

WEAR RESISTANCE OF LAYERS HARD FACED BY THE HIGH-ALLOYED FILLER METAL

Dušan Arsić¹, Vukić Vukić¹, Ružica Radoslava Nikolić^{1,2,*}, Milan Mutavdžić³, Srbislav Aleksandrović¹, Milan Djordjević¹

¹Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia

²Research Center, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic

³High Technical School, November nn, 38218 Leposavić, Serbia

*correspondingauthor: e-mail: ruzicarnikolic@yahoo.com

Resume

The objective of this work was to determine the wear resistance of layers hard faced by the high-alloyed filler metal, with or without the austenite inter-layer, on parts that operate at different sliding speeds in conditions without lubrication. The samples were hard faced with the filler metal E 10-UM-60-C with high content of C, Cr and W. Used filler metal belongs into group of alloys aimed for reparatory hard facing of parts damaged by abrasive and erosive wear and it is characterized by high hardness and wear resistance. In experiments, the sliding speed and the normal loading were varied and the wear scar was monitored, based on which the volume of the worn material was calculated analytically. The contact duration time was monitored over the sliding path of 300 mm. The most intensive wear was established for the loading force of 100 N and the sliding speed of 1 m.s⁻¹, though the significant wear was also noticed in conditions of the small loading and speed of 0.25 m.s⁻¹, which was even greater than at larger speeds.

Article info

Article history:

Received 02 February 2016

Accepted 22 July 2016

Online 22 October 2016

Keywords:

Hard facing;

Filler metal;

Abrasive wear;

Wear resistance;

Sliding speed.

Available online: <http://fstroj.uniza.sk/journal-mi/PDF/2016/12-2016.pdf>

ISSN 1335-0803 (print version)

ISSN 1338-6174 (online version)

1. Introduction

Large number of machine parts and devices, especially in construction industry are exposed, on a daily basis, to rigorous exploitation conditions when the working parts of machines and devices are in the constant contact with hard and brittle abrasive materials. Due to their high hardness, such materials affect the working life of parts causing its shortening. Frequently, the working parts lose their original designed geometry, while the fracture of parts is frequent, as well. To prevent that and to extend the working life of parts, like the stone crusher's teeth [1], loading excavator bucket's teeth [2] knives of the terrain leveling grader board [3] and others, there is a tendency to manufacture them from the high quality and more adequate materials. However, even thus manufactured parts are worn relatively quickly, so the necessity

for their replacement or repair occurs. Considering that waiting for purchase of the new part could last quite a long time, what is usually accompanied with high costs, the alternative is repair by hard facing of the damaged parts.

The repair by hard facing can create significant savings [4, 5], while simultaneously the working surfaces, which are more wear resistant than those on the original new parts are, are obtained. This subject was investigated by authors of paper [6 - 8] and [9 - 19] and in those papers the previously stated observations were confirmed. Thus, the objective of this work was to establish the possibility for extending the working life of the machine parts by hard facing the damaged surfaces with use of the adequate filler metal and to determine the influence of the sliding speed in the tribological

tests on the hard faced layers' characteristics.

The previous investigations of certain materials with similar properties to those used in this research have established that the loss of materials' mass increases with increase of the loading, which can be taken for granted, and with increase of the sliding speed, which was to be confirmed with experiments performed within this investigation. Authors of [20] have investigated the grey cast iron with high carbon content, while in [21] authors were dealing with analysis of the Fe-Cr-B alloy aimed for hard facing, which has the similar content as the filler metal used in this paper. The applied sliding speeds were of 0.25, 0.5 and 1 m.s⁻¹, while the applied loads were of 50, 75 and 100 N and the purpose was to determine the wear resistance of the analyzed filler metal.

2. Samples preparation and plan of experiments

One of the most difficult steps in prescribing the hard facing technology is selection of the filler metal (FM). It should be selected in such a manner that it possesses high hardness and wear resistance and simultaneously to have the favorable weldability. The filler metal, analyzed in this paper, is the high-alloyed steel with high content of carbon, chromium and tungsten, marked as E 10-UM-60-C (DIN standard 8555). Such a chemical composition ensures the high hardness and wear resistance of this filler metal, which is prescribed by the manufacturer for parts that work in such conditions.

