V. LAZIĆ, D. MILOSAVLJEVIĆ, S. ALEKSANDROVIĆ, P. MARINKOVIĆ, G. BOGDANOVIĆ, B. NEDELJKOVIĆ, M. MUTAVDŽIĆ

RESEARCH

Tribological Investigations of Hard-Faced Layers and Base Materials of Forging Dies with Different Kinds of Lubricants Applied

This paper gives a procedure for choosing the right technology for reparative hard facing of damaged forging dies. Since they are subject to impact loads and cyclic temperature elevations, forging dies should be made of steel that is able to withstand great impact loads, maintain good mechanical properties at elevated temperatures and that is resistant to wear and thermal fatigue. For these reasons, forging dies are made of conditionally weldable alloy tool steels; however it makes hard facing of damaged tools even more difficult. In this paper, wear resistance of base materials, hard-faced layers and heat-affected zones are tribologically investigated when two different lubricants - pure synthetical oil LM 76 and LM 76 with 6% molybdenum disulfide (MoS_2) are applied. Tribological investigations have shown that the wear resistance of the hard faced layers is considerably greater than the wear resistance of the base material. However, the base material has better properties concerning friction.

Keywords: *hard facing, forging dies, wear, lubricant, hardness, microstructure.*

1. INTRODUCTION

Main causes of forging dies damages are studied in great details in the papers [1, 2, 3, 4, 5, 6, 7, 8, 9], therefore, only some factors related to the hot metal treatment that require the following tribological investigations of hard-faced layers and base materials will be studied here. According to the literature [6, 7, 8, 9], main factors that influence tribological characteristics are classified as:

1. *Geometric factors.* They refer to the contact surface macro geometry (the geometric shape of the contact surface - area, line or point), the contact surface micro geometry (defined by roughness, corrugation, the coefficient of profile irregularities, linear and surface load), deformations of the macro and micro contact zones and the actual contact area.

Vukić Lazić[1)], Dragan Milosavljević[1)], Srbislav Aleksandrović[1)], Petar Marinković[2)], Gordana Bogdanović[1)], Branislav Nedeljković[2)], Milan Mutavdžić[2)]
[1)]Faculty of Mechanical Engineering, S. Janjić 6, 34000 Kragujevac, Serbia
[2)] Zastava cars, Trg topolivaca 4, 34000 Kragujevac, Serbia
[3)] Company for Road maintenance Kragujevac a.d., Tanaska Rajića 16, 34000 Kragujevac
e-mail: vlazic@kg.ac.rs; dmilos@kg.ac.rs

2. *Kinematic factors.* They are related to the type and character of motion, speed and the time of contact;

3. *Dynamic factors.* These refer to the distribution and magnitude of normal pressures (loads) and their variations over time;

4. *Physical-chemical factors.* They are related to the kind of material the coupled pairs are made of, the chemical affinity of the material of the contact pairs and its crystal structure, the kind of oxides formed during the forging procedure and the kind of lubricant;

5. *Energy factors.* These factors depend on the temperature in the micro contact zone, heat balance in the macro and micro contact zones etc.

The factors 1 and 4 define basic properties of the contact pairs, while the others define basic parameters of the friction process. In the further text, these factors will be described in greater details.

1. Investigations of the influence of geometric factors on the friction coefficient have yielded a lot of results but insufficient to define mathematical relations, i.e., to establish correlations between the part geometry and wear parameters.

Prior to each tribological test performed in this paper, roughness of the contact surfaces was measured and its influence on the friction coefficient was studied. A line contact of the working surfaces was adopted as initial. Then, after elasto-plastic and plastic contacts it grew into an area contact. The initial (extreme) unit contact pressure dropped to a measurable level of working pressure. As a result, the friction coefficient changed during the contact.

2. Numerous investigations [4, 7, 8] have shown that with an increase in the working speed (of a tool) the friction coefficient generally decreases. However, due to specificity of the plastic metal shaping, the influence of other numerous parameters should be also considered. During tribological tests, the influence of the sliding speed and the time of the contact on the friction coefficient i.e. on the width of the wear scar zone was studied. The slide speed and the contact time were varied within the span of the testing device.

3. The investigations carried out so far [4, 7, 8], have shown that the dependence of the friction coefficient on the load is of a nonlinear character and that at great pressures the friction coefficient increases significantly. Therefore, at the beginning, when the contact between the two tribo elements is still a line contact, the friction coefficient has high values. In this paper, the normal contact force was varied and its influence on the friction coefficient and the width of the wear scar width was investigated.

4. The choice of the material of the contact pairs plays an important role [4, 5, 6, 7, 8, 9]. In that sense, chemical affinity of the contact pairs and its influence on the friction and wear was primarily investigated. The crystal structure has also a great influence on tribological processes, because two coupled metals with hexagonal crystal lattices have a considerably smaller friction and adhesion coefficients compared to the contact of two metals with cubic lattices. The friction coefficient has the highest value when two metals with surface centered cubic lattices are coupled, and the lowest value in the case of a contact between a metal with surface centered and a metal with hexagonal lattice [10, 11, 12].

