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Searching for Possibilities of Lubricating and Cutting Fluids Modification with Copper Micro- and Nanopowders

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The paper discusses an influence of lubricating and cutting fluids modification on tribological properties of friction couples. The modification of above fluids consisted in metal powders of micro- or nanosize grains. Results of earlier tests as well as reports of other authors bring facts about positive influence of metal powders of different dispersion degree (grain sizes from micrometers to nanometers) addition to lubricants on their tribological properties, manifested in mixed friction couples. Results of friction tests, made with Amsler friction machine and with T-05 tribological apparatus as well as results of wear measurements made using scanning profile meter Form Talysurf Series 2, testify to positive effect of copper micro- and nanopowders on tribological properties of oils manifesting in couples of materials characteristic, among others, for machining processes.

Keywords: lubricant, tribological properties, nanostructure, nanopowder.

1. INTRODUCTION

The main features of lubricating fluids used in different kinematical joints are ability to decrease frictional resistance, to absorb heat and to remove wear debris from friction zone. Operational efficiency of these fluids depends to a great extent on their tribological properties as they substantially shape a course of machining process [1, 2].

The problem of efficiency assurance is very good identified and intensively examined in the field of lubricating oils and especially engine oils. Attention is paid in a less degree to other fluids like cutting fluids e.g. cutting oils. One of the ways to improve properties of these fluids is to introduce to fluid composition powders of metals or their alloys consisting of micro- or even nanoparticles.

Such a conclusion is based on a few existing references as well as on author's preliminary investigations [3 – 14]. Some of these investigations were carried out on friction couples made of materials (steel 45), applied frequently in machining processes, using well known Amsler tribological machine with modified friction couple presented schematically in Fig. 1 [8]. As a lubricant the base type oil Hydrorafinat II without and with addition of 0.05 % (wt) Cu micropowder of 2 μm mean grain size was used. The load of friction couple was increased stepwise every 20 minutes by 80 N. An example of obtained results is presented in Fig. 2 [8].

Results of the examination testify to effective influence of oils modification with metal powders addition on improvement of their tribological properties, manifested in kinematical pairs, like antifrictional and antiwear properties, leading to frictional resistance and wear decrease. Especially interesting seems to be applications of nanopowders or even – in wider scope – nanostructures as they developed in extreme extent in last few years.

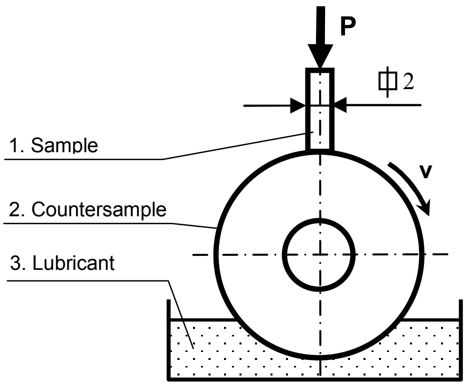

Fig. 1. Modified friction couple of Amsler machine [8]

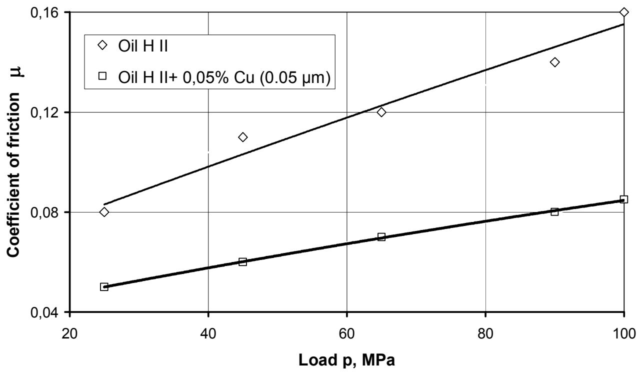

Fig. 2. Dependence between coefficient of friction μ and load p for couple steel 45 – steel 45 lubricated with oil Hydrorafinat II without (◇) and with (□) addition of 0.05 % (wt) Cu micropowder (2 μm) [8]