Prior to hard facing, the base metal (BM)

is usually preheated to improve its weldability; in this case, the preheating temperature was defined as 250 °C. However, in some cases, due to some restrictions, like the BM chemical composition or lack of the preheating equipment in the field, the preheating cannot be done, so it is usually replaced by deposition of the interlayer of the austenitic FM. The applied BM is the stainless steel marked as E 18 8 Mn B 20+ (DIN standard 8555).

The chemical composition of the base metal (BM) and the filler metals (FM#1 and FM#2) is given in Table 1.

The hard facing parameters were current 125 A and voltage 25 V, with the welding speed of 1.9 mm.s⁻¹. The plate of BM of 10 mm thickness was hard faced with such parameters, with three layers, so that adequate thickness is obtained to enable cutting out the samples for tribological investigations. For samples with the interlayer, the first layer was deposited by the FM of the stainless steel (#2), while the other two layers were deposited by the FM for hard facing (#1). Preparation – cutting out – of the samples for tribological investigations was done according to Fig. 1a, while the samples for measurement of hardness and analysis of microstructure were prepared according to Fig. 1b. In addition, besides samples (blocks) prepared from the hard faced layers, the blocks of the same dimensions were prepared from the base metal.

Tribological test assumed subjecting the samples, cut-out from the hard faced layers and the BM, to the wear test on the tribometer with the block-on-disc contact (Fig. 2).

Table 1
Chemical composition of base metal and filler metals.

Steel/Electrodes	Alloying elements %										Hardness HRC
	C	Si	Mn	P	S	Cr	Mo	W	Ni	Al	
BM S355J0	0.2	0.55	1.4	0.045	0.045	0.3	0.08	-	0.3	0.02	≈ 28
FM1 E 10-UM-60-C	4.0	-	-	-	-	26	-	4.0	-	-	57 - 62
FM2 E 18 8 Mn B 20+	0.12	0.8	7.0	-	-	19	-	-	9.0	-	-

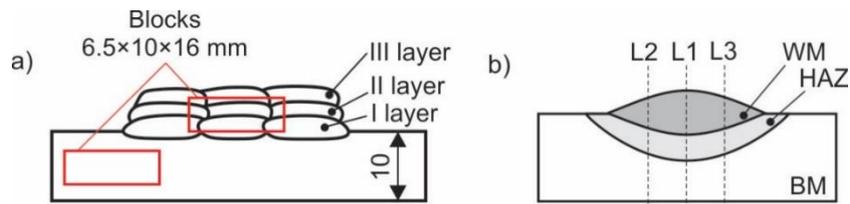
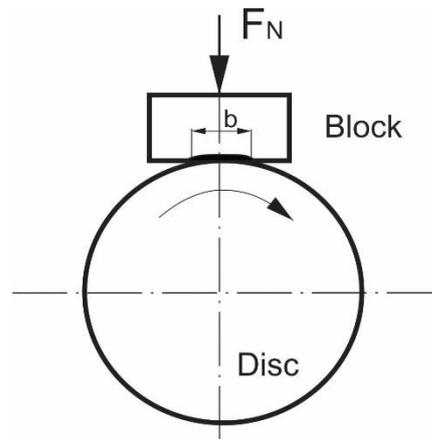


Fig. 1. Layer deposition and block for tribological testing (a) and metallographic sample (b); L1, L2 and L3 denote the directions of hardness measurements.
(full colour version available online)



a) prepared blocks and discs

(full colour version available online)



b) block-on-disc contact scheme

Fig. 2. Prepared blocks and discs and block-on-disc contact scheme.
(full colour version available online)