When friction is studied, solubility of the metal of the contact pairs in its liquid and solid state should be taken into consideration. Metals that are fully soluble in their liquid and solid state are characterized by high friction resistance. Metals that are fully soluble in their liquid state and partially soluble in their solid state have average friction resistance. Metals that are soluble neither in the liquid nor in the solid state are characterized by low friction resistance. Therefore, the knowledge of binary equilibrium phase diagrams is important for choosing contact pairs of different metals and alloys.

Hardness of the contact pairs has also a significant influence on the wear. Metals of higher hardness are assumed to have better tribological properties. Since forging dies are studied here, oxides formed during the heating of the metal workpiece have to be taken into consideration. When the outer oxide layer of the workpiece comes into the contact with the tools of significantly lower temperature, it gets colder, contracts, crumbles and separates from the workpiece because it cannot cope with the plastic deformation. The separated, rough oxide layer (mainly Fe_2O_3), is crushed and then it can act either favorably as a lubricant or infavourable increasing the abrasive wear, which is together with other types of wear observed in forging dies.

Lubrication, i.e., the kind of lubricant applied has an influence on wear in forging processes. Adsorption and chemisorption of the lubricant change the friction and wear mechanisms and influence the properties of the outer layers of the workpiece and tools.

5. From the aspect of energy, friction is a process in which mechanical energy changes into other types of energy in accordance with the first law of thermodynamics. Based on the energy theory of friction, external friction cannot be studied separately from internal friction in the contact layers, and the complexity of this process is particularly evident in hot forging [6, 7, 9].

In our experiments different lubricants were used and their influence on the friction coefficient, the wear scar width and the layout of the damaged surfaces was studied. Besides lubricants for hot metal processing, we used some others, which pinpointed the differences in properties of the filler materials used for reparation of forging dies [4].

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of the pin and disc

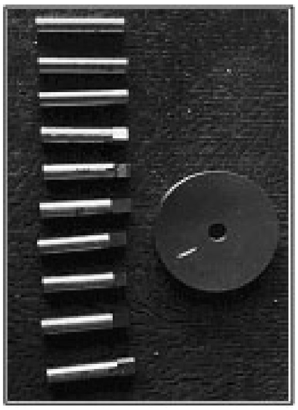
In order to determine tribological characteristics of the hard faced layers, the samples of two base materials, Č5742 - JUS (56NiCrMoV7-DIN) and Č4751-JUS (X38CrMoV51-DIN), were hard-faced [14] using two filler materials UTOP 38 - (E3-UM-40T – DIN 8555) - ϕ 3.25 *mm* and UTOP 55 – (E6-UM-60T – DIN 8555) ϕ 5.0 *mm*) [13]. Hard facing was performed in two and three layers in accordance with the technology given in Figure 1 and Table 1.

The hard-faced pins were further grinded into shapes suitable for tribological investigations. Two pins of steel Č5742 and Č4751 (ϕ 10×50) thermally tempered to 380-410HB were also prepared. The coupled pairs – discs were made of steel Č3840 – JUS (90MnCrV8 – DIN), with dimensions ϕ 75×10 and hardness 742-839 HV1.

2.2 Hardness distribution and microstructure of the disc and pins

Hardness HV1 was measured on the pins in the directions I-I, II-II and III-III (Figure 2a,b). It was measured at different distances, starting from the hard-faced layer surface. Figure 2 shows characteristic diagrams of the pin hardness variation (1, 3, 6 and 8) in the given directions [4].

Table 1. Technology of pins preparation [4]

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	2.4-3.2	
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	-	-	-	

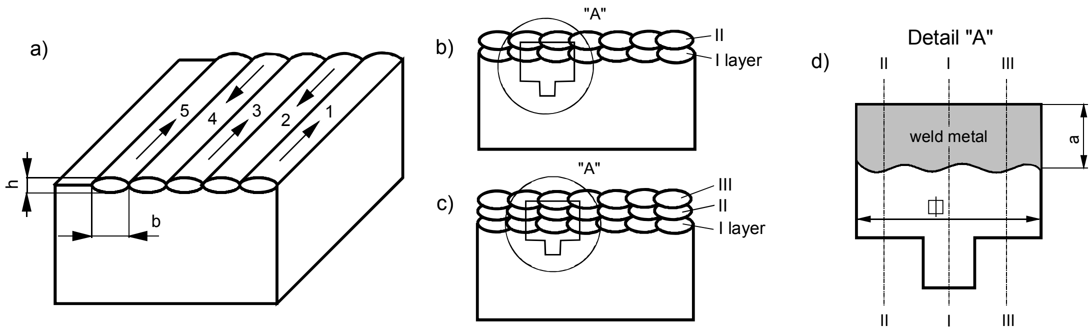
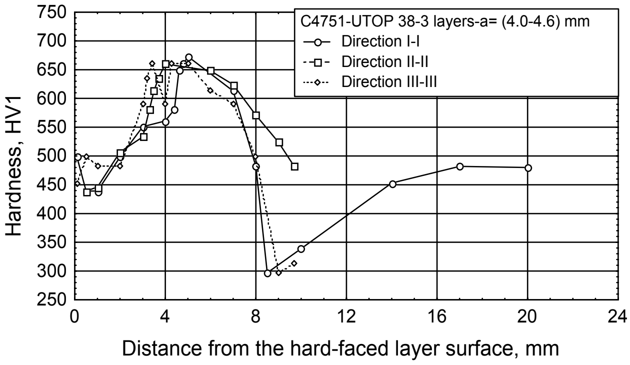
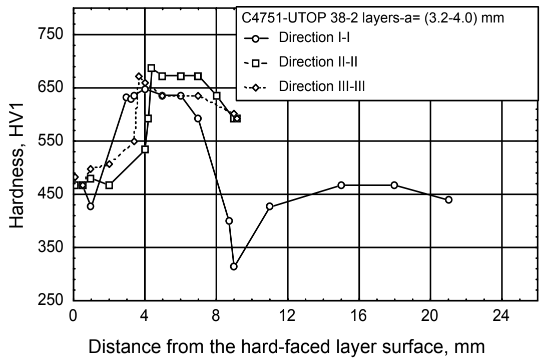


