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THE IMPACT OF ADDITIVES APPLIED TO THE LUBRICANT ON THE BURNISHING PROCESS AND TRIBOLOGICAL PROPERTIES

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The aim of this study was to determine the impact of additions of tungsten carbide and silicon carbide microparticles to the lubricant used in the burnishing process on the tribological properties of friction pairs. The cylinders made of AISI 1045 steel constituted a workpiece. Burnishing was made with a lubricant the SN150 base oil with addition of tungsten carbide and silicon carbide microparticles. The tested materials were burnished with forces of *1000 N* and *1500 N*. Before and after the burnishing process, the surface roughness and hardness of the tested materials were measured. The study also presents the results of tribological properties of friction pairs with the tested structural materials. It was found that the addition of tungsten carbide microparticles to the base oil in the burnishing process can result in improved surface quality and reduced surface roughness. The results also confirmed the effect of addition of tungsten carbide and silicon carbide to the lubricant used in the burnishing process on tribological properties.

Key words: burnishing, lubricants, lubricants additives, friction pairs.

1. Introduction

One of the environmentally friendly finishing methods used after machining or abrading metals is burnishing [1]. It involves the use of localized plastic deformation produced in the surface layer of an object due to a specific contact interaction between a hard and a smooth tool called a burnishing tool. The plastic deformation induced in the burnishing process causes the displacement of surface asperity peaks and their crushing in the surface layer of the workpiece. The result is a reduction in the roughness of the machined surface and a change in the properties of the surface layer of the machined workpiece. Burnishing, compared to traditional machining methods, makes it possible to obtain a surface with very low roughness and increased resistance to wear and surface corrosion. The surface layer obtained as a result of burnishing is characterized by a greater hardness in relation to the hardness of the material's core. The high operational quality of the surfaces obtained by burnishing

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results in an increase in the durability and reliability of parts during operation. This results in the use of burnishing in the aerospace and engine industries, as well as in the construction of rail and automotive vehicles. To date, a number of scientific studies have been conducted to determine the effect of burnishing on surface quality and hardness. It has been shown that with the use of appropriate burnishing parameters, this process reduces surface roughness [2] and increases the hardness of the surface layer [3].

A very important parameter of burnishing is the burnishing force. It is the main factor affecting the surface obtained in the burnishing process and the hardness of the surface layer. The authors [4] conducted research related to determining the effect of the burnishing force on the quality of the obtained surface. On the basis of the research, it was found that the roughness of the surface obtained in the burnishing process decreases with an increase in the burnishing force. The research [5, 6] showed that exceeding a certain value of heating force causes an increase in surface roughness due to compressive residual stresses developed in the surface layer. The properties of the surface layer obtained by burnishing also depend on the lubricant used in the process. The authors [7] conducted research to determine the effect of applying an operating lubricant to the lubricant on the tribological properties of cast iron. Analysis of the test results confirmed the positive effect on tribological properties and on the improvement of the *Ra* surface roughness parameter for samples burnished in the presence of base oil and operating lubricant. In [8], the research results obtained earlier were confirmed. In modern aerospace and other high-tech industries, increasing demands are being made to enhance the capability and functionality of lubricating materials. In recent years, attempts to apply microparticles of various metals to lubricants have been noted [9, 10]. The mechanism of action of lubricants prepared in this way has been evaluated in numerous studies [11, 12]. On the basis of research [13], the positive effect of modifying lubricants with nanoparticles on tribological properties was established. It has been found that the addition of microparticles to a lubricant improves its anti-seizure and anti-wear properties [14]. The possibilities of using microparticles in the fields of manufacturing and operating technology have not been sufficiently explored by scientists yet. Therefore, in this study, an attempt was made to determine the effect of using selected metal microparticles on the tribological properties of friction pairs burnished in the presence of lubricant with tungsten carbide and silicon carbide microparticle additives.

2. Materials and method

The tested workpiece material is AISI 1045 non-alloy steel, which is widely used for the fabrication of components of equipment and machinery, such as shafts, levers, axles, spindles, etc. Table 1 shows the mechanical properties and chemical composition of the steel according to the certificate provided by the manufacturer.

Table 1. Chemical composition and mechanical properties of the AISI 1045 steel.