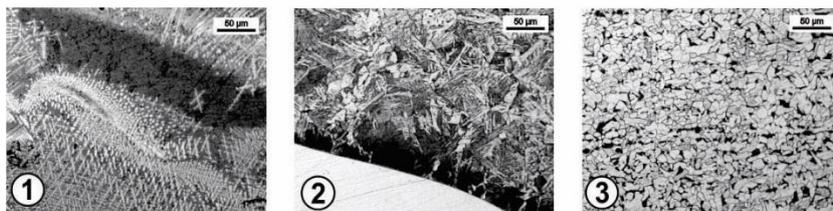
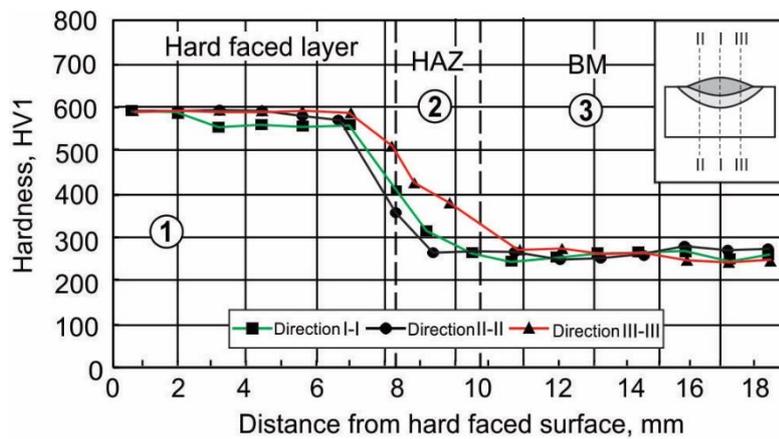


Fig. 3. Hardness distribution (diagram above) and the microstructures of the WM (1), HAZ (2) and BM (3) pictures (below).

(full colour version available online)

3. Results and discussion

3.1 Hardness measurement and microstructure analysis

Hardness was measured on samples prepared according to Fig. 1 and it was used to form curves of the hardness distribution in the three characteristic parallel directions (L1, L2 and L3). Besides that, the characteristic microstructures were recorded in the three zones of the hard faced layer – in the weld metal (WM), heat affected zone (HAZ) and in the base metal (BM). Etching of samples was done in two phases. In the first phase, samples were etched by the 3 % Nital solution (in denatured alcohol) and after that, only the zones of the BM and the HAZ were visible. Then, in the second phase, the samples were etched by the 4 % Vilelle solution. This solution is very aggressive and it can provide good quality etching of the highly alloyed hard faced layers. Results of the hardness measurements and the microstructures of the individual hard faced layer's zones are presented in Fig. 3.

From the graph in Fig. 3 one can see that the hard faced layer hardness is about 600 HV1, what corresponds to the data provided by the manufacturer. It can also be noticed that hardness was maintained over the whole cross section of the hard faced layer (average thickness of about 7 mm), after which it drops within the HAZ and the BM.

The BM microstructure was estimated as ferritic-perlite, while the microstructure of the FM was ledeburite–cast structure with excreted carbides. They possess the high hardness what should ensure the improved wear resistance.

3.2 Tribological test

The wear resistance was determined by measurements of the wear scar and then it was used to calculate the volume of the worn material. The wear scar width was recorded by the optical microscope with magnification 50×. The parameter for the contact duration was the path of 300 mm, which means that

the contact time was different for different sliding speeds. The friction coefficient was also recorded, besides the wear scar width, during the sliding process under different conditions. The tests were done without application of lubricants. Obtained results are presented as graphs in Fig. 4 and in Table 2, while the macroscopic and microscopic appearances of the damaged surface of some blocks are shown in Fig. 5. The worn material volume was calculated based on the measured length and width of the wear scar. In the computer program the volume of the block mass, "eaten" by the disc is then calculated.

Obtained results show that the hard faced layers possess significantly higher wear resistance than the base metal, as it was expected. The curves in Fig. 4 show increase of the worn material mass with increase of the sliding speed and the normal loading, all the way up to reaching the highest degree of wear at maximum load of 100 N and at the highest speed of 1 m.s⁻¹ (Fig. 4c), what was also confirmed by some other investigations [17, 20].