Application of nanostructures lasts more than 100 years because so long such natural nanostructure like carbon black (particle size from 10 nm to 500 nm) is used for tyres production as a filler of rubber mixtures. Natural nanostructures and especially nanostructures produced by nanotechnology (fullerenes, nanotubes, nanowires and also ordinary nanoparticles) find in last years wider and wider applications in different branches of technology – from technologies used in scientific research through medical

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technologies up to production technologies [15 – 24]. Machining processes are these areas where application of metal nanoparticles as additives to cutting fluids seems to be possible and profitable because of nanoparticles specific features resulting from different aspects of their existence. One of them is quantum aspect, dominating first of all in the nanometric scale, and the other is superficial aspect. The last one results from the fact that the smaller object the bigger relation of atoms quantity on the object surface to all composing it atoms. For this reason sets of very small particles are characterized by very big surface in relation to the volume and, because many phenomena occur on the surface, this feature can be used to their intensification. Thanks to high specific surface nanoparticles possess much more active centres than bigger particles of the same mass and demonstrate very strong catalytic properties. This feature, in the case of nanoparticles addition to cutting fluid, can facilitate machining process, the more so because that their ability to penetration (on account of small size) is also much bigger what afford possibilities for their closer penetration of cutting zone. The cutting process can be also intensified on account of phenomena occurring on quantum level between nanoparticles, tool material and machined material.

Some examinations discussed in the paper are of initial nature and are focused on recognition of possibilities lying in tribological properties modification of lubricating oils with micro- and nanopowders of metals.

2. EXPERIMENTAL

2.1. Tribological examination

Tribological examination was made using T-05 tester (produced by ITeE – Radom, Poland) equipped with modified friction couple (Fig. 3) consisting of carbide blank S20S type as the sample, mounted in special holder, and the ring made of steel 45 and heat treated to 45 ±2 HRC hardness.

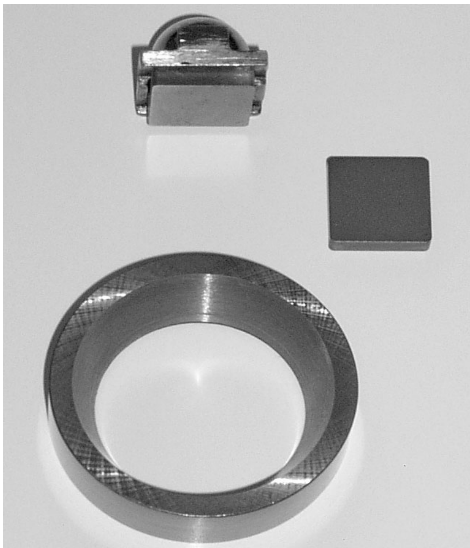


Fig. 3. Special holder with sample (carbide blank), sample and countersample (ring)

The base oils Hydrorafinat II (kinematic viscosity $v_{50} = 58.40$ mm^2/s), SAE 30/95 ($v_{40} = 90.50$ mm^2/s, $v_{100} = 10.46$ mm^2/s) and SN 100 ($v_{40} = 19.35$ mm^2/s, $v_{100} = 2.87$ mm^2/s) without and with addition of 0.25 % (wt) Cu nanopowder of 66 nm mean grain size were used as lubricants. Concentration of copper nanopowder in oils was determined in previous tests. During all tribological tests each oil was heated to the temperature of 150 °C in order to liken test condition the real one existing in friction zone of cutting tool – workpiece system.

The examination consists of the tests made in two stages for each oil. In the first stage pure oil without additive was tested while in the second stage the oil with addition of copper nanopowder was used. During all tests the sliding speed was equal 0.4 m/s and the load of friction pair was increased stepwise every 5 minutes by 50 N.

Measurement of friction force was made continuously but measured values were recorded with 0.1 Hz frequency and collected in the computer memory. Than mean values were used for diagrams construction.