Chemical composition (%)							
C	Si_{max}	S_{max}	P_{max}	Mn	Cr_{max}	Cu_{max}	Ni_{max}
0.42÷0.5	*0.4*	*0.045*	*0.04*	*0.5÷0.8*	*0.3*	*0.3*	*0.4*

Mechanical properties			
R_e (*MPa*)	R_m (*MPa*)	A_5 (%)	*HB*
305	*580*	*16*	*250*

The burnishing process was carried out using a CU-502 universal lathe. The burnishing process was carried out using a single-rod vice (Fig.1) mounted in a tool vice. The device used makes it possible to obtain the value of the pressing force P in the range from $0 \div 5000$ *N*. The burnishing roller was made of X210Cr12 steel with a hardness of *60 HRC*.

a) b)

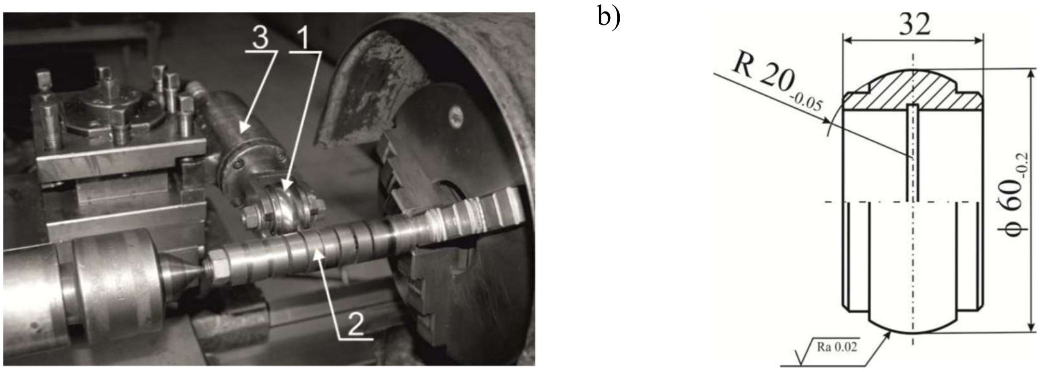


Fig.1. The burnishing set-up: a) general view: 1-burnishing disc, 2-burnishing material, 3-actuator, b) the geometry of the burnishing disc.

The research involved the burnishing of AISI 1045 steel cylinders in the presence of SN-150 base oil, as well as the same oil modified with tungsten carbide and silicon carbide in the form of a *2-μm* powder. The samples for each lubricant were burnished with two forces – *1000 N* and *1500 N*. Each cylindrical sample was processed at a constant burnishing speed $v_n = 60\ m/min$, burnishing feed $f_n = 0.083\ mm/rev$ and number of passes $i = 1$ Before and after the burnishing process, the hardness and surface roughness of each sample were measured.

The hardness test of the samples before and after the burnishing process was carried out on a Zwick Roell ZHV 10 hardness tester (Fig.2). The hardness test according to the Brinell method consisted of pressing an indenter, which took the form of a hardened steel ball, into the surface of the tested material.

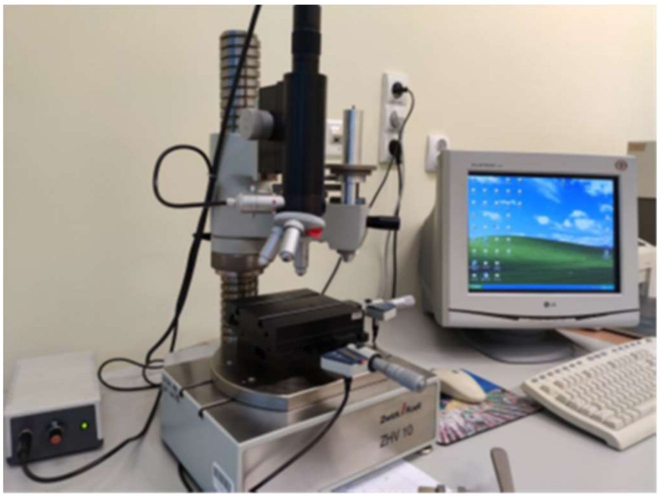


Fig.2. Zvick Roell ZHV 10 hardness tester.

Fig.3. The universal surface roughness measuring instrument profile meter TR-200.

Surface roughness measurement of the specimens before and after the burnishing process was carried out using a TR-200 universal profile meter (Fig.3). Roughness measurements were made in accordance with the standard PN-EN ISO 4287.

Tribological research was carried out using a T-05 tester (Fig.4). The T-05 tribological tester is designed to test the tribological properties of lubricants. The test contact is a stationary sample in the form of a block, which is pressed by a force *P* against a rotating roller to form a linear or staggered contact.

