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EXPERIMENTAL COMPARISON OF THE TRIBOLOGICAL PROPERTIES OF SELECTED SURFACES CREATED BY THERMAL SPRAYING TECHNOLOGY

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Abstract

TÓTH FRANTIŠEK, HAAS PETER, RUSNÁK JURAJ, KADNÁR MILAN. 2016. Experimental Comparison of the Tribological Properties of Selected Surfaces Created by Thermal Spraying Technology. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis,* 64(3): 893–899.

The scientific article titled “Experimental comparison of the tribological properties of selected surfaces created by thermal spraying technology” deals with the surface condition of selected pairs working within the mixed friction before and after experimental tests. Based on the chosen methodology, the experimental tests were performed on the Tribotestor M’06 testing machine. The ecological oil MOGUL HEES 46 (manufactured by Paramo) was used as a lubricant. The tests were performed on selected material pairs. The first friction element was a shaft of steel 14 220. The second friction element was a steel plate of steel 11 373 with a friction surface created by two materials, i.e. CuSn10 and NP 40. The results are statistically elaborated and illustrated in figures and tables.

Keywords: journal bearing, flame-powder coating, thermal spraying

INTRODUCTION

Agricultural technical practise requires improving lifetime and reliability of machines constantly. One option is to implement new technologies of surface finishing works. That opens an area for research and application of new unconventional technologies of surface finishing works with untraditional added materials and their specific features. The technology of flame spraying belongs to those technologies.

The aim of our research in the area is to analyse selected tribological features of different material pairs where one of the surface is modified by the technology of flame spraying. Biodegradable oil was chosen as a lubricant for tribological node. The oil was selected based on the experiments within laboratory as well as real conditions (Kosiba *et al.*, 2013; Kučera *et al.*, 2010; Majdan *et al.*, 2010; Tkáč *et al.*, 2010).

MATERIALS AND METHODS

Tribological experimental tests were performed on Tribotestor M’06 (Fig. 1). The following tests can be performed on the machine: limit load test (seizing test), terminal velocity test (velocity seizing test), load tests to determine PV diagram and lifetime tests (durability test).

The experimental machine is made of three main parts. The testing part is created by servo units of samples rotary movement, vertical load force and testing head. The second part includes pneumatic circuit and all electronic devices. The last part is a control and evaluation unit, i.e. a computer used to start, check, control, collect data and to evaluate the test itself.

Our experiment was performed by a seizing test.

The sliding system was created of four parts. The sliding pair was created by a shaft and a sliding plate. The third part is a lubricant, i.e. ecological oil in this case. The ambient conditions form the fourth part of the sliding node. The influence of atmosphere will not be included within the experiment due to the relatively short course of the experimental test. The bushing of a shaft, with outside diameter of ϕ28 mm, length of 25 mm, made of steel 14 220 and pressed on the cylindrical part of bearing shaft,

1: *Testing device Tribotestor M'06*

was the first friction element. The bearing shaft was attached to the servo unit by cone bearing via tightening force through the internal thread in the cone. The second friction element was the steel plate of material 11 373, according to the Slovak Technical Standard (Fe 360 B according to ISO) with dimensions of 20×20×5 mm. The plate was a material on which the testing sliding surface was coated. In the first case, the reference material was CuSn10. It was coated on the basic material by the technology of flame spraying. The coating itself was performed at Welding Research Institute in Bratislava. The chemical composition and mechanical features of the material are illustrated in Tab. I. CuSn10 is tin bronze which is commonly used material to create a sliding bearing. In the second case, the sliding surface was created of NP 40 material which is an alloy based on NiBCrSi. NP 40 powder was coated on the surface of the plate by the technology of flame-powder coating. The coating was performed at the Department of Quality and Engineering Technologies, the Faculty of Engineering, the Slovak University of Agriculture in Nitra. Generally, the powder is used to weld surface of steel parts which are exposed to abrasive, corrosion and thermal stress. The welded surface can be further lathed and grinded. The material was chosen as a sliding material for our experiment based on the results of author's experiment (Tóth *et al.*, 2014). The chemical composition and mechanical features are illustrated in Tab. II. The lubrication of sliding elements by testing ecological oil was performed by wading movement; the oil was added at the beginning of the experiment.

Both sliding elements were weighed before and after experiment on Voyager Pro VP 613CN precise scales and the roughness was measured on Mitutoyo SJ-201 roughness meter. The monitored parameter was 'Ra'. The value of 'Ra' is a mean arithmetic value of absolute deviations of a profile and 'n' selected points of a profile on the base length. The ferrograms for both sliding pairs were made by analytical ferrogram maker Spectro, T2FM model. Their evaluation was done by Carl Zeiss, Axio Scope series, microscope in thousand times magnification.