2.2. Amount of wear examination

Measurements of carbide blanks wear occurred in tribological process were carried out using scanning profile meter Form Talysurf Series 2. The apparatus, thanks to program controlled scanning table, enables roughness 3D measurements as well as calculation of all roughness parameters with error not exceeding 2 % (±0.004 µm). The profile meter due to broad measurement range collects information about all dimensional deviations of the examined surface and records so called unfiltered profile. Than special program separates respective constituents of surface profile according to needs. The isometric images of carbide blanks surface areas with friction paths were obtained using the profile meter as well as diagrams of roughness of friction paths with wear amount calculation.

2.3. Material examination

Measuring system with scanning electron microscope Hitachi S-2460N was used to carry out sample material examination. X-ray microanalyser with energy dispersion system was attached to the microscope in order to identify chemical elements in excited microzone of the sample (qualitative analysis) and determine their mass or atomic concentration (quantitative analysis). The microanalyser Voyager 3050 (produced by Noran-USA) was equipped with SiLi crystal window of 133 eV resolution.

3. RESULTS AND DISCUSSION

3.1. Tribological examination

The results of tribological tests (in load range characteristic for cutting tool – workpiece interaction), for three examined base oils (Hydrorafinat II, SAE 30/95 and SN 100) without and with addition of 0.25 % (wt) copper nanopowder are presented in Figs. 4, 5 and 6 respectively.

Characteristics obtained in all tests demonstrate that addition of Cu nanoparticles to tested base oils lubricating friction couple improved frictional cooperation between its elements made of steel 45 and of sintered carbide S20S. Meanly, frictional resistance between rubbing parts decreased by 15 % in the case of lubricating oil Hydrorafinat II, by 12 % for oil SAE 30/95 and by 24 % for oil SN 100.

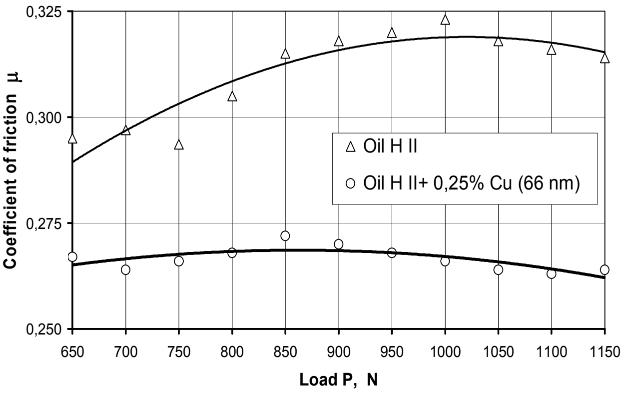


Fig. 4. Dependence between coefficient of friction μ and load P for couple steel 45 – sintered carbide S20S lubricated with oil Hydrorafinat II without (△) and with (○) addition of 0.25 % (wt) Cu nanopowder (66 nm)

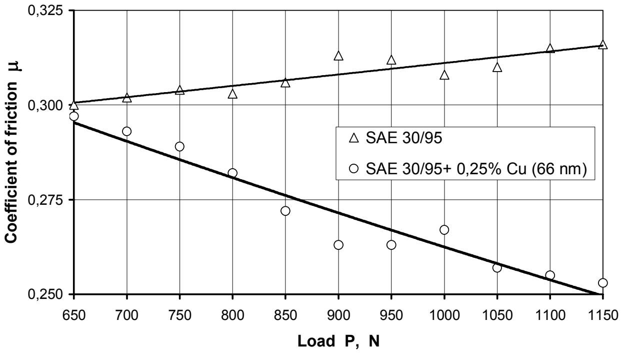


Fig. 5. Dependence between coefficient of friction μ and load P for couple steel 45 – sintered carbide S20S lubricated with oil SAE 30/95 without (△) and with (○) addition of 0.25 % (wt) Cu nanopowder (66 nm)