However, it is interesting that almost the same results were obtained for the case of the applied force of 75 N at sliding speeds of 0.5 and 1 m.s⁻¹ (Fig. 4b). This means that increase of speed from 0.5 to 1 m/s, at that load does not have any influence. In addition, results show that at the loading force of 50 N, the optimal sliding speed 0.5 m.s⁻¹, since the wear is the least (Fig. 4a). Results have also shown that there is no big difference in wear behavior between samples with and without austenitic interlayer (Table 2 – sample #3 has even somewhat higher resistance), what means that the interlayer can be used whenever it is necessary and that would not influence the wear resistance of the hard faced layers.

Photos in Fig. 5 show the characteristic damages of the tested materials surfaces. The characteristic phenomena in the initial stadium of wear are appearances of crevices and wear scars. However, after a certain distance,

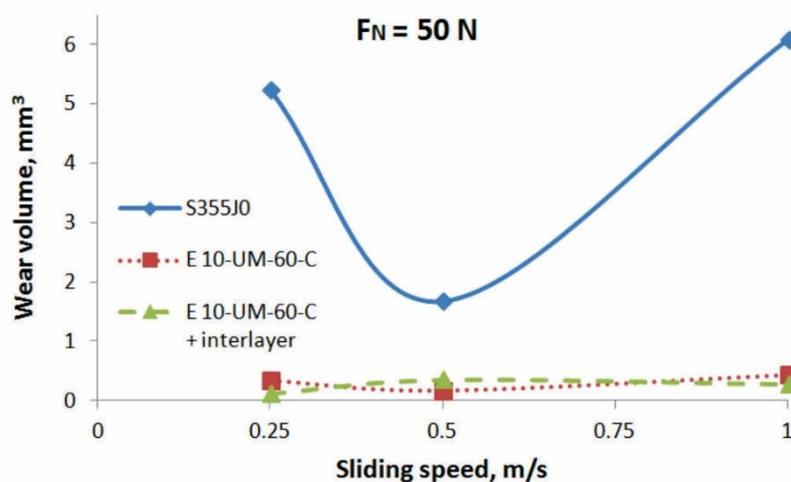
at the crack sites material particles started to detach from the sample's surface, usually due to adhesion to disc material [20]. Those particles can later also act as the abrasive and induce further damages. The shown damages are in accordance with the results obtained for steel

S355J0 [22], verifying the fact that it possesses poor wear resistance. On the other hand, the hard faced sample exhibits the higher wear resistance and its wear scar is significantly smaller and there is no appearance of spots of the material detachments from individual zones.

Table 2

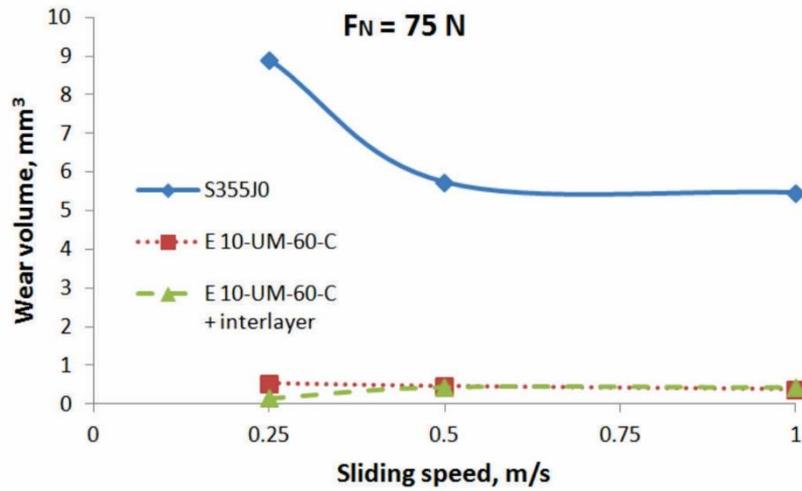
Obtained values of the wear scar width and volume of the worn material for the BM and FM.