The ecological product MOGUL HEES 46 (produced by Paramo) was as a lubricant which is environmentally friendly, quickly bio-degradable, hydraulic liquid on the basis of synthetic esters of HEES type according to VDMA 24 568 standard.

MOGUL HEES 46 is compatible with materials which are commonly used in hydraulic systems. The basic liquid as well as used additives are toxicologically harmless. The liquid does not include heavy metals and chlorine compounds; it is bio-degradable to more than 90% according to CEC-L-33-A-93.

I: *Chemical composition and mechanical features of testing plate CuSn10*

Parameter	Value, unit	
CuSn10 Chemical composition	Sn, %	9.5–11
	Pb, %	0.25
	P, %	max. 0.4
	Mn, %	0.2
	Fe, %	0.2
	Ni, %	1.5
	Zn, %	0.5
	Cu, %	the rest
Bulk density	5–6 g.cm^{-3}	
Granulometric composition	> 0.160 mm	max. 10
	0.100–0.160 mm	25–60
	0.063–0.100 mm	30–60
	< 0.063 mm	max. 6
Tensile strength R_m	220 MPa	
Yield strength $R_{p0,2}$	140 MPa	
Hardness	60 HB	
Expansivity A_5	15%	

II: *Chemical composition and mechanical features of testing plate NP 40*

MATERIAL	NP 40	
CHEMICAL COMPOSITION (%)	Ni	the rest
	Si	3.5–4.5
	B	1.5–2.5
	Cr	1.5–2.5
	Cu	max 0.3
	Fe	max 0.5
	C	max 0.1
MECHANICAL FEATURES	Bulk density	4.8 g.cm^{-3}
GRANULOMETRIC COMPOSITION (%)	Fraction > 0.100 mm	max 10
	Fraction 0.100 mm	max 90
	Fraction 0.063 mm	
	Fraction < 0.063 mm	

This product can be used in the range from –20 °C to maximum 85 °C. If the system has thermal peaks of maximum 90 °C, these are tolerable with regard to limit viscosity.

MOGUL HEES 46 is a universal oil applicable in all hydraulic and circulation systems which requires the usage of oil of ISO VG 46 class. This product is suitable for mobile and stationary hydraulic systems. It is used mainly in system working within the environment where the danger may occur, i.e. leaking hydraulic liquid may threaten the soil, underground water or surface water. If the oil leakage occurs, the product is captured mainly in the top layers of the soil where it is quickly bio-degradable. The specific application is mainly in the field of construction, management of water sources, agriculture and forestry.

During the experimental test, the revolutions of shaft reached the value of 180 revolutions per minute clockwise. The time for the test was set to 70 minutes; 10 minutes for trial run and 60 minutes for the test itself. The load force was set from 500 to 3000 N. The trial run included the increasing of load force by jump increase of its value by 500 N every 120 seconds.

RESULTS AND DISCUSSION

The results of laboratory measurements on Tribotestor M'06 experimental machine were statistically processed and consequently the following were evaluated: weight loss, changes in roughness, elements in lubricant after experimental tests and surface of material pairs.

The Voyager pro VP 613CN precise scales provided us information about weight loss of both sliding elements. As for material pair NP 40 – 14 220 a specific phenomenon occurs when at absolute value the wear of plate is zero and weight increase of

III: *Values of mean weight losses*

Weight loss (g)							
		Plate			Shaft		
Material pair	**Number of experimental test**	**Before experiment**	**After experiment**	**Difference**	**Before experiment**	**After experiment**	**Difference**
NP 40 - 14 220	1	20.924	20.929	–0.005	405.249	405.245	0.004
	2	19.652	19.655	–0.003	398.810	398.798	0.012
	3	22.305	22.309	–0.004	392.630	392.616	0.014
	4	21.676	21.679	–0.003	399.053	399.044	0.009
	5	22.836	22.841	–0.005	405.817	405.804	0.013
	6	19.952	19.949	0.003	395.862	395.854	0.008
	7	18.766	18.768	–0.002	398.593	398.590	0.003
	8	20.661	20.665	–0.004	402.736	402.730	0.006
Average				**–0.003**			**0.009**
		Plate			**Shaft**		
Material pair	**Number of experimental test**	**Before experiment**	**After experiment**	**Difference**	**Before experiment**	**After experiment**	**Difference**
CuSn 10 - 14 220	1	17.569	17.518	0.051	407.163	407.158	0.005
	2	17.168	17.120	0.048	392.994	392.983	0.011
	3	17.622	17.578	0.044	399.552	399.547	0.005
	4	17.378	17.322	0.056	409.068	409.056	0.012
	5	17.090	17.035	0.055	405.695	405.689	0.006
	6	17.334	17.316	0.018	399.78	399.774	0.006
	7	17.425	17.356	0.069	399.075	399.07	0.005
	8	17.453	17.433	0.020	411.446	411.442	0.004
Average				**0.045**			**0.007**