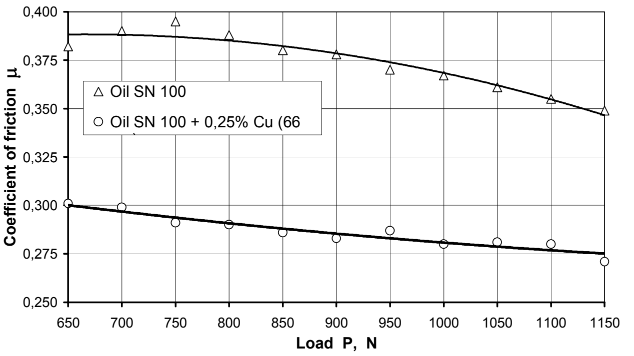
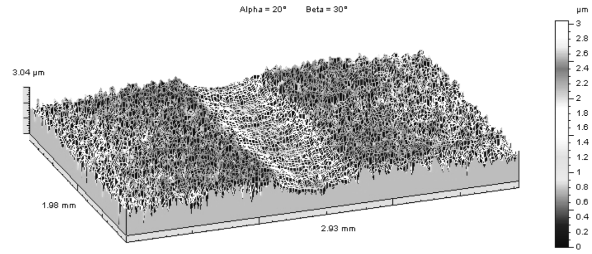


Fig. 6. Dependence between coefficient of friction μ and load P for couple steel 45 – sintered carbide S20S lubricated with oil SN100 without (△) and with (○) addition of 0.25 % (wt) Cu nanopowder (66 nm)

3.2. Amount of wear examination

Images of friction path cross-sections in planes perpendicular to motion direction as well as areas of these cross-sections (which represent the wear amount) were obtained with scanning profile meter Form Talysurf Series 2. Figs. 7 – 9 show images of friction paths on carbide blanks before and after addition of copper nanopowder to each oil. Figs. 10 – 12 show roughness diagrams of friction paths on carbide blanks with dark areas representing amount of wear. Each figure shows diagram for another type of oil. As it results from figures and diagrams addition of copper nanoparticles to oils influences their antiwear properties in different degree. The best results were obtained for SN 100 oil (about 40 % reduction of wear) and the worst for SAE 30/95 oil (no real reduction of wear). In the case of Hydrorafinat II oil wear reduction was about 10 %. Differences in obtained results can be explained by differences in viscosity of the oils. Kinematic viscosity of SN 100 oil in 40 ºC is equal 19.35 mm^2/s and in 100 ºC is equal 2.87 mm^2/s while for SAE 30/95 oil ν_{40} = 90.50 mm^2/s and ν_{100} = 10.46 mm^2/s. Viscosity of Hydrorafinat II oil shows medial values.



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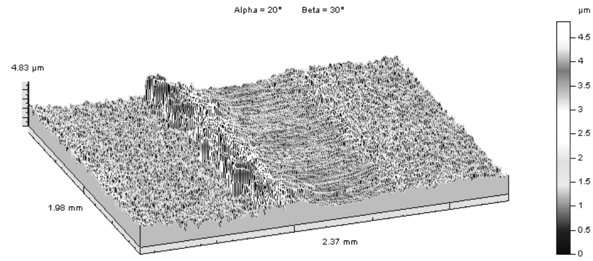
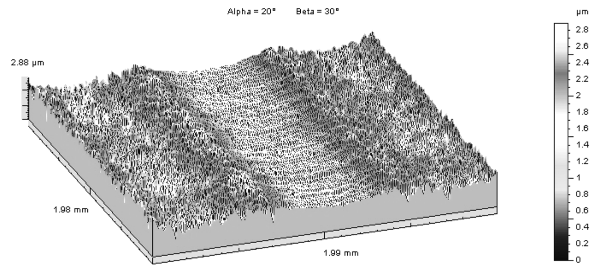


b

Fig. 7. Image of wear of sintered carbide S20S sample after work in couple with steel 45 lubricated with base oil Hydrorafinat II without addition (a) or with addition of 0.25 % Cu nanopowder (b)



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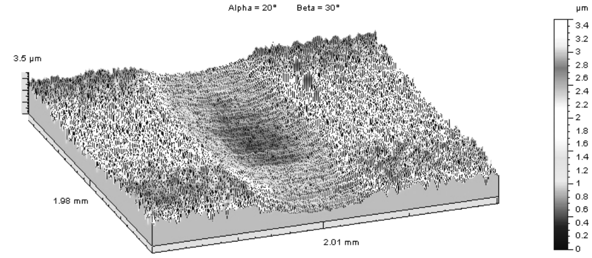

