material	Hard faced layer material	Number of layers	Hard faced layer height, *mm*	Layout of disk and pins
1.	Č4751	UTOP 38	3	4.0-4.6	
2.	Č5742	UTOP 38	2	2.9-3.2	
3.	Č4751	UTOP 38	2	3.2-4.0	
4.	Č5742	UTOP 38	3	4.5-5.0	
5.	Č5742	UTOP 55	2	4.0-5.1	
6.	Č5742	UTOP 55	3	4.6-5.8	
7.	Č4751	UTOP 55	3	4.3-6.1	
8.	Č4751	UTOP 55	2	3.2-4.6	
9.	Č5742	-	-	-	
10.	Č4751	-	-	-	

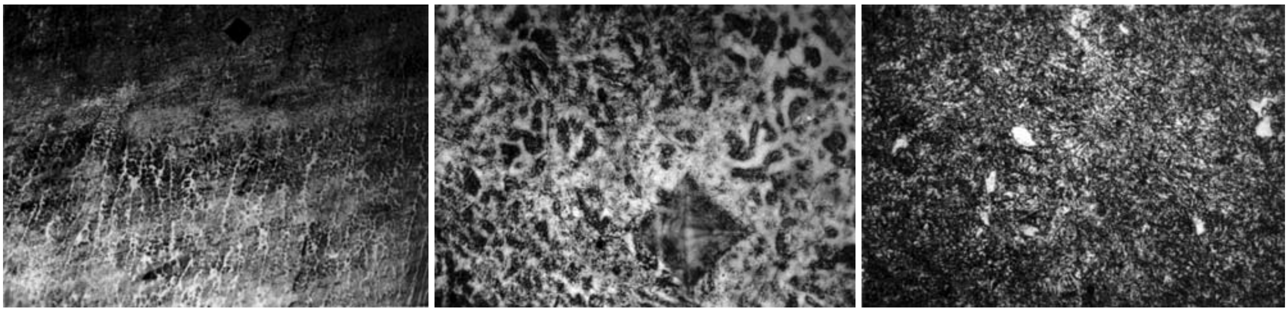


a) b)

Figure 2. Hardness distribution: a) UTOP 38 and b) UTOP 55

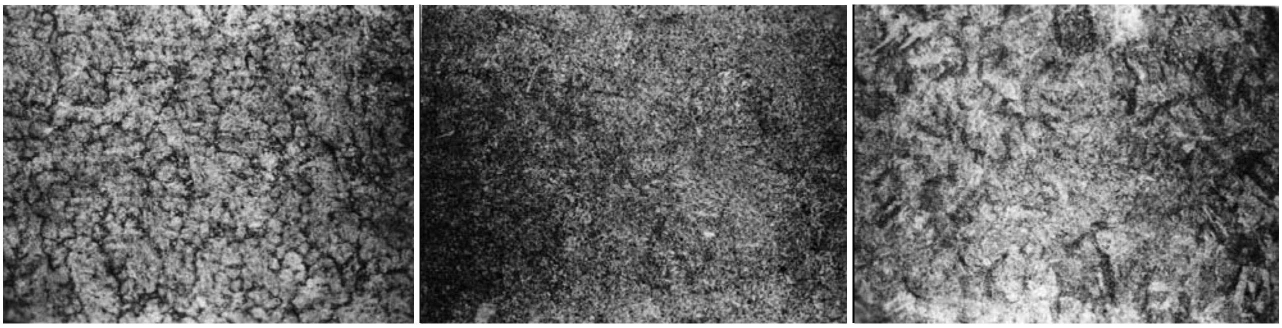
By analysis of hardness distribution diagrams the stability of micro hardness can be noticed, especially in the hard faced layers zones. In preparation of pins from the hard faced layer sample, where relaxation was not performed in order to reduce the residual stresses, the cracks were noticed [2, 3, 14].