Figure 1. Order of the hard-faced layers deposition: a - 1st layer, b - 2nd layer, c - 3rd layer, d - pin lay out [4]

Analyzing the hardness distribution diagrams, we can notice stability of the micro hardness, especially in the hard faced layers zones. The microstructure of characteristic zones of the two-layer hard-faced metal obtained by electrodes UTOP 38 and UTOP 55 (Fig 3), does not significantly differ from the hard-faced metal obtained by three-layer hard facing [7, 8]. The metallographic samples for hardness, metallographic and tribological tests were polished and etched with appropriate solvent (nital/2-4% HNO_3 in alcohol, and "czar water" – 20/30 *ml* HCl + 10 *ml* HNO_3 + 20/30 *ml* glycerin). The hardness was measured in the accredited Zastava cars laboratory on appropriate devices Zwick (HV) or Knoop (HK). The microstructure was studied by an optical microscope Reichert with maximum magnification of 2000 times [4, 15].

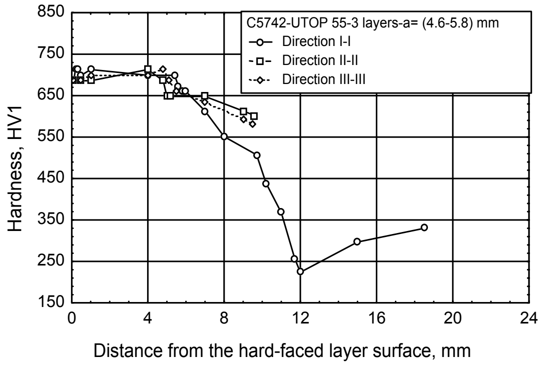


a) PIN No. 1

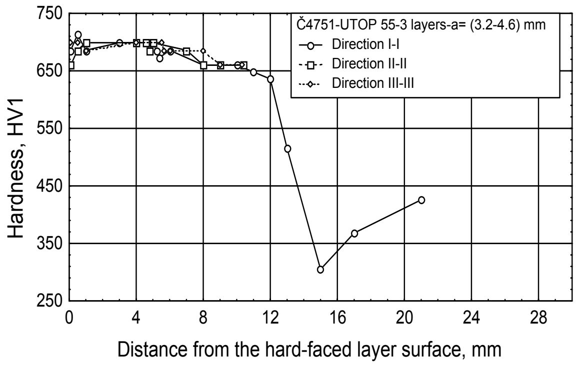


b) PIN No. 3

Figure 2.a Hardness distribution



a) PIN No. 6



d) PIN No. 8

Figure 2.b Hardness distribution

F. M. UTOP 38 – Hard-faced layer HV1= 580
Dendrite structure directed perpendicularly to the hard-faced metal surface

F. M. UTOP 55 - Hard-faced layer HV1= 700
Dendrite structure directed perpendicularly to the hard-faced metal surface

Figure 3. Microstructure of the hard-faced metal obtained with different filler materials

3. TRIBOLOGICAL INVESTIGATIONS

3.1 Measuring and computer equipment

Tribological characteristics of the prepared pins and oils for lubrication were performed at the Tribology Laboratory at the Faculty of Mechanical Engineering in Kragujevac. We used synthetic oil LM 76 [13-Company Catalogue: Liqui Moly] and the same oil with 6% molybdenum disulfide added [4, 7]. Under these conditions the friction force, the friction coefficient and the wear parameters were determined [1, 3, 4, 5]. The synthetic oil LM 76 is normally used for lubrication while operating at elevated temperatures and high loads. According to the manufacturer's catalogue, it exhibits excellent adhesive properties in a wide temperature range, and when synergic additives are added it becomes very resistant to wear, oxidation and corrosion.

The experiments were carried out using the following measuring and computer equipment: a tribometer TPD-93, a roughness measuring system *Talysurf 6*, a universal tool microscope UIM-21, a personal computer, a four channel pen recorder Rikadenki R-54, an artificial thermocouple for measuring temperature and UPM60 – an amplifier system with AD conversion.