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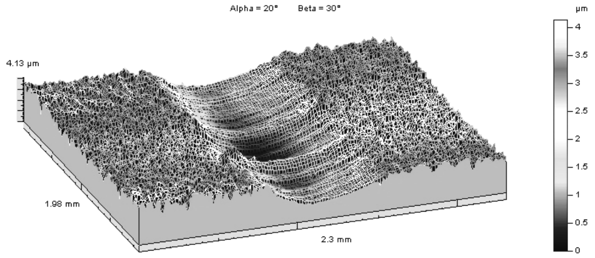
Fig. 8. Image of wear of sintered carbide S20S sample after work in couple with steel 45 lubricated with base oil SAE 30/95 without addition (a) or with addition of 0.25 % Cu nanopowder (b)



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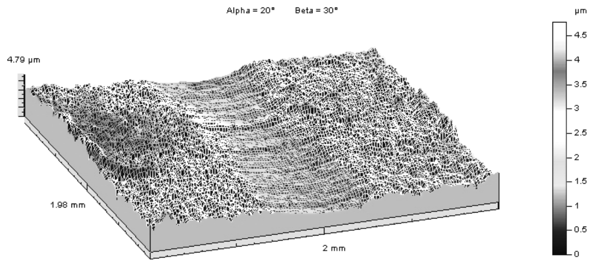


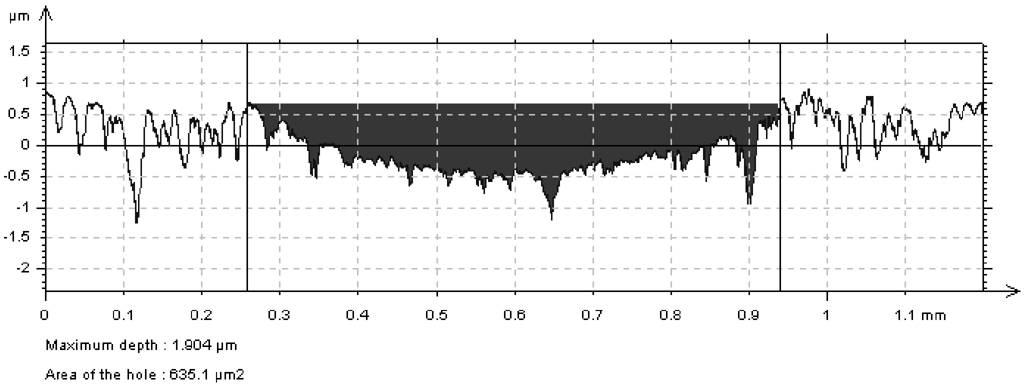
b

Fig. 9. Image of wear of sintered carbide S20S sample after work in couple with steel 45 lubricated with base oil SN 100 without addition (a) or with addition of 0.25 % Cu nanopowder (b)

3.3. Material examination

Examination results were obtained using scanning electron microscope Hitachi S-2460N equipped with X-ray microanalyser with energy dispersion system. The results were obtained in the form of X-ray emission spectra and on their base the computer program counted atomic and weight share of particular elements. The spectra were taken from areas of carbide blank surfaces located on friction path and on the zone not influenced by the friction motion. The examples of X-ray spectra with attached tables of some elements concentration, obtained for sample examined in Hydrorafinat II oil, are presented in Figs. 13 and 14. In each diffractometer peaks of analysed elements are visible. As analysed oils were modified with copper nanoparticles only Cu content is important in order to understand a nature of friction processes in pure oils and in modified oils. For this reason Cu content is underlined in each table. The other detected elements originate from the sample or countersample material or from the oil.

Results obtained for the samples examined in the other oils are similar. All results show that copper exist only on friction path despite of fact that whole samples were immersed in oils during tribological tests. This leads to the conclusion that durable layers, reducing frictional resistance and wear of tool materials, form in a friction process. The fact that these layers form on friction paths only demonstrate tribological nature of the process which can take place under the condition of sufficient amount of energy delivery.