Microstructure of characteristic zones of the two-layer hard faced material, done with the UTOP 38 (Figs. 3.a and 3.b) and UTOP 55 (Figs. 4.a, and 4.b), does not differ very much from the hard faced material realized by the tree-layer hard facing [5].



a) b) c)

Figure 3.a Microstructure of sample hard faced with electrode: UTOP 38 a) Hard faced layer (50×), b) Hard faced layer (500×), c) BM (500×) - after hard facing

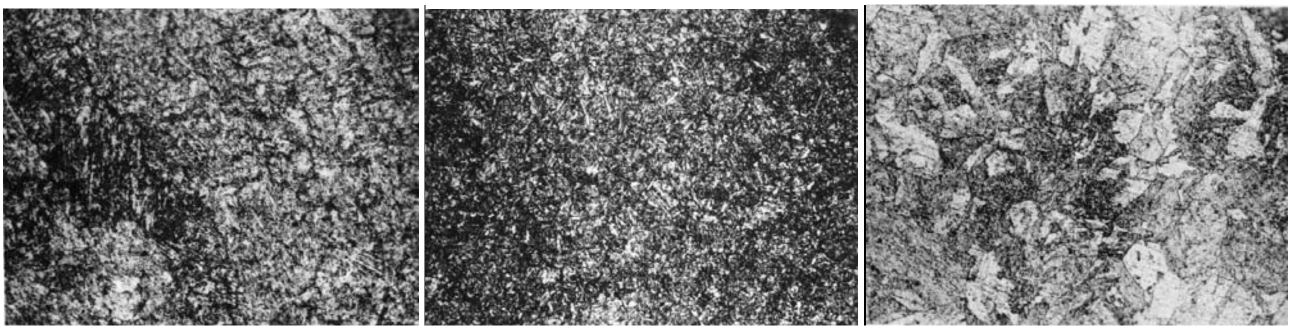


a) b) c)

Figure 3.b Microstructure of sample hard faced with electrode UTOP 38: a) Hard faced layer (200×), b) HAZ (200×), c) BM (200×) - after hard facing and tempering

a) b) c)

Figure 4.a Microstructure of sample hard faced with electrode UTOP 55: a) Hard faced layer (50×), b) Hard faced layer (500×), c) BM (500×) - after hard facing



a) b) c)

Figure 4.b Microstructure of sample hard faced with electrode UTOP 55: a) Hard faced layer (200×), b) HAZ (200×), c) BM (200×) - after hard facing and tempering

Figures 5 and 6 show hard faced microstructure obtained with filler materials UTOP 38 and UTOP 55. On the metal grain boundaries are formed carbides of vanadium, chromium, and molybdenum. Samples are cut, then grinded, and finally etched with Nital (solvate – 2% of HNO_3 in alcohol) and "Aqua regia" (solvate – 20 ml HCl + 10 ml HNO_3 + 30 ml glycerol).

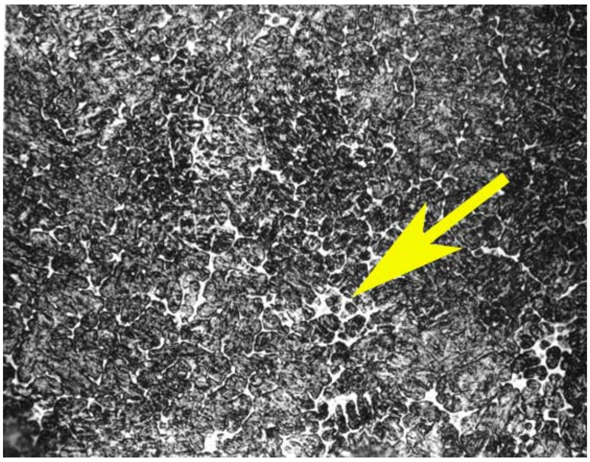


Figure 5 Carbides in microstructure (200×) UTOP 38 - after hard facing

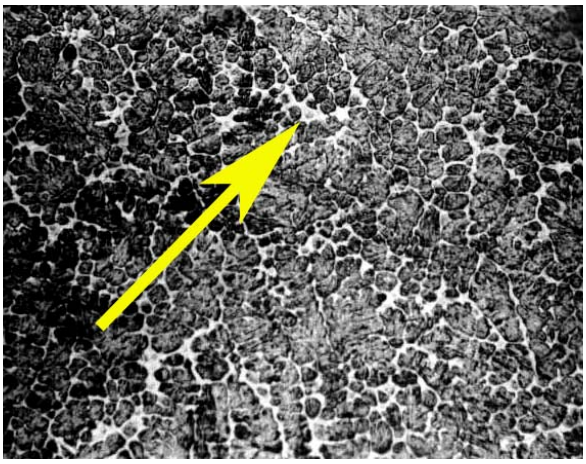


Figure 6. Carbides in microstructure (200×) UTOP 55 - after hard facing

5.c) Tribological investigations

Tribological investigations were done with tribometer TPD-93 (Fig. 7) at Faculty of Mechanical Engineering in Kragujevac. The aim of these investigations was to determine resistance to wear of the substrate materials, as well as of the deposited coatings - the hard faced layers. In that sense the "pin-on-disk" contact was realized, in which the contact force, the sliding speed, and the lubricant were varied.