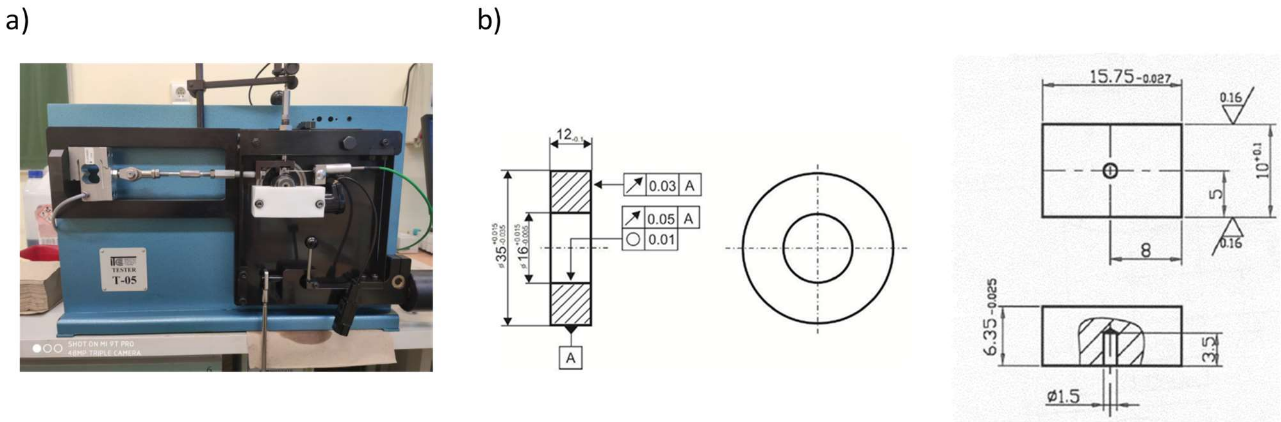


Fig.4. The T-05 tester: a) general view, b) dimensions of the sample and counter sample.

Research on the tribological properties of friction pairs was carried out for two loads changed every *15* minutes starting with a load of *P = 300 N* and ending with a load of *P = 900 N* and at a constant rotational speed of *n = 180 rpm*. The duration of the test was *30* minutes. The counter-sample for the previously burnished samples made of the AISI 1045 steel was a cube made of X210CR12 steel with a hardness of *60 HRC*.
The tested friction pairs worked in the presence of the SN150 base oil lubricant. As a result of the research, the courses of friction force variability, friction node wear and friction node temperature as a function of time were determined.

3. Results

Figure 5 shows the results of research on selected surface roughness parameters before and after the burnishing process in the presence of the SN150 base oil lubricant and the same oil with additives of tungsten carbide and silicon carbide microparticles.

Based on the results obtained, it was found that the process of burnishing the AISI 1045 steel has a significant effect on the obtained surface roughness parameters. The application of the SN150 base oil to the burnishing process with a force of *1000 N* resulted in a decrease in the values of all tested surface roughness parameters. The values of the *Ra* and *Rz* parameters decreased by about *70* %. Increasing the burnishing force to *1500 N* also contributed to a reduction in the values of all tested surface roughness parameters (Fig.5a).

The use of the SN150 base oil with tungsten carbide microparticles in the burnishing process reduced the values of all tested surface roughness parameters compared to the condition before the burnishing process. For the two burnishing forces, the values decreased by more than *60* % (Fig.5b). Modification of the base oil, which takes part in the burnishing process, with silicon carbide microparticles also had a positive effect on the condition of the surface layer. The values of all tested surface roughness parameters decreased significantly compared to the state before the burnishing process. For both burnishing forces, the parameter values decreased by more than *60* % (Fig.5c). High quality surfaces decrease fluids flow resistance and eliminate formations of habitat for bacteria as well as corrosion sources [15].

Figure 6 shows the results of research on selected surface roughness parameters after the burnishing process in the presence of base oil lubricant the SN150 and the same oil modified with the addition of tungsten carbide and silicon carbide.