3.2 Tribometer TPD-93

The tribometer TPD-93 (Fig. 4) was developed at the Centre for Revitalization of Industrial Systems of the Faculty of Mechanical Engineering in Kragujevac. It enables a point contact (disc on disc), a line contact (pin on disc) and an area contact (block on disc). The contact can be realized with or without lubrication. A lubricant is applied to the lower part of the disc (Fig. 4 in the middle). The lubrication is boundary.

The line contact is realized between the front surface of the pin and the rim of the disc surface. The sliding speed can vary within the range of v_{kl} = 0.1-5 *m/s*, the normal force is chosen in the range of F_N= 0.1-1000 *N*, while the power is P = 1.5 *kW*.

Talysurf 6 is a measuring system used for measuring microgeometric characteristics of the contact surfaces. This is a computerized measuring system with a wide range of applications such as measurement of primary and additional wear parameters and corrugation, statistical evaluation of the roughness measurement results, display of the results on the screen, their memorizing, printing, drawing and spatial scanning.

For the control of the oil temperature a thermoelement type Thermocoax 2 AB AC 15 manufactured by Philips was used. The elements of the thermocouple include wires of NiCr (+) and Ni (-). The signal was recorded using a four channel pen recorder Rikadenki R-54. In addition to a direct recording, the temperature signal can be transferred into the computer by the amplifier UPM-60; this enables process monitoring.

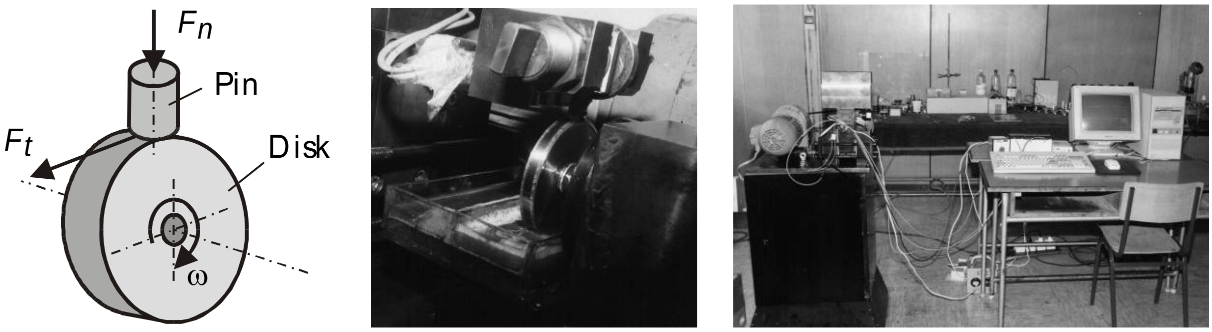


Figure 4. Tribometer TPD-93 and other measuring equipment for performance of tribological tests

4. TRIBOLOGICAL INVESTIGATIONS WITH LUBRICANT LM 76

Prior to the contact, topography of the pin and disk surfaces was measured on the computer measuring system *Talysurf 6.* Then, the contact was realized with variation of the normal force (F_N = 100, 150, 200, and 250 *N*), and the sliding speed (v_{kl} = 1.5, 2.0, and 2.5 *mm*). These measurements, performed during the running-in period of ≈ 6 *min*, enabled determination of the friction coefficient and thus the friction force. Than 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 (Fig. 5, 6 and 7). When the contact stopped the topography of the pin and disk surfaces was measured, i.e., the wear scar width of the pin was determined (Fig. 8). The wear scar width was measured using a universal microscope UIM-21, with magnification of 50× [4].

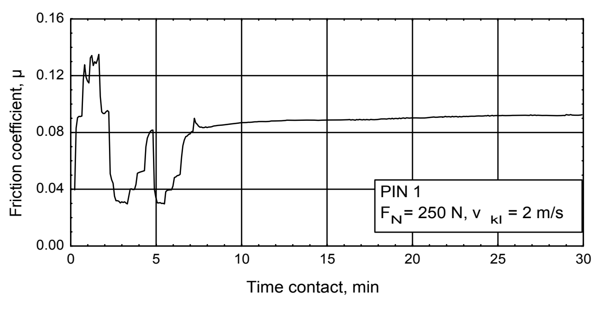


Figure 5. Change of the friction coefficient during the contact period of 30 min – PIN No. 1

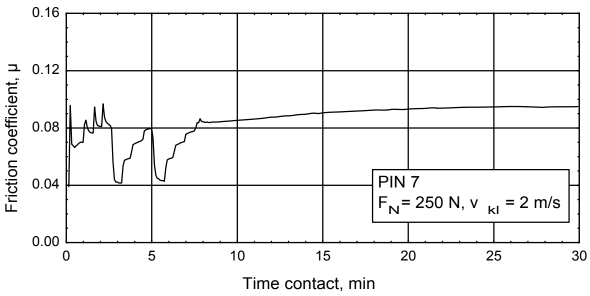


Figure 6. Change of the friction coefficient during the contact period of 30 min – PIN No. 7