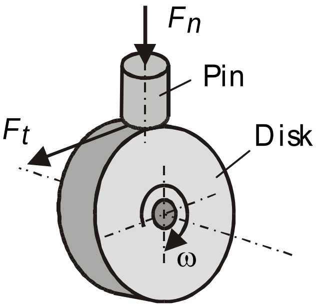


Figure 7. Work principle of tribometer TPD-93

Prior to contact beginning the topography of the pin and disk surfaces were measured on the computer measuring system Talysauf 6, then the contact was realized with variation of both the normal force (F_N = 100, 150, 200, and 250 N), and the sliding speed (v_{kl} = 1.5, 2.0 and 2.5 m/s). The friction coefficient was determined during these measurements, namely the friction force, and this period is considered as the running-in period (≈ 6 min). Then the normal force F_N = 250 N was adopted with the sliding speed v_{kl} = 2 m/s, and during the contact period of ≈ 30 min the friction coefficient variation was registered (Figs. 8, 9 and 10). After the contact stops the topography of the pin and disk surfaces was measured again, i.e., the wear scar width of the pin was measured (Fig. 11). In this way, tribological characteristics of pins were determined (according to Tab. 5). The wear scar width was measured on the universal microscope UIM-21, with magnification of 50x [2, 3, 14].

In Figure 12 is given the variation of the friction coefficient after the conducted tests, and in Figure 13 is shown the average wear scar width for different pins. Based on these investigations, it can be noticed that significantly higher resistance to wear exhibit hard faced layers (especially those hard faced with the UTOP 55 electrode), with respect to the substrate material, what points to a complex procedure of selection the filler materials suitable for real technological working conditions of the forging dies [2, 3, 14].

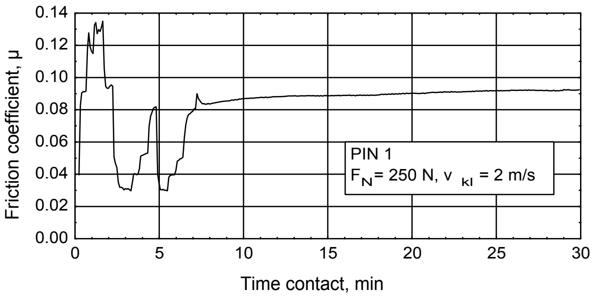


Figure 8. Change of friction coefficient during the contact period of 30 min (UTOP 38 - 3 layers)

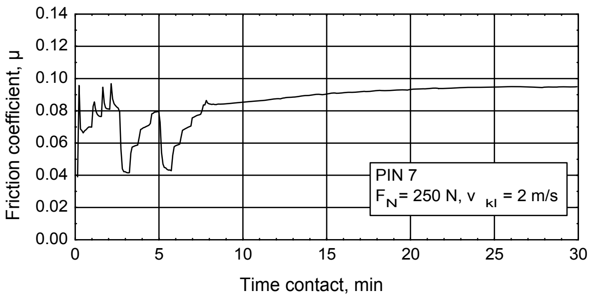


Figure 9. Change of friction coefficient during the contact period of 30 min (UTOP 55 - 3 layers)

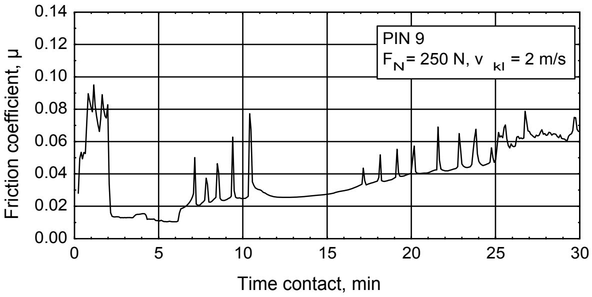


Figure 10. Change of friction coefficient during the contact period of 30 min (B.M. 5742)