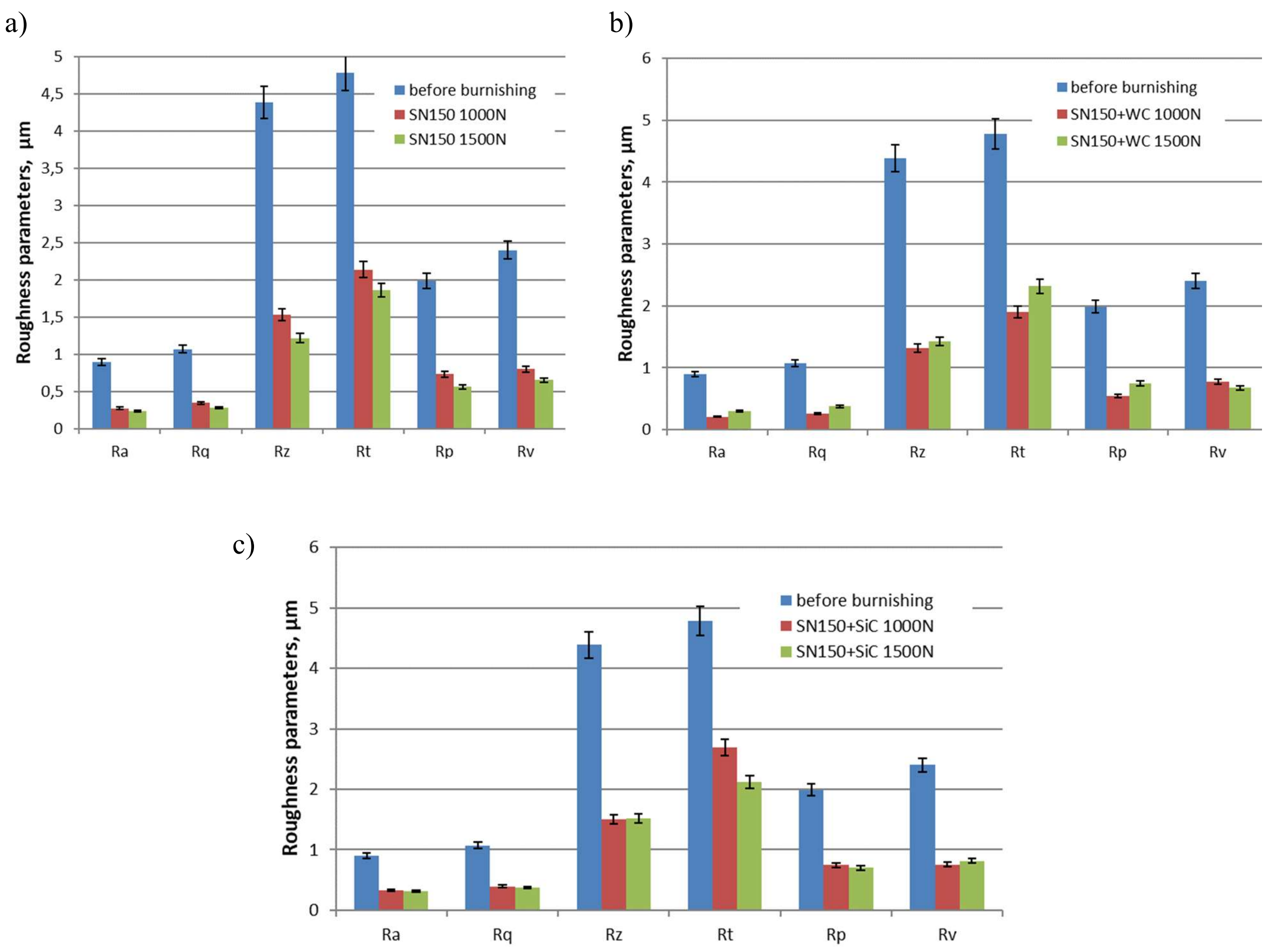


Fig.5. Results of measurements of surface roughness parameters of samples: before and after the process of burnishing with forces of *1000 N* and *1500 N*: a) with lubricant the SN150, b) with lubricant the SN150 and the addition of tungsten carbide microparticles, c) with lubricant the SN150 and the addition of silicon carbide microparticles.

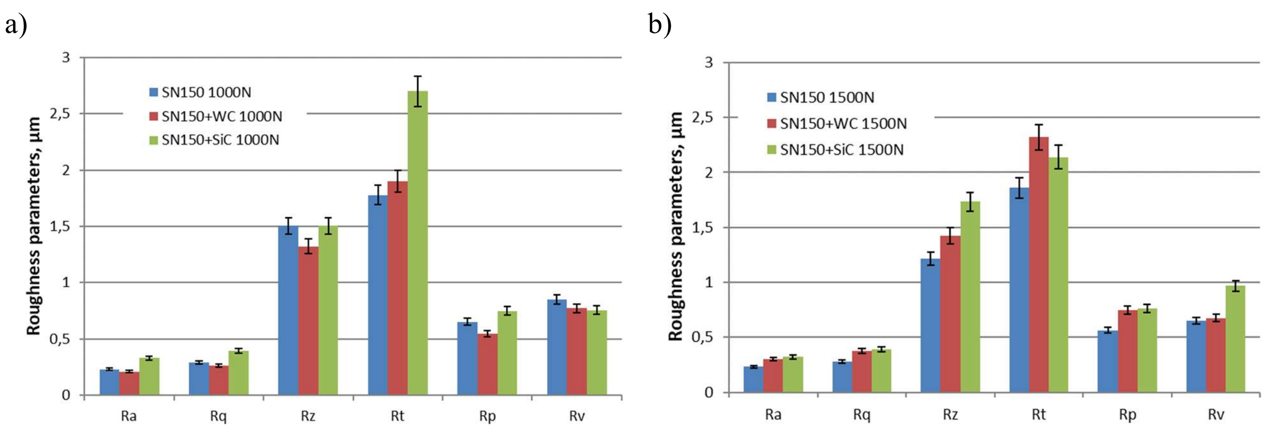


Fig.6. Results of measurements of surface roughness parameters of samples burnished in the presence of tested lubricants: a) for a burnishing force of *1000 N*, b) for a burnishing force of *1500 N*.