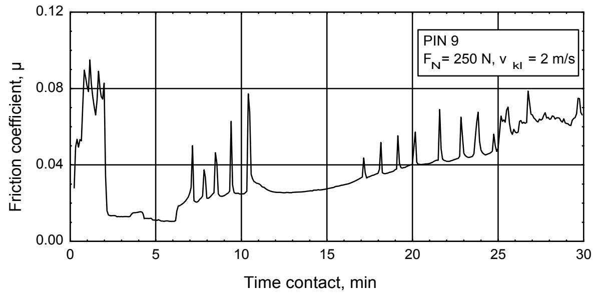


Figure 7. Change of the friction coefficient during the contact period of 30 min – PIN No. 9

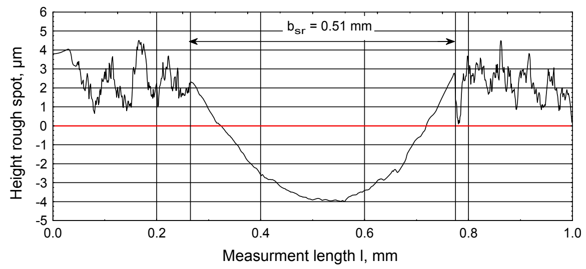


Figure 8. The layout of the wear scar –PIN No 7 (after the contact period of 30 min)

Figure 9 gives the average variation of the friction coefficient after the conducted tests, and Figure 10 shows the average wear scar width for different pins.

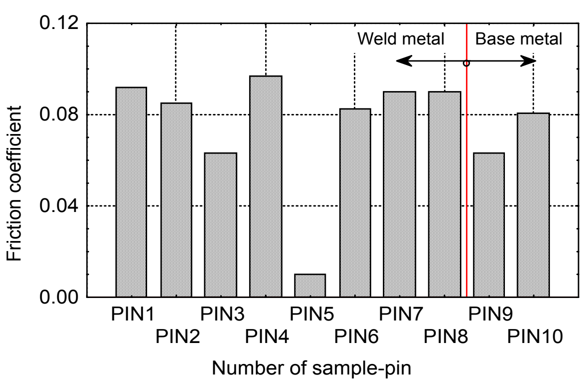


Figure 9. The friction coefficient after the 30 minutes contact (lubricant LM 76)

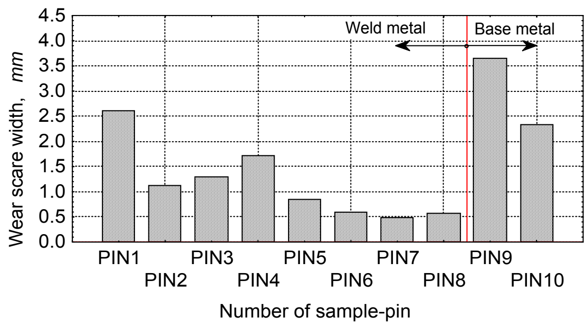
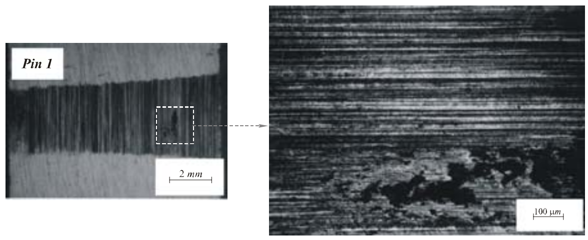


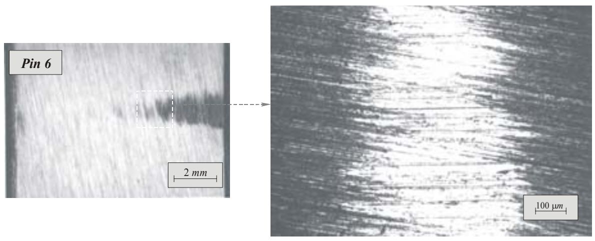
Figure 10. The wear scar width after the 30 minutes contact time (lubricant LM 76)

The results of these investigations show that the hard faced layers exhibit a significantly higher resistance to wear than the base materials, which justifies hard facing of damaged working surfaces of dies and tools, if performed using proper filler materials for real working conditions e.g. UTOP 55 [1, 2, 3, 4].

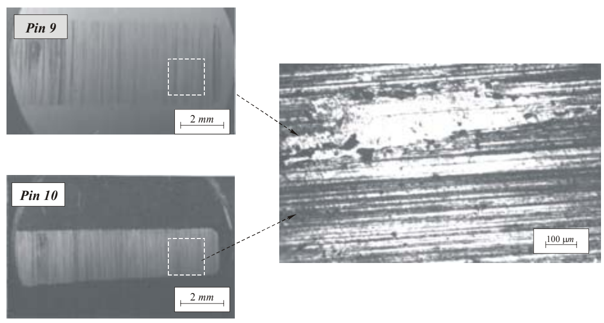


a) F.M. - UTOP 38

Figure 11.a Wear of the pins



b) F.M. - UTOP 55



c) B.M. - Č5742 and Č4751

Figure 11.b,c Wear of the pins

After the tribological investigations, the analysis of both macroscopic and microscopic damages was done. Figure 11a,b,c shows some typical pin damages.