		Worn material volume, mm ³			Wear scar width, mm		
SAMPLE #1		Base metal - S355J0			Base metal - S355J0		
Sliding speed, m.s ⁻¹	Load, N			Load, N			
	50	75	100	50	75	100	
0.25	5.23779	8.89852	9.36935	4.97	5.91	6.01	
0.5	1.67035	5.73512	9.95678	3.41	5.12	6.13	
1	6.08405	5.46604	17.9884	5.22	5.04	7.42	
SAMPLE #2		Filler metal - E 10-UM-60-C			Filler metal - E 10-UM-60-C		
Sliding speed, m.s ⁻¹	Load, N			Load, N			
	50	75	100	50	75	100	
0.25	0.33811	0.54007	0.61469	2.007	2.345	2.448	
0.5	0.16379	0.47241	0.63226	1.577	2.243	2.471	
1	0.43419	0.39641	1.24646	2.181	2.116	3.095	
SAMPLE #3		Filler metal - E 10-UM-60-C + austenite interlayer			Filler metal - E 10-UM-60-C + austenite interlayer		
Sliding speed, m.s ⁻¹	Load, N			Load, N			
	50	75	100	50	75	100	
0.25	0.118771	0.156112	0.323632	1.417	1.552	1.978	
0.5	0.350939	0.426453	0.469876	2.032	2.168	2.239	
1	0.279109	0.421149	0.556171	1.883	2.159	2.368	

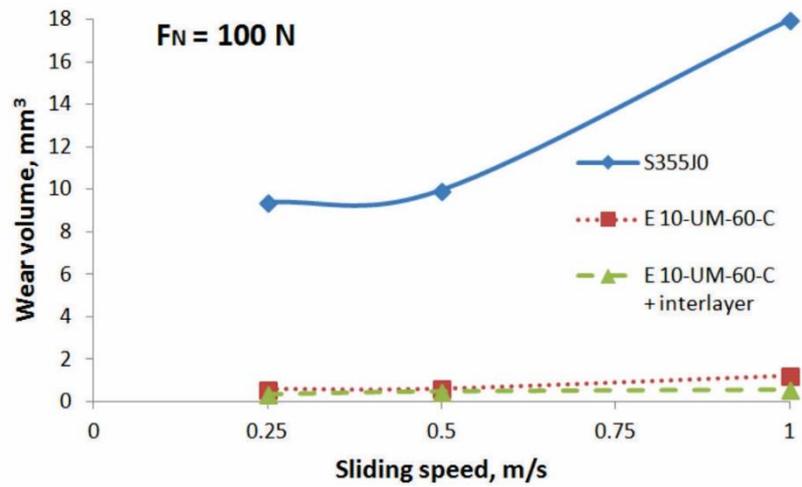


a) 50 N

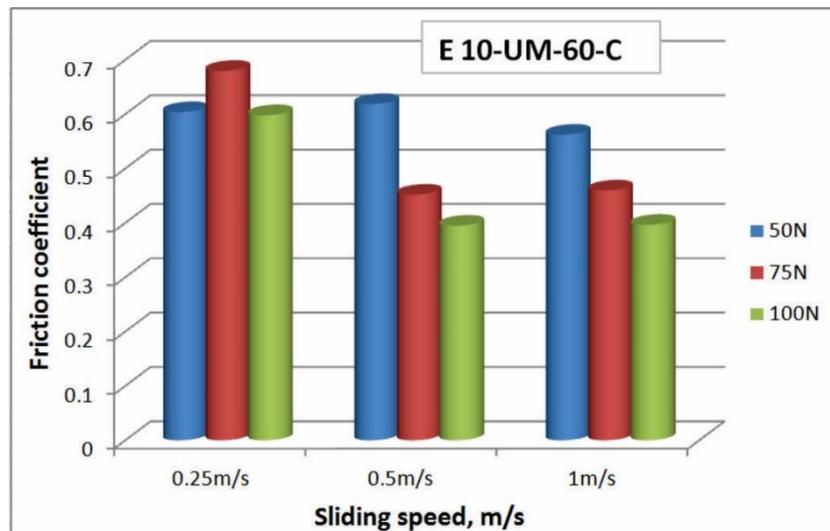
Fig. 4. Worn material volume at different loads and histogram of the friction coefficient average values for all the loads and sliding speeds.