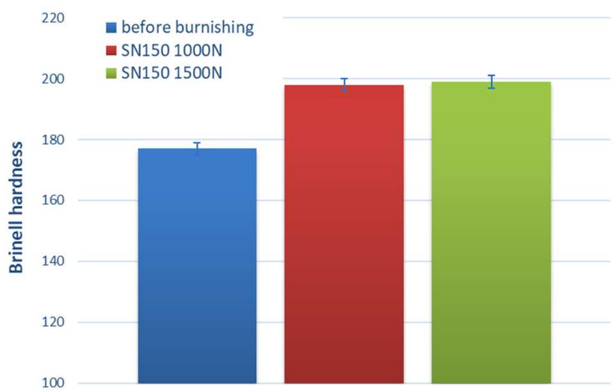
Comparing the results on the surface roughness parameters of samples burnished with the SN150 base oil and the same oil with the addition of tungsten carbide and silicon carbide, it was found that modifying the base oil with microparticles differently affects the condition of the surface layer (Fig.6).

For the samples burnished with a force of *1000 N* in the presence of the SN150 base oil with the addition of tungsten carbide microparticles, the parameters *Ra*, *Rq*, *Rt* reach comparable values (difference of about ± *5*%) to those of the samples burnished in the presence of base oil. The exceptions are the surface roughness parameters *Rz*, *Rp* and *Rv*, whose value decreased by about *10* %. In the samples burnished with a force of *1000 N* in the presence of a lubricant with silicon carbide microparticles, it was observed that the values of the parameters *Ra*, *Rq*, *Rt*, *Rp* increased compared to the values obtained for the samples burnished in the presence of base oil. The *Rz* parameter did not change, while *Rv* decreased by more than *10* % (Fig.6a).

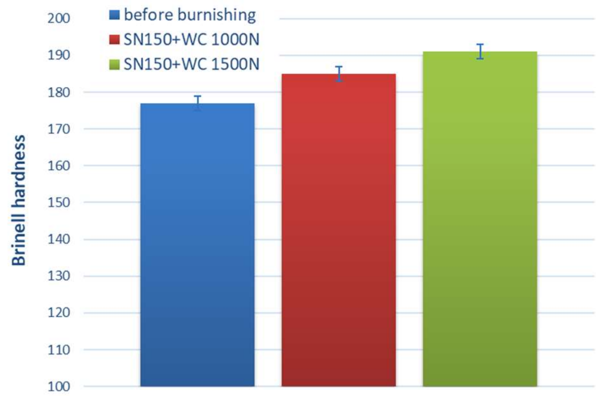
For samples burnished with a force of *1500 N* in the presence of the SN150 base oil with the addition of tungsten carbide microparticles, the values of almost all parameters increased by about *20* % with the exception of the *Rv* parameter, whose value was comparable to a value reached for samples burnished in the presence of base oil. In the case of burnishing in the presence of the SN150 base oil with the addition of silicon carbide microparticles, an increase was observed in all parameters tested compared to the parameters of samples burnished in the presence of base oil (Fig. 6b).

Figure 7 presents the results of surface hardness tests before and after the burnishing process in the presence of the SN150 base oil lubricant and the same oil with the addition of tungsten carbide and silicon carbide microparticles.

a)



b)



c)

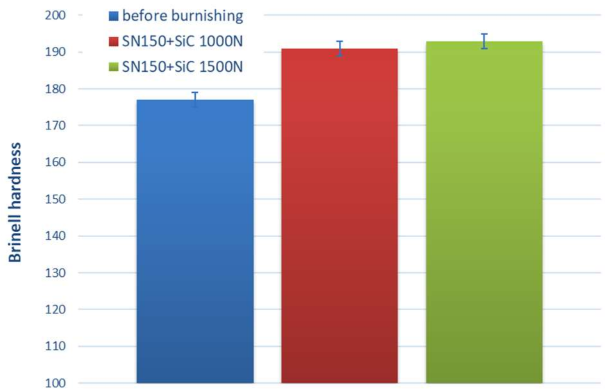


Fig.7. Results of surface hardness measurements of specimens before and after burnishing with *1000 N* and *1500 N* forces: a) in the presence of the SN150 lubricant, b) in the presence of the SN150 lubricant with addition of tungsten carbide microparticles, c) in the presence of the SN150 lubricant with addition of silicon carbide microparticles.

Based on the obtained results of the hardness measurements, it was found that the burnishing of the test samples in the presence of the SN150 base oil and the same oil with the addition of tungsten carbide and silicon carbide microparticles increased the hardness of the obtained surface layer compared to the hardness before the burnishing process (Fig.7).

The hardness of the samples after the burnishing process in the presence of the SN150 base oil increased by more than *10* % for both burnishing forces (Fig.7a). When the samples were burnished in the presence of the SN150 base oil with the addition of tungsten carbide microparticles, a *5* % increase in hardness was observed for the *1000 N* burnishing force and an *8* % increase for the *1500 N* force compared to the hardness before the burnishing process (Fig.7b). The use of the SN150 base oil with silicon carbide microparticles in the burnishing process increased the hardness of the workpiece material by about *10* % for both burnishing forces (Fig.7c).