5. TRIBOLOGICAL INVESTIGATIONS WITH THE LUBRICANT (LM 76 + 6% MoS_2) APPLIED

Based on the manufacturer's claims [13- Company Catalogue: Liqui Moly] the lubricant LM 76 + 6% MoS_2 can reduce wear by 50% while keeping good lubricant properties at a wide temperature range. Therefore, this lubricant is better than graphite grease because it can be used for lubrication at temperatures from -45 to 400ºC. The results of these tribological investigations are shown in Figs. 12, 13, 14, 15 and 16.

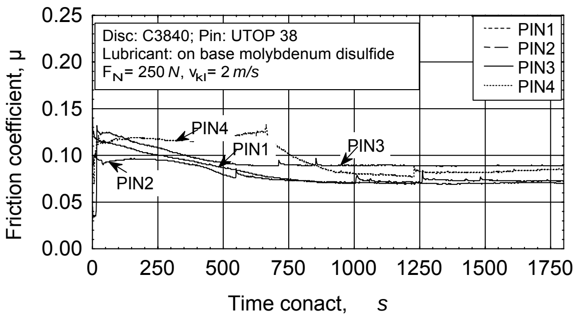


Figure 12. Change of the friction coefficient during the contact period of 30 min

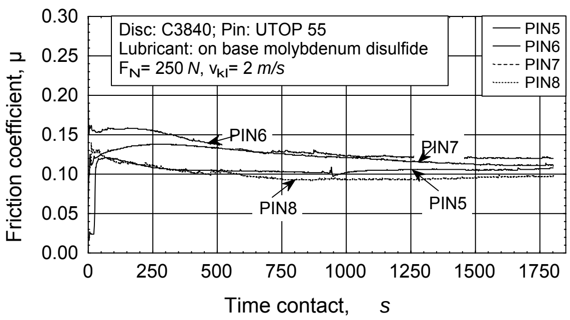


Figure 13. Change of the friction coefficient during the contact period of 30 min

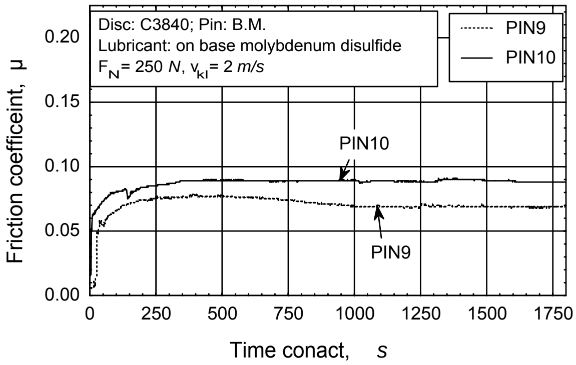


Figure 14. Change of the friction coefficient during the contact period of 30 min

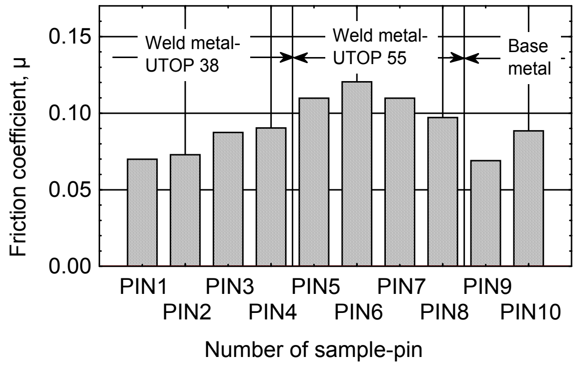


Figure 15. The friction coefficient after the 30 minutes contact time (lubricant LM 76+6% MoS_2)

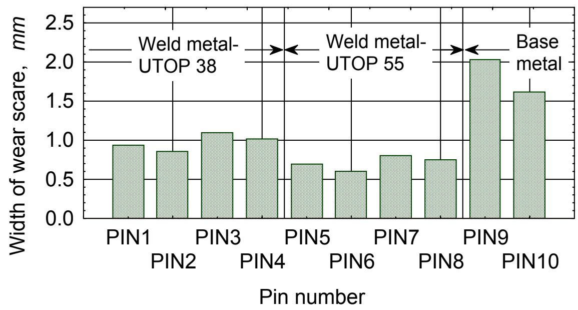
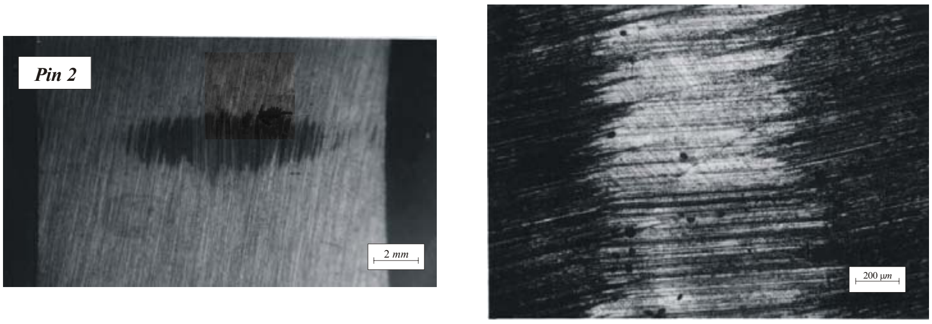