IV: *Values of mean changes of 'Ra' roughness*

'Ra' change (μm)							
		Plate			Shaft		
Material pair	**Number of experimental test**	**Before experiment**	**After experiment**	**Change**	**Before experiment**	**After experiment**	**Change**
NP 40 - 14 220	1	0.355	0.660	0.305	0.815	0.620	–0.195
	2	0.340	0.520	0.180	1.025	0.685	–0.340
	3	0.190	0.545	0.355	0.960	0.600	–0.360
	4	0.220	0.491	0.271	0.935	0.564	–0.371
	5	0.175	0.490	0.315	1.220	0.760	–0.460
	6	0.300	0.285	–0.015	1.190	0.835	–0.355
	7	0.350	0.660	0.310	1.070	0.675	–0.395
	8	0.260	0.710	0.450	1.175	0.680	–0.495
Average				**0.271**			**–0.371**
		Plate			**Shaft**		
Material pair	**Number of experimental test**	**Before experiment**	**After experiment**	**Change**	**Before experiment**	**After experiment**	**Change**
CuSn 10 - 14 220	1	0.805	0.350	–0.455	0.46	0.415	–0.045
	2	0.665	0.485	–0.180	0.49	0.345	–0.145
	3	1.055	0.555	–0.500	0.37	0.39	0.02
	4	0.840	0.665	–0.175	0.405	0.57	0.165
	5	0.845	0.330	–0.515	0.395	0.395	0
	6	0.820	0.420	–0.400	0.385	0.315	–0.07
	7	0.775	0.360	–0.415	0.375	0.32	–0.055
	8	1.050	0.595	–0.455	0.33	0.385	0.055
Average				**–0.387**			**–0.009**

plate is caused by sticking or welding of mechanical parts located in the lubricant area in the results of adhesive wear of the shaft. The weight loss of plate with sliding surface based on CuSn10 is significantly higher than plate with sliding surface based on NP 40. The weight losses within both shafts were approximately the same.

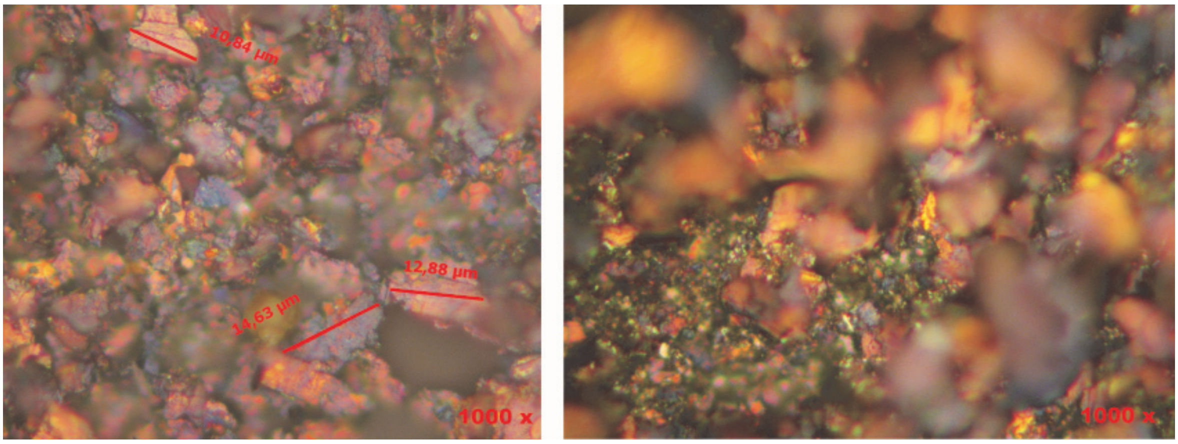
The roughness of the plate and the shaft were determined by Mitutoyo SJ-201 roughness meter. The value of mean change of roughness 'Ra' means the change of roughness on sliding element's surface during the time of experimental test. As for material pair 14 220 – NP 40, there was smoothing of the shaft what means that the 'Ra' value was lower and the 'Ra' value on plate NP 40 was higher. This phenomenon is caused by sticking or welding of mechanical parts of the shaft to the composite plate. The phenomenon is also confirmed by the analysis of the weight losses. As for material pair 14 220 – CuSn10 the 'Ra' value decreased within both parts, i.e. the shaft and the plate. This change is almost identical within both sliding pairs. The reason is that both sliding surfaces were consequently smoothed during the tribological test.