Figure 8 shows the results of sample surface hardness tests after the burnishing process in the presence of base oil lubricant the SN150 and the same oil modified with the addition of tungsten carbide and silicon carbide microparticles.

a) b)

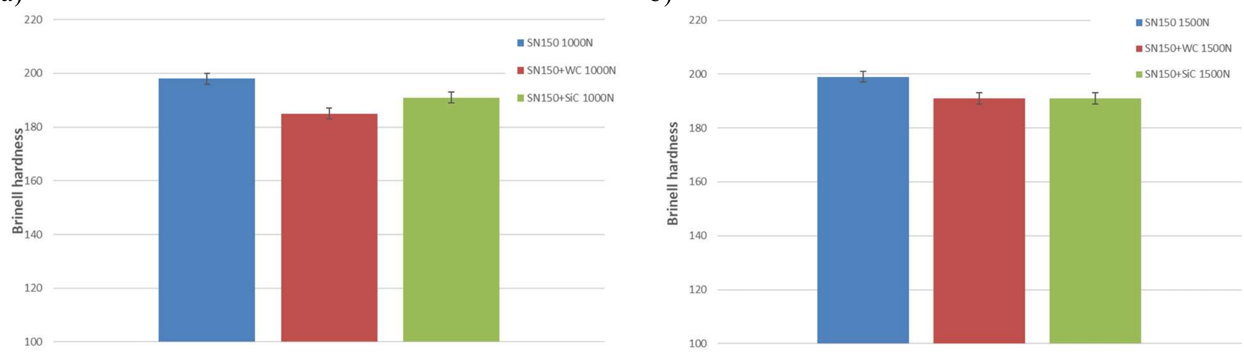


Fig.8. Results of hardness measurements of samples burnished in the presence of the tested lubricants: a) for a burnishing force of *1000 N*, b) for a burnishing force of *1500 N.*

It was found that the highest surface hardness for *1000 N* and *1500 N* burnishing force was obtained during burnishing in the presence of the SN150 base oil. For *1000 N* burnishing, the lowest hardness was shown for samples burnished in the presence of the SN150 base oil with the addition of tungsten carbide microparticles. For burnishing with a force of *1500 N*, the hardness of the tested samples was the same, independently on the type of carbide microparticles added to the lubricant.

Figure 9 shows the variation of friction force, friction node wear and friction node temperature with respect to time for a friction pair: samples burnished with a force of *1000 N* of AISI 1045 steel / X210CR12 steel working in the presence of the SN150 base oil and the same oil modified with additives of tungsten carbide and silicon carbide microparticles.

The lowest friction force was observed for the friction pair with a burnished sample in the presence of the SN150 base oil when the friction node was loaded with a force of *300 N*, and the highest for the pair with a burnished sample in the presence of the SN150 base oil with the addition of tungsten carbide microparticles. Increasing the load on the friction node resulted in an increase in the friction force values for all pairs. The last observed value of friction force for the sample being burnished in the presence of the SN150 base oil was *57.36 N*, for the SN150 base oil with the addition of silicon carbide microparticles - *60.63 N*, for the SN150 base oil with the addition of tungsten carbide microparticles - *60.87 N* (Fig.9a).

The smallest value of friction node wear was observed for the pair with a sample burnished in the presence of the SN150 base oil with the addition of tungsten carbide microparticles, while the largest value was observed for a sample burnished in the presence of the SN150 base oil with the addition of silicon carbide microparticles. The last observed value of friction node wear for the pair with a sample burnished in the presence of the SN150

base oil lubricant was *12 µm*, for the SN150 base oil with the addition of silicon carbide microparticles - *40.375 µm*, for the SN150 base oil with the addition of tungsten carbide microparticles - *11.5 µm* (Fig.9b).
The lowest temperature value of the friction node was observed for the friction pair with a sample burnished in the presence of the SN150 base oil. Friction pairs with samples burnished in the presence of base oil with additives recorded higher temperature values. For both additives, the temperatures are comparable.