b) 75 N



c) 100 N



d) histogram of the friction coefficient average values for all the loads and sliding speeds
 Continuing of Fig. 4. Worn material volume at different loads and histogram of the friction coefficient average values for all the loads and sliding speeds.
 (full colour version available online)

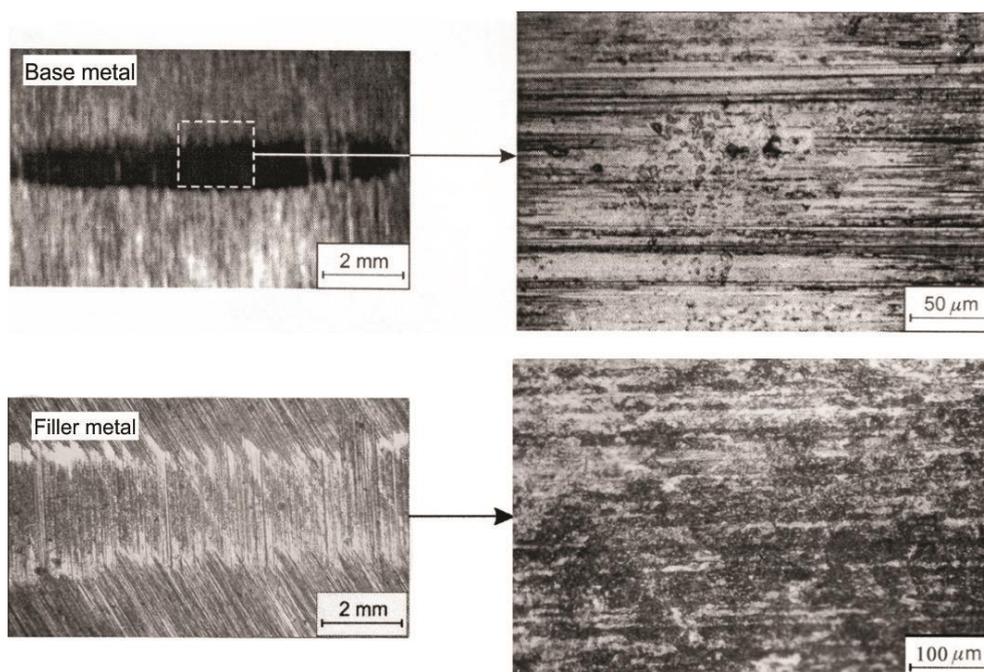


Fig. 5. Macroscopic (left) and microscopic (right) appearances of the damaged blocks of the hard faced layers.

4. Conclusions

An analysis of the sliding speed influence in tribological tests, on the wear resistance of the base metal and the hard faced layers of the test samples is presented in this paper. Measurements of hardness and analysis of microstructure have shown that the base metal and the filler metal differ significantly and that the filler metal is characterized by the cast structure with the excreted carbides, what predetermines it as a material favorable for application in hard facing. The highest hardness was obtained in the surface welded hard faced layers (FM) and then it was gradually decreasing down to the base metal hardness.

Besides varying the sliding speed and absence of lubrication, the investigation also included varying of the normal loading. Results have shown that the tested FM possesses high wear resistance. On the other hand, the sample hard faced with the same FM, but with austenitic interlayer, have exhibited slightly better wear resistance, what points to recommendation to apply the interlayer whenever the preheating cannot be executed.

Influence of the sliding speed is obvious, since it is expected that the wear would increase with increasing sliding speed. It was maximal at sliding speed of $1 \text{ m}\cdot\text{s}^{-1}$ and load of 100 N, for both the BM and the FM. However, there were certain cases of deviation from the usual behavior, at loads of 50 and 75 N, when the wear was the more intensive at the smallest sliding speed of $0.25 \text{ m}\cdot\text{s}^{-1}$, then it decreased and later increased again (Fig. 3a) or when it settled at lower values (Fig. 3b).

The technology presented in this paper was later applied on real parts – the blades for asphalt mixing were hard faced and then used in exploitation.

Acknowledgements

This research was partially financially supported by European regional development fund and Slovak state budget by the project "Research Centre of the University of Žilina" – ITMS 26220220183 and by the Ministry of Education, Science and Technological Development of Republic of Serbia through grants: ON174004, TR32036, TR35024 and TR33015.