Ferrography analysis of material pair CuSn10 – 14 220 is illustrated in Fig. 2, on the left part of the figure there are non-ferrous elements Cu, Sn located at the beginning of the ferrogram. Based on their size and in comparison with sample book from the Catalogue of wear particles, this wear can be characterized on the upper level of adhesive wear. On the right part of the figure the wear particles in ferrogram are focused.

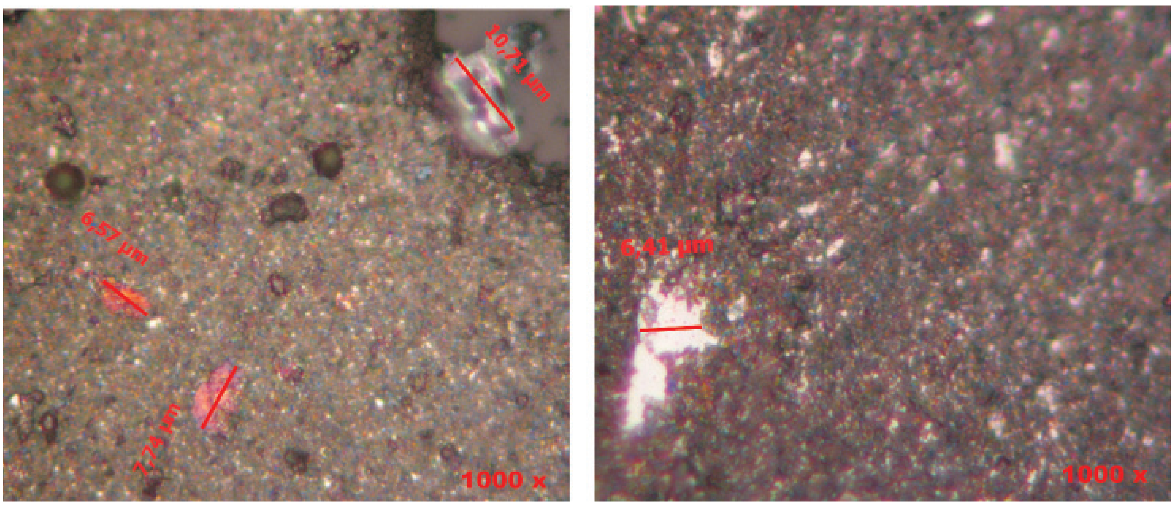
Fig. 3 illustrates ferrography analysis of material pair NP 42 – 14 220. On the left part there is a strip of ferrous particles of adhesive wear captured in the upper part of the ferrogram. The size of the highlighted particle is 6.41 µm; it can probably be chromium.

The first part of the figure shows the lower part of the ferrogram which illustrates ferrous particles created by adhesive wear as well as bigger non-ferrous particle with the approximate size of 10 µm.

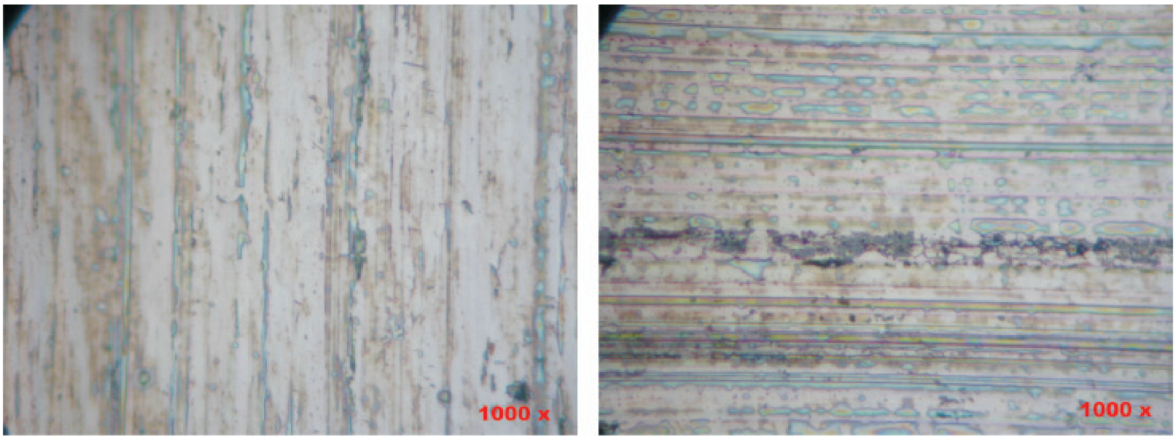
The observation of plates' surface before and after experiment was provided by Carl Zeiss microscope (Figs. 4 and 5). This observation confirmed the previous measurements of weight losses and lower wear of plates with surface created of NP 40 material.