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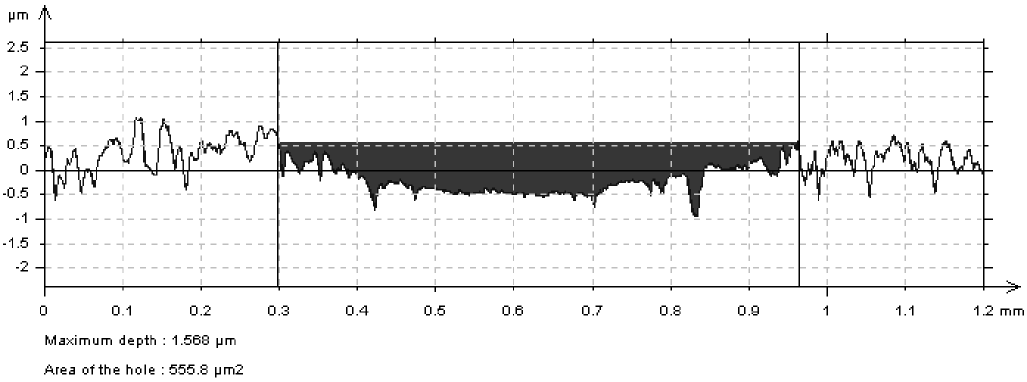

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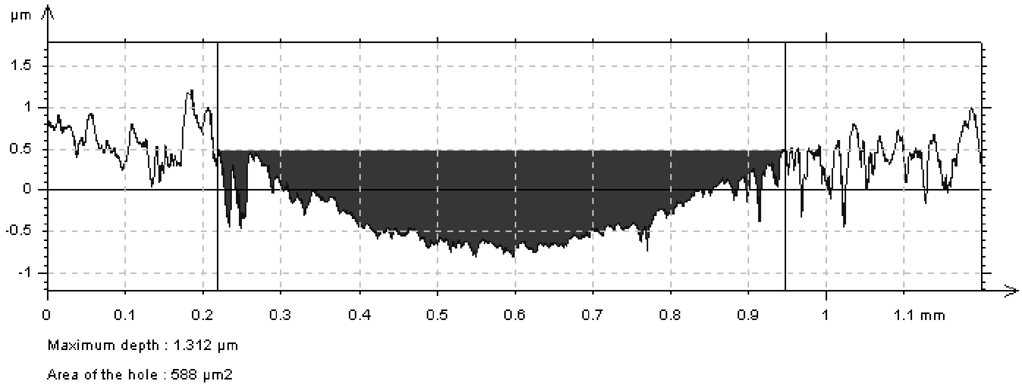
Fig. 10. Amount of wear of sintered carbide S20S sample after work in couple with steel 45 lubricated with base oil Hydrorafinat II without addition (a) or with addition of 0.25 % Cu nanopowder (b)