Note

The shorter version of this research was presented at the SEMDOK 2016 International Seminar, 27. – 29. January, 2016, Terchova, Slovakia, reference [22].

References

- [1] S. Jozić, D. Bajić, A. Stoić: *Metalurgija – Metallurgy* 54(2) (2015) 343-346.
- [2] Z. Lazarević, I. Arandelović, S. Kirin: *Structural Integrity and Life* 15(3) (2015) 143-146.
- [3] B. Nedeljković, M. Babić, M. Mutavdžić, N. Ratković, S. Aleksandrović, R. Nikolić, V. Lazić: *J. Balkan Tribol. Assoc.* 16(1) (2008) 46-57.
- [4] V. Lazić, D. Arsić, M. Mutavdžić, R. Nikolić, B. Hadzima, N. Ratković: In *Proc. Of 43. International Conference Zvaranie 2015, Tatranská Lomnica, Slovakia 2015*, pp. 15-27.
- [5] V. Lazić, R. Čukić, S. Aleksandrović, D. Milosavljević, D. Arsić, B. Nedeljković, M. Djordjević: *Tribology in Industry* 36(3) (2015) 287-292.
- [6] D. Arsić, V. Lazić, I. Samardžić, R. Nikolić, S. Aleksandrović, M. Djordjević, B. Hadzima: *Tehnički Vjesnik – Technical Gazette* 22(5) (2015) 1353-1358.
- [7] V. Lazić, M. Jovanović, D. Milosavljević, M. Mutavdžić, R. Čukić: *Tribology in Industry* 30(1&2) (2008) 3-10.
- [8] V. Lazić, A. Sedmak, S. Aleksandrović, D. Milosavljević, R. Čukić, V. Grabulov: *Tehnički Vjesnik – Technical Gazette* 16(4) (2009) 107-113.
- [9] V. Lazić, M. Mutavdžić, D. Milosavljević, S. Aleksandrović, B. Nedeljković, P. Marinković, R. Čukić: *Tribology in industry* 33(1) (2011) 18-27.
- [10] S. Marković, Lj. Milović, A. Marinković, T. Lazović: *Structural Integrity and Life* 11(2) (2011) 127-130.
- [11] J. Truhan, R. Menon, F. LeClaire, J. Wallin, J. Qu, P. Blau: *Wear* 263 (2007) 234-239.
- [12] A. S. Kang, G. S. Cheema, S. Singla: *Procedia Engineering* 97 (2014) 1442-1451.
- [13] D. Liu, R. Liu, Y. Wei, Y. Ma, K. Zhu: *Applied Surface Science* 271 (2013) 253-259.
- [14] J. Laurila, A. Milanti, J. Nurminen, M. Kallio, P. Vuoristo: *Wear* 307 (2013) 142-149.
- [15] Chi-Ming Lin, Chia-Ming Chang, Jie-Hao Chen, Weite Wu: *J. of Alloys and Compounds* 498 (2010) 30-36.
- [16] W. Żurowski: *Eksploatacja i Niezawodność – Maintenance and Reliability* 14(1) (2012) 19-23.
- [17] C. Chang, Y. Chen, W. Wu: *Tribology International* 43(5-6) (2010) 929-934.
- [18] A. Zavos, P. Nikolakopoulos: *FME Transactions* 43(3) (2015) 191-197.
- [19] M. Hawryluk, M. Marciniak, G. Misiun: *Eksploatacja I Niezawodność – Maintenance and Reliability* 16(4) (2014) 600-607.
- [20] B. K. Prasad: *Tribology – Materials, Surfaces & Interfaces* 2(3) (2008) 128-138.
- [21] G. Cui, J. Wei, G. Wu: *Industrial Lubrication and Tribology* 67(4) (2015) 336-343.
- [22] D. Arsić, V. Lazić, R. R. Nikolić, S. Aleksandrović, M. Djordjević: In *Proc. of Abstracts of 21st International Seminar "SEMDOK 2016"*, Terchova, Slovakia 2016, 8.