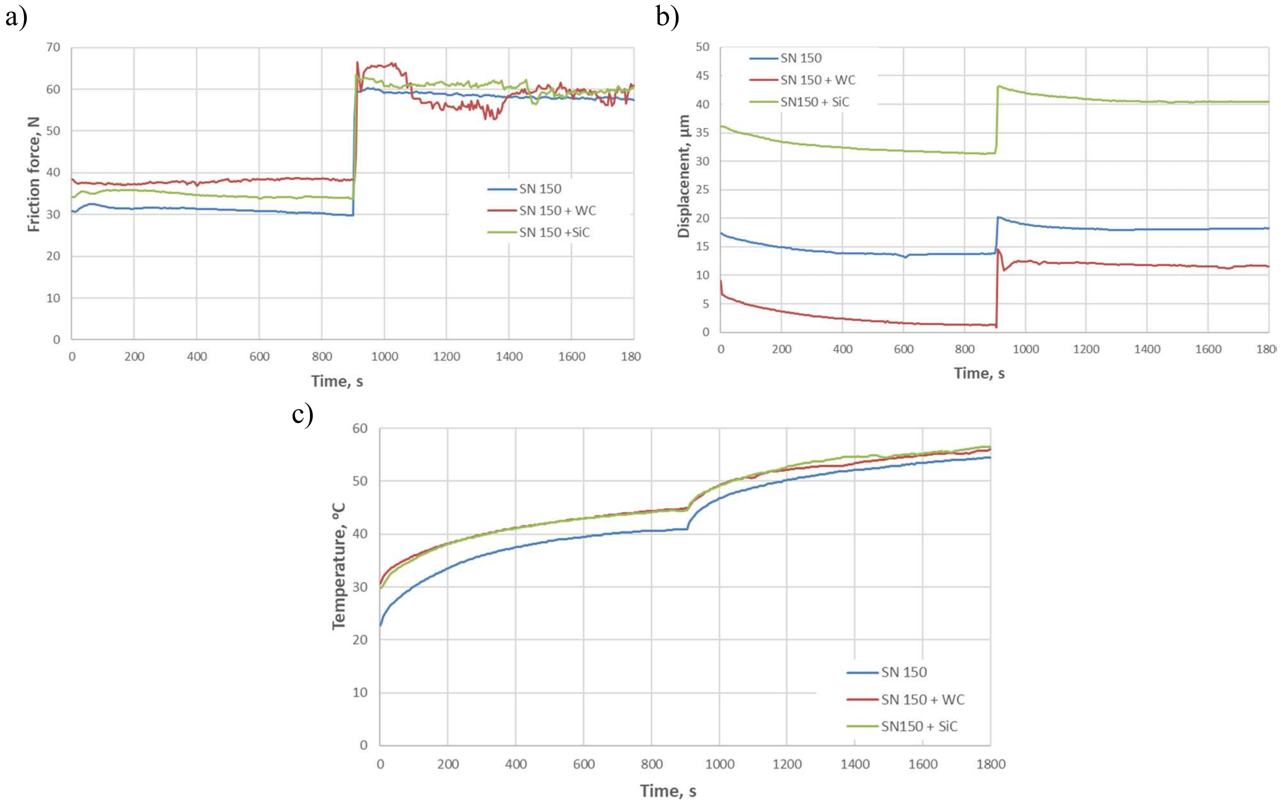


Fig.9. The variation of friction force, friction node wear and friction node temperature against time for friction pairs: sample burnished with a force of *1000 N* of AISI 1045 steel / X210CR12 steel, working in the presence of the SN150 base oil and the same lubricant modified with microparticles.

Figure 10 shows the variation of frictional force, friction node wear and friction node temperature in regard of time for friction pairs: samples burnished with a force of 1500 N from AISI 1045 steel / X210CR12 steel working in the presence of the lubricant base oil SN150 and the same modified with additives of tungsten carbide and silicon carbide microparticles.

The lowest value of friction force was observed for the friction pair with the burnished sample in the presence of tungsten carbide microparticle base oil, and the highest for the pair with the burnished sample in the presence of SN150 base oil (Fig.10a).
The wear curves of the friction node for samples burnished in the presence of the SN150 oil and the same oil with the addition of silicon carbide microparticles are comparable and the wear values are the smallest. For the pair with the sample burnished in the presence of base oil with the addition of tungsten carbide microparticles, the wear value of the friction node is very high compared to the other friction pairs and amounts to *74.1 µm* (Fig.10b).

Analyzing the curves of changes in the temperature of the friction node over time, it was found that the lowest temperature of the friction node was observed for the pair with the sample burnished with tungsten carbide microparticle lubricant and the highest for the pair with the sample burnished in the presence of silicon carbide microparticle lubricant (Fig.10c).