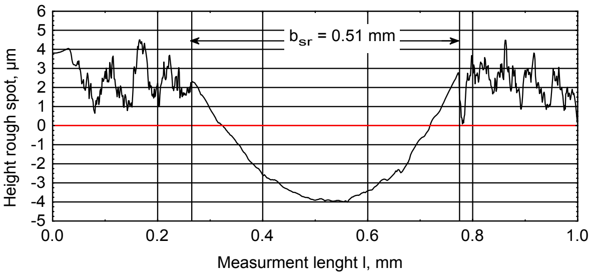


Figure 11. Layout of the wear scar width –PIN No 7 (after the contact period of 30 min)

After the tribological investigations, the analysis of macroscopic as well as microscopic damages was done. Figures 13, 14 and 15 show these damages at of some chosen pins [2, 3, 14].

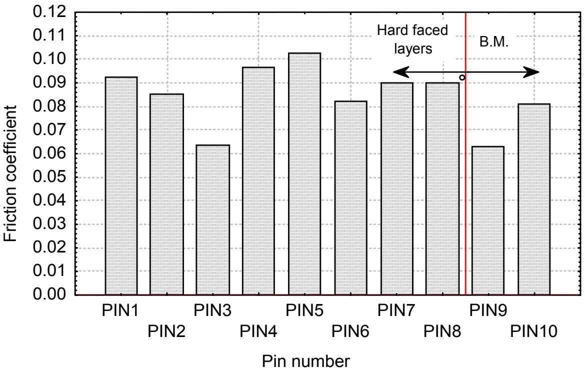


Figure 12. Friction coefficient after the 30 minutes contact [2, 3, 14]

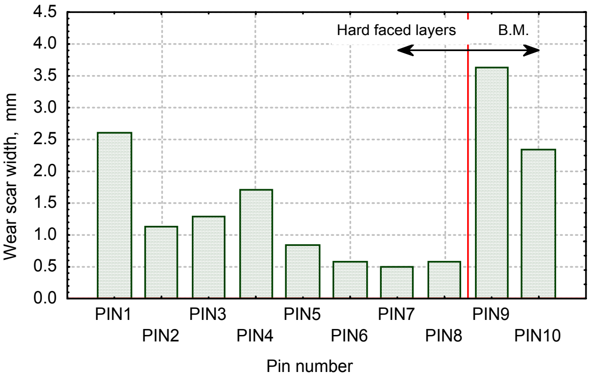


Figure 13. Wear scar width after the 30 minutes contact [2, 3, 14]

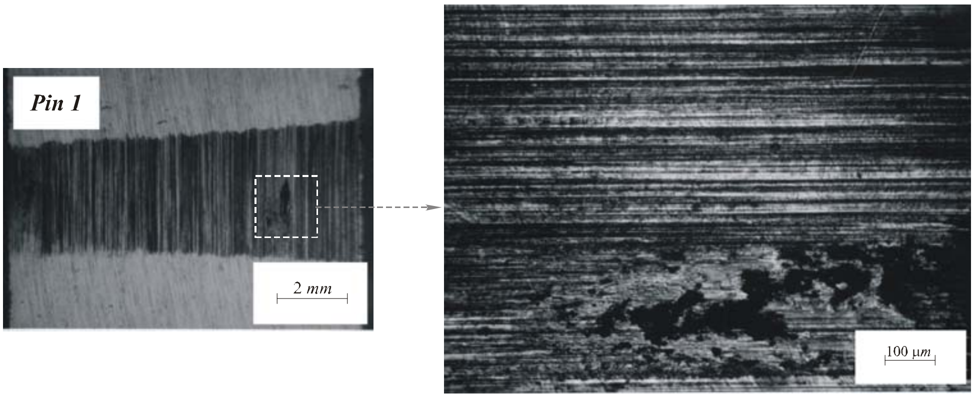


Figure 14. Wear of the pin 1 (UTOP 38)