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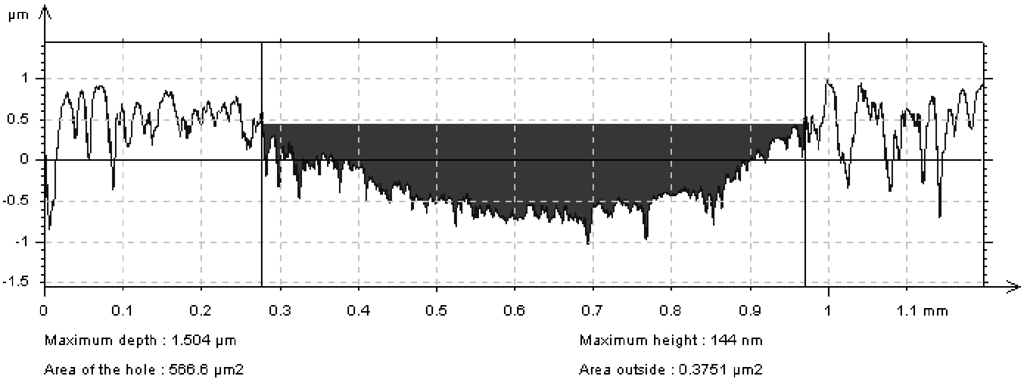
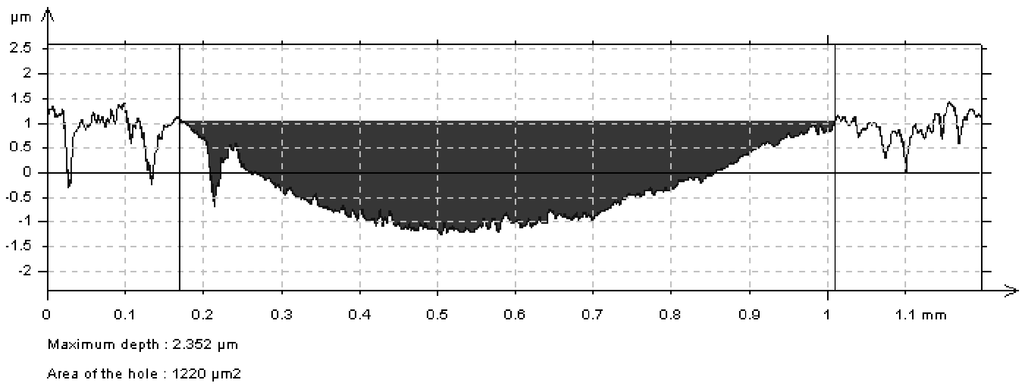


b

Fig. 11. Amount of wear of sintered carbide S20S sample after work in couple with steel 45 lubricated with base oil SAE 30/95 without addition (a) or with addition of 0.25 % Cu nanopowder (b)



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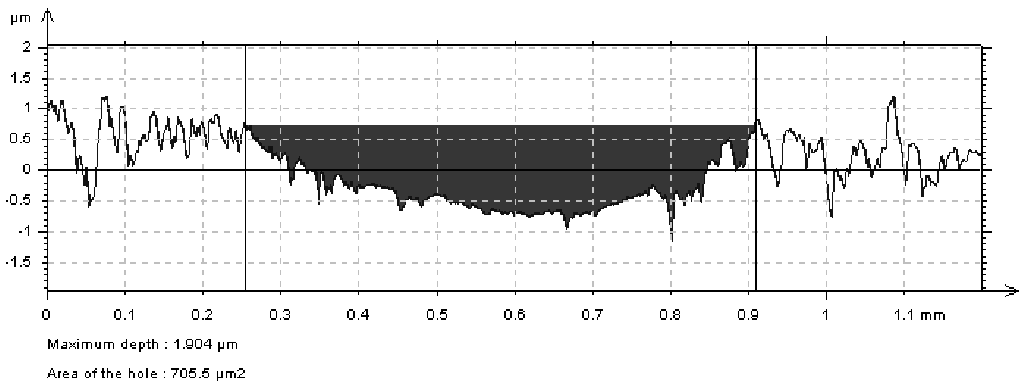

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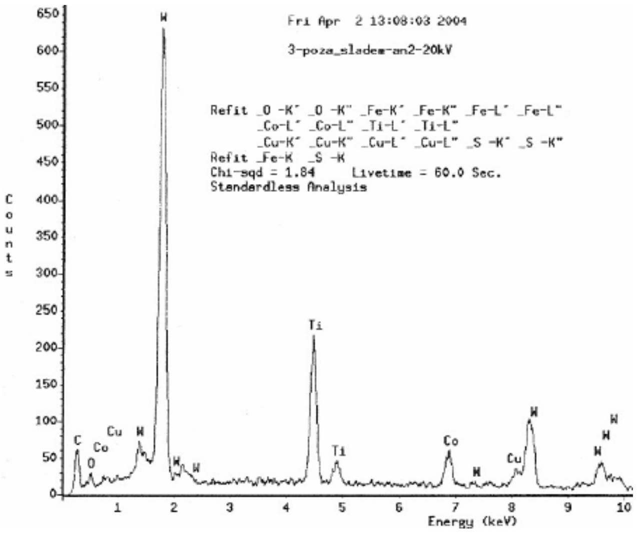
Fig. 12. Amount of wear of sintered carbide S20S sample after work in couple with steel 45 lubricated with base oil SN 100 without addition (a) or with addition of 0.25 % Cu nanopowder (b)