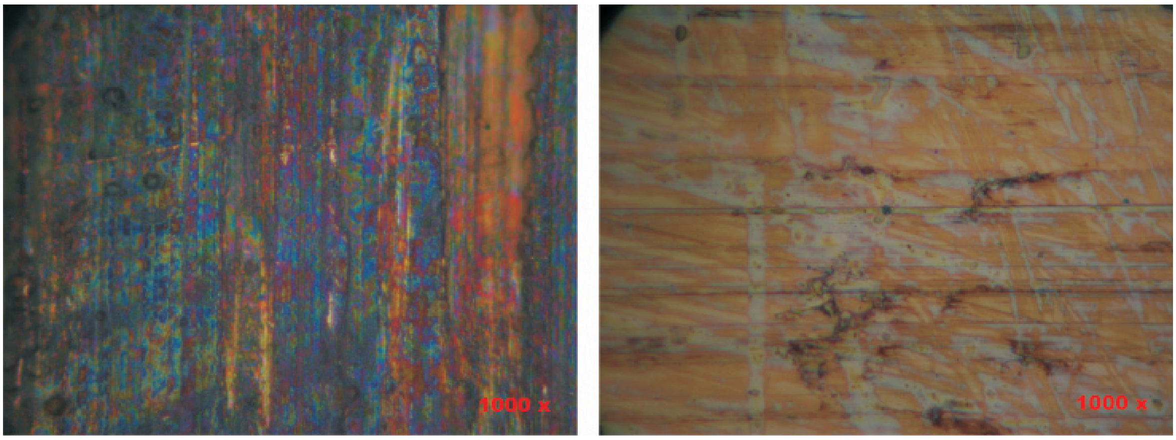
2: *Evaluation of ferrogram of material pair CuSn10 – 14 220 (magnified thousand times)*



3: *Evaluation of ferrogram of material pair NP 40 – 14 220 (magnified thousand times)*



4: *Plate NP 42 marked as 3 before experiment (on the left) and after experiment (on the right) magnified thousand times*



5: *Plate CuSn10 marked as 3 before experiment (on the left) and after experiment (on the right) magnified thousand times*

CONCLUSION

The scientific article analyses the geometry change of sliding pair using the ecological oil. Based on the results of weight losses, the material pair 14 220 – NP 40 has more convenient course where the specific phenomenon can be observed, i.e. there is a zero wear of plate in the absolute value and the weight decrease of the plate is caused by sticking or welding mechanical parts located in the lubricant area caused by adhesive wear of the shaft. The weight loss of plate with sliding surface based on CuSn10 is significantly higher than material pair based on NP 40. The results reflect on conditions of the experiment itself where the sliding pair works in the lubricant area without possibility of oil filtration. The next parameter was the evaluation of roughness change of observed surfaces. The roughness was evaluated via 'Ra' parameter which was measured before and after experiment in the contact of sliding surfaces. As for material pair 14 220 – NP 40 there was smoothing of the shaft with decreasing Ra value and increasing Ra value on the composite plate NP 40. As for material pair 14 220 – CuSn10 the Ra value decreased within both material pairs, i.e. on the surface of the shaft as well as on the composite plate. The values were confirmed also by the ferrograms of sliding pairs as well as microscopic picture of surface on both plates. We are convinced that in the real operational conditions where the cooling and filtration of oil is provided, the composite material NP 40 towards reference composite material CuSn10 will reach better tribological features from the point of values and course of friction coefficient as well as from the point of wear and Ra parameter. Those authors who deal with this issue came to the similar conclusion (Choťeborský *et al.*, 2013; Kročko *et al.*, 2008; Kučera *et al.*, 2013).

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