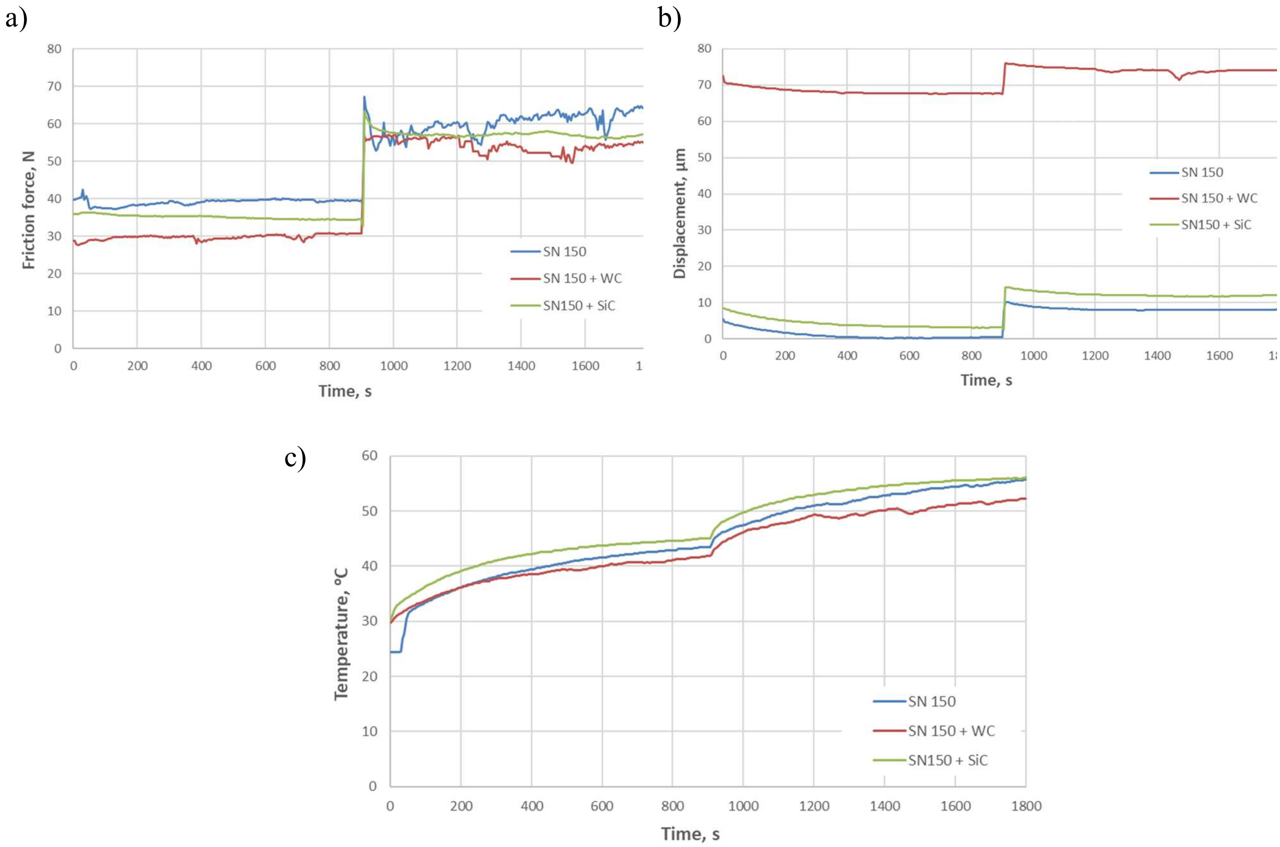


Fig.10. The process of variation of frictional force, friction node wear and friction node temperature, against time for friction pairs: sample burnished with a force of *1500 N* of AISI 1045 steel / X210CR12 steel, working in the presence of the SN150 base oil and the same lubricant modified with microparticles.

4. Conclusions

Based on the results of the research, it was found that the addition of tungsten carbide microparticles to the SN150 base oil during the process of burnishing differently affected the surface roughness parameters of the surface layer compared to samples burnished in the presence of pure base oil. Excessively high burnishing force caused the surface quality of samples burnished in the presence of the lubricant with tungsten carbide and silicon carbide microparticles to deteriorate compared to values reached for samples burnished in the presence of pure base oil. Samples burnished in the presence of the SN150 base oil with the addition of silicon carbide microparticles obtained the highest values of surface roughness parameters. Thus, it can be concluded that in the tested range of burnishing forces, a burnishing force of *1000 N* should be used to obtain the optimal surface roughness parameters' values.

Based on hardness measurements, it was found that the addition of microparticles of silicon carbide and tungsten carbide to the lubricant affects the hardness of the surface layer obtained in the burnishing process. The hardness of samples after the burnishing process in the presence of microparticles of both tungsten carbide, and silicon carbide is lower than the hardness of samples obtained during burnishing with base oil.

Tribological research has determined that the use of samples burnished in the presence of the SN150 base oil and the samples burnished with the SN150 base oil and the addition of tungsten carbide microparticles differently affect the tribological properties of the tested friction pairs. The presence of microparticles of tungsten carbides and silicon carbides in the lubricant did not significantly affect the temperature of the friction node for both the *1000 N* and *1500 N* burnished samples. The application of these additives to the lubricant had different effects on the wear of the friction node, as well as on the frictional force in the case of samples that were burnished with both tested forces. Therefore, it can be concluded that the selection of lubricant and the burnishing force in the burnishing process is very important to obtain the best possible quality and hardness of the surface layer.

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Nomenclature

HRC – Rockwell hardness
HB – Brinell hardness
v_n - burnishing speed [m/min]
f_n – burnishing feed [mm/rev]
i – number of passes
Ra – arithmetical mean roughness value [μm]
Rz – mean roughness depth [μm]
Rt – total height of the roughness profile [μm]
Rq – root mean square roughness [μm]
Rp – maximum profile peak height [μm]
Rv – maximum profile valley depth [μm]
Rm – tensile strength [Mpa]
Re – yield strength [Mpa]
WC – tungsten carbide
SiC – silicon carbide

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