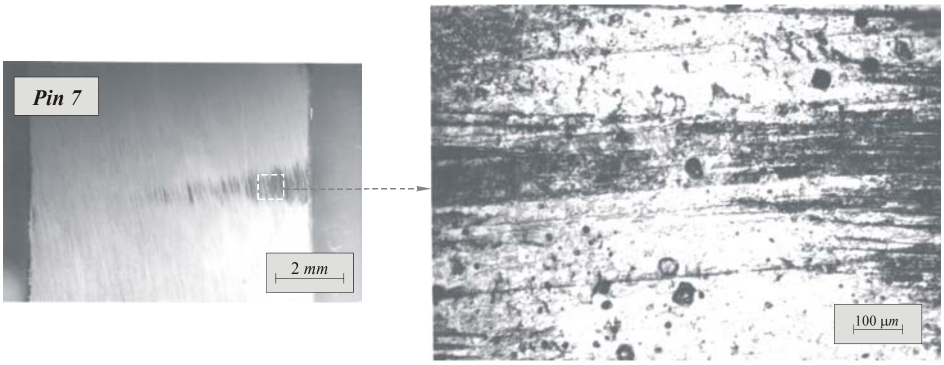


Figure 15. Wear of the pin 7 (UTOP 55)

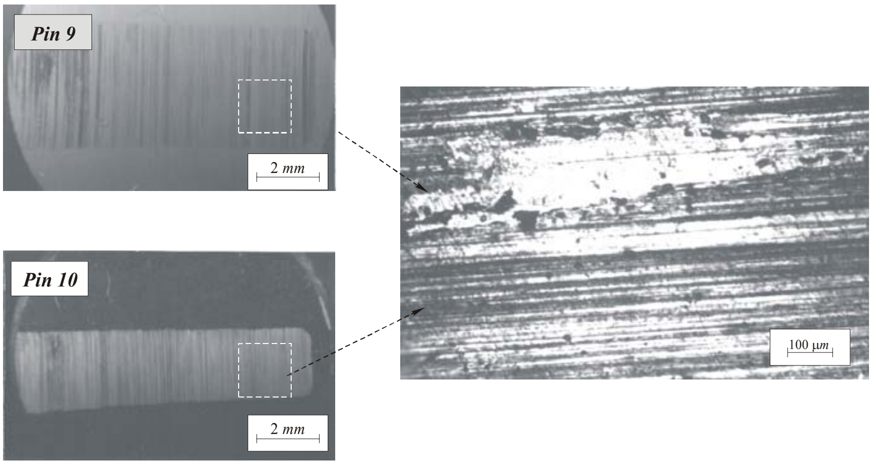


Figure 16. Wear of the pins (B.M. - Č5742 and Č4751)

6. CONCLUSION

Research of models and real parts leads to conclusion that crucial influence on hard faced layer properties, beside applied reparation technology, has kind of filler material. Depending on working conditions, that is on which kind of hard facing is dominant, may be chosen the most suitable filler material, and repairing hard facing technology. Performed tribological examinations lead to conclusion that, considering wear resistance indicated by smaller width of wear trace, resistance of hard faced layers is considerably higher than wear resistance of base material, and, considering energy saving indicated by smaller friction coefficient, base material is slightly superior. Tests, performed for determination of values of friction forces, friction coefficients and wear traces width, with pins of different properties, such as hardness or microstructure, lead to main conclusion that increase of hardness leads to increase of friction coefficient and decrease of wear scare width. Wear scare width is the smallest in hard faced layers made with UTOP 55 electrodes, bigger made with UTOP 38, and the biggest in base material. That result may be explained with the fact that carbides in hard faced layers made with filler material UTOP 55, considerably more stable and steady in comparison to hard faced layers made with filler material UTOP 38.

In this paper, it has shown that the successful hard facing of forging dies is possible only after detailed investigations on models. The presented investigations, as well as those that were not presented in this paper, point to the fact that here presented reparation procedure, verified on models, can give satisfactory results also in real working conditions. Besides requirements for good mechanical properties of the hard faced layers, wear resistance, and thermal fatigue, it is also necessary that they have good toughness, convenient microstructure, as well as the good machinability. These contradictory requirements can be satisfied by proper selection of the reparation procedure and corresponding filler material, then by selection of optimal technology of hard facing, including into that the cheapest possible final machining of the repaired part.

It is shown that lifetime of hard faced parts may be much longer than lifetime of new parts. Cost of hard facing is lower than cost of purchase and storage of new spare parts, which leads to better productivity. Techno-economical effects displayed here may lead to wider application of advanced technology.

Present research also point out the fact that the reparation jobs can be performed successfully only in specialized institutions, which have adequate equipments and high professional expert teams.

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