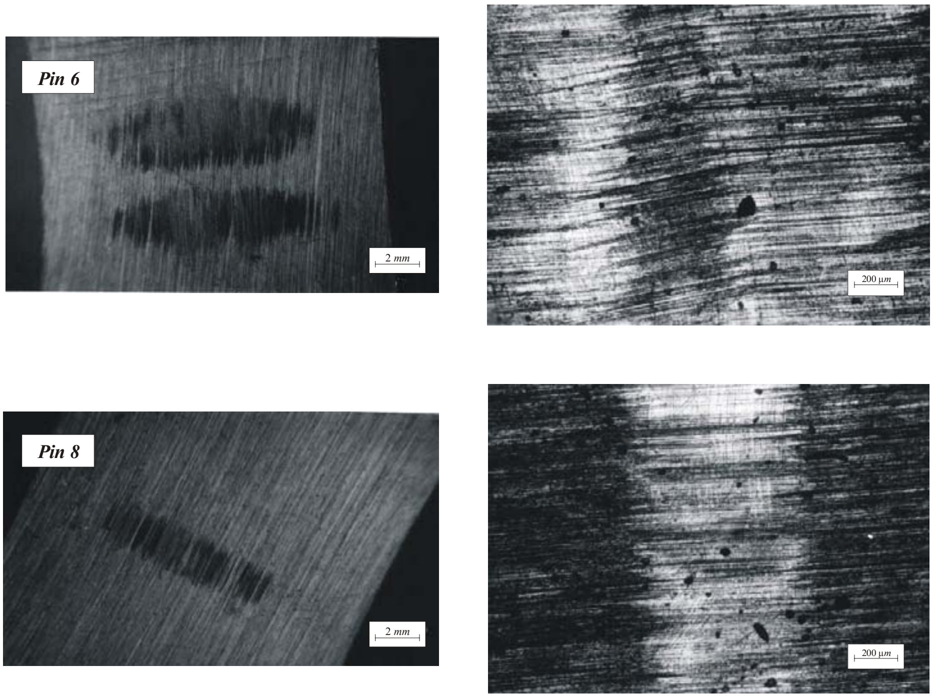
Figure 16. The wear scar width after the 30 minutes contact time (lubricant LM 76+6% MoS_2)

After the tribological tests with the new lubricant had been carried out, macroscopic and microscopic damages of the pins were analyzed. Figure 17a,b,c shows these pin damages. The analyzed wear scars are significantly less pronounced than in the case when the pure lubricant LM 76 (Fig 11a,b,c) was applied, which is compliant with the measured wear scar widths.

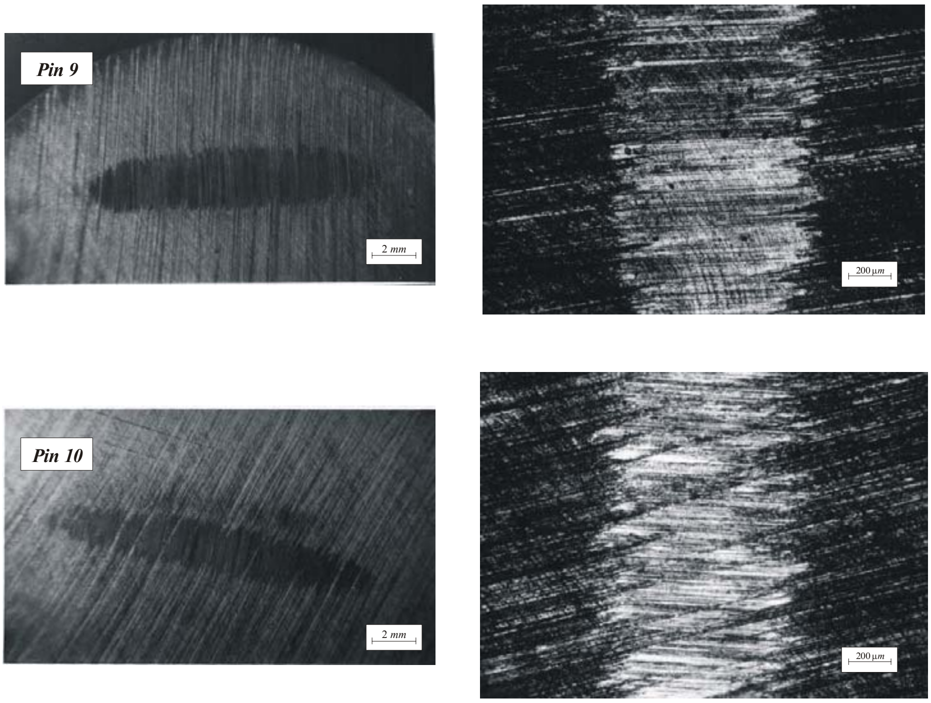
Finally, the tribological investigations have shown that the hard-faced layers are much more resistant to wear compared to the base material, but from the aspect of energy (a lower friction coefficient) the base material has better properties. The experiments performed in order to determine the friction forces, the friction coefficient and the wear scar width for pins of different properties (hardness, microstructure), show that with an increase in the pin hardness, the friction coefficient increases and the wear scar width decreases. The wear area is the narrowest in the layer hard-faced using a UTOP 55 electrode, a little wider in the layers hard-faced using a UTOP 38 electrode, and the widest on the base material. Increased wear on the contact area between the tool and the workpiece leads to an increase in the amount of energy needed for deformation.