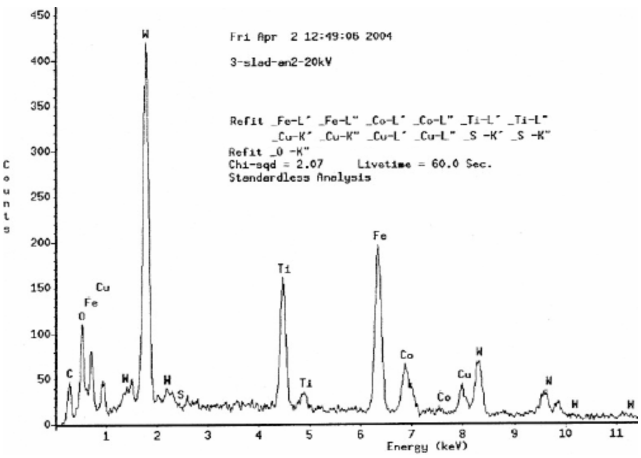


PROZA Correction Acc.Volt.= 20 kV Take-off Angle=25.00 deg
Number of Iterations = 7

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)	No. of Cations
C -K	0.1222	3.524	80.94	43.07	+/- 2.70	241.078
O -K	0.0069	8.247	8.06	5.71	+/- 0.91	---
Fe-K	0.0000	1.029	0.00	0.00	+/- 0.00	0.000
Co-K	0.0407	1.096	1.71	4.46	+/- 0.51	5.085
W -M	0.3000	1.214	4.47	36.43	+/- 0.61	13.320
Ti-K	0.0804	1.235	4.68	9.93	+/- 0.35	13.932
Cu-L	0.0014	2.889	0.14	0.40	+/- 0.51	0.425
S -K	0.0000	2.312	0.00	0.00	+/- 0.00	0.000
Total			100.00	100.00		273.841

The number of cation results are based upon 24 Oxygen atoms

Fig. 13. Results of X-ray energy dispersive analysis of area not influenced by friction of carbide blank S20S after work in couple with steel 45 lubricated with base oil Hydrorafinat II with addition of 0.25 % Cu nanopowder



PROZA Correction Acc.Volt.= 20 kV Take-off Angle=25.00 deg
Number of Iterations = 7

Element	k-ratio (calc.)	ZAF	Atom %	Element Wt %	Wt % Err. (1-Sigma)	No. of Cations
C -K	0.0740	3.832	55.97	28.34	+/- 2.33	46.873
O -K	0.0318	6.070	28.66	19.33	+/- 0.98	---
Fe-K	0.1184	1.097	5.52	12.99	+/- 0.53	4.620
Co-K	0.0328	1.091	1.44	3.57	+/- 0.50	1.205
W -M	0.1585	1.467	3.00	23.25	+/- 0.53	2.513
Ti-K	0.0491	1.184	2.88	5.81	+/- 0.27	2.410
Cu-L	0.0185	3.583	2.47	6.61	+/- 0.60	2.068
S -K	0.0005	1.830	0.07	0.10	+/- 0.10	0.061
Total			100.00	100.00		59.749

The number of cation results are based upon 24 Oxygen atoms

Fig. 14. Results of X-ray energy dispersive analysis of area from friction path of carbide blank S20S after work in couple with steel 45 lubricated with base oil Hydrorafinat II with addition of 0.25 % Cu nanopowder

CONCLUSIONS

On the basis of the examination results it can be stated that:

1. Frictional test method used in presented examinations enables distinct differentiation of oils as regards their tribological properties manifested in frictional systems.
2. Nanopowders of some metals effectively influence on the characteristics of lubricants.
3. The method of oils modification with nanopowder consisting of nanoparticles of some metals can be used to improve cutting oils (fluids) tribological properties manifested in couples consisted of materials occurring in machining systems.

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