a) PIN No. 2 – lubricant with 6% MoS_2 – F.M. - UTOP 38



b) Pins No. 6 and 8 - lubricant with 6% MoS_2 – F.M. - UTOP 55



c) Pins No. 9 and 10 – lubricant with 6% MoS_2 - B.M. - Č5742 and Č4751

Figure 17. Wear of the pins

The quality of different lubricants normally used for hot forging was also evaluated in these experiments. Our tribological investigations show that the working life of the hard-faced dies can exceed the working life of new dies. However, a definite evaluation can be made only after a long term follow-up of a tool performance in the real technological conditions.

7. CONCLUSIONS

The results of the experiments performed show that a lower friction coefficient and a significantly narrower wear scar are obtained when the lubricant LM 76 with 6% MoS_2 is applied. A more uniform change of the friction coefficient is also noticed both with the hard-faced layer and with the base metal. The change of the friction coefficient is especially uniform with the base materials - pins 9 and 10, where the change of this coefficient was occasionally abrupt when the lubricant LM 76 was applied. An increased efficiency of the new lubricant is explained with the essential role of the molybdenum-disulphide, which has a hexagonal structure with atoms of S and Mo arranged in layers on the crystal lattice. These layers slide easily over one another so that the lubricant layer is difficult to break through.

REFERENCES

[1.] Lazić, V., et al.: Selection of the optimum technology of the forging dies reparation from the aspect of tribological characteristics, Tribologia – teoria i praktika, rok XXXVI, NR 2/2005 (200), pp. 11-31.

[2.] Jovanović, M., et al.: Determination of Optimum Relaxation Temperature in Hard Facing of the Forging Dies for Working at Elevated Temperatures, JOM 9, Helsingor, Denmark, 1999., pp. 312-317.

[3.] Mutavdžić, M., et al.: Model investigations of the filler materials for regeneration of the damaged parts of the construction mechanisation, Tribology in Industry, 3&4/2008., pp. 3-9.

[4.] Lazić, V.: Optimization of hard facing process from the aspect of tribological properties of hard-faced metal and remaining stresses, PhD thesis (in Serbian), Faculty of Mechanical Engineering in Kragujevac, 2001.

[5.] Lazić, V., et al.: The choice of the most faviourable technology of reparation of forging dies from the aspect of tribological characteristics, Welding 2003., International Conference, Belgrade, 2003., (in Serbian).

[6.] Dziubinski, J., Klimpel, A.: *Napawanie i natryskiwanie ciepline*, Wydanictwa Naukovo - Techniczne, Warsawa, 1985., (in Polish).

[7.] Gierzynska, M.: *Tarcie zużycie i smarowanie w obrobce plastycznej metali*, Wydawnictwa Naukowo-Techniczne, Warszawa, 1983., (in Polish).

[8.] Ivković, B., Rac, R.: *Tribologia*, Yugoslav Society for Tribology, Kragujevac, 1995., (in Serbian).

[9.] Wernoski, A.: *Zmeczenie cieplne metali*, Wydawnictwa Naukowo - Techniczne, Warsawa, 1983., (in Polish).

[10.] Lazić, V., et al.: Carbide type influence on tribological properties of the hard faced steel layer – part I – theoretical considerations, Tribology in Industry, Vol. 32, No. 2, 2010., pp. 11-20.

[11.] Lazić, V., et al.: Carbide type influence on tribological properties of the hard faced steel layer – part II – experimental results, Tribology in Industry, Vol. 32, No. 3, 2010, pp. 3-12.

[12.] Nedeljković, B., et al.: *Reparatory hard facing of the rotational device knives for terrain leveling*, Journal of the Balkan Tribological Association, Vol. 16, No 1. 2010, pp. 46-75.

[13.] Catalogues and Prospects of Electrode Materials Manufacturers**:** FEP-Plužine, Elvaco-Bijeljina, Železarna-Jesenice, Bohler-Kapfenberg, Messer Griesheim-Frakfurt am Main, Esab- Göteborg, Lincoln Electric-USA, etc.

[14.] Standards: JUS, UNI, DIN, IVECO, ASTM

[15.] Nedeljković, B., et al.: *Influence of the carbide type on tribological properties of the hard-faced layers*, Metalurgija – Journal of Metallurgy, Vol 16, No 2, 2010, pp. 77-90.