Marek JAŁBRZYKOWSKI [1], Sławomir OBIDZIŃSKI [2]
Politechnika Białostocka
[1] Wydział Mechaniczny, Katedra Inżynierii Materiałowej i Biomedycznej
[2] Wydział Budownictwa i Inżynierii Środowiska, Zakład Inżynierii Rolno-Spożywczej i Leśnej
ul. Wiejska 45E, 15-351 Białystok, Poland
e-mail: m.jalbrzykowski@pb.edu.pl; s.obidzinski@pb.edu.pl

SELECTED ISSUES OF EXPLOITATION OF WOOD MACHINING DEVICES ON THE EXAMPLE OF A CHIPBOARD PRESS

Summary

The paper presents selected results of performance tests of working elements of a wood machining device. The focus was on operational durability of its working elements. In order to assess the condition of these elements, tests of mechanical properties, the chemical composition of the operational surface layer, and microscope observations of selected areas were carried out, as well as evaluation of lubricating properties of lubricants for the working elements of the device. Diverse mechanical properties, diverse wear patterns, and physiochemical changes of surface layers of the elements were noted. A significant impact of the lubricants on the observed phenomena was stated. Due to industrial secret, the name and type of the tested machines were hidden.
Key words: *operational durability, mechanical properties, tribological wear, lubricating properties*

WYBRANE ZAGADNIENIA EKSPLOATACJI MASZYN DO OBRÓBKI DREWNA NA PRZYKŁADZIE PRASY DO PŁYT WIÓROWYCH

Streszczenie

W artykule przedstawiono wybrane wyniki badań właściwości użytkowych elementów roboczych maszyny do wiórowej obróbki drewna. Skupiono się na trwałości eksploatacyjnej jej elementów roboczych. W celu oceny stanu tych elementów wykonano badania właściwości mechanicznych, składu chemicznego eksploatacyjnej warstwy wierzchniej, obserwacji mikroskopowych wybranych obszarów oraz wykonano badania właściwości smarnych substancji do smarowania elementów roboczych tej maszyny. Zwrócono uwagę na zróżnicowane właściwości mechaniczne, zróżnicowane formy zużycia oraz modyfikację fizykochemiczną warstwy wierzchniej tych elementów. Wskazano na istotny wpływ środków smarowych na obserwowane zjawiska. Ze względu na tajemnicę przemysłową ukryto nazwę oraz typ maszyny, którą poddano ocenie.
Słowa kluczowe: *trwałość eksploatacyjna, właściwości mechaniczne, zużycie tribologiczne, właściwości smarne*

1. Introduction

Operational durability and reliability of machines and devices are the key factors influencing the functional quality of machines [13, 15, 21]. As a term from the diagnostics and reliability theory, exploitation can be stated to cover issues connected with both rational use of machinery and its rational exploitation [6, 11]. Both the manner of use of the machine (e.g. using the values of externally-applied parameters such as speed, load, pressure, etc.) and the quality of the operational elements used, as well as the general technical culture of exploitation, have an impact on its durability and reliability [3, 7, 16, 20].

In this context, this paper presents the influence of the aspects in question on the condition of working elements of the selected woodworking machine. The following issues are addressed here: transformation of the surface layer from a technological into an operational one and the impact of such a transformation on the operational durability on the analysed working node, among others. Specialised literature [9, 12] shows that the course of this transformation can be controlled to a certain extent, therefore the course of this process and its final effect can be designed. As far as generation of the operational surface layer is concerned, kinematic nodes of machines and devices should be treated in a systemic manner. Cooperating nodes of machines and devices comprise an individual tribological system, whose generalized scheme is presented in fig. 1 [2, 8, 17, 19]. Analysing the presented example of a tribological system, it can be stated that uncontrolled quantities, difficult to eliminate, occur in it, as well as factors that can be controlled by the machine user. A rational approach to uncontrolled input quantities can contribute to taking partial control over them and a more rational exploitation of the technical object. Machine users, however, often neglect these issues. By way of example: using low quality substitutes wherever work safety allows it and it is possible to recreate the condition of the machine's fitness for use and performance. Substitutes are both typically structural elements and operating fluids.

Woodworking machines are exposed particularly to significant static and dynamic mechanical overload. This makes an important factor of the use of high quality construction materials.

These materials, in addition to the necessity of bearing high mechanical loads, must also be characterized with corrosion, chemical, friction, heat, and gas resistance, among others, factors which result from the technological process [10, 14, 18]. Cooperating kinematic nodes of the machine are supported with lubricants. These substances, enriched with reactive additives, as a result of high temperatures, react with metallic surfaces, causing physicochemical modification of surface layers of cooperating elements [1, 4, 5]. Summing up the aspects discussed above, it can be stated that for a rational machine use and operation, a comprehensive approach to the issue of inspections, repairs, replacement of parts, oils, etc. is essential.

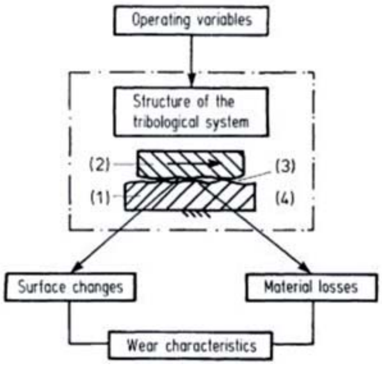

Fig. 1. An example scheme of a tribological system [15, 17] and according to DIN 50320 [22]; 1 and 2 wear couples, 3 - interfacial medium, 4 - surrounding medium

Rys. 1. Przykładowy schemat system tribologicznego [15, 17] zgodny z normą DIN 50320; 1 i 2 - elementy pary ciernej, 3 - medium pośredniczące, 4 - mikrootoczenie

Considering the above, this paper analyses the condition of working elements of a selected woodworking machine. The analysis includes a lubricant as a factor that has a significant impact on the diagnostic condition of the working elements of the machine. Due to industrial secret, the name and type of the evaluated machine were hidden.

2. Aim of the research

The aim of the research was to assess the causes of premature damage of working elements of a wood machining device during the process of operation.

3. Research methodology

Two types of steel samples were prepared for the tests – rolls with a length of 2700 mm and a diameter of 16 mm. These were sampled from elements (press rolls) exploited for approx. 6 years during machine operation. In order to evaluate changes in their properties, samples from an unused (brand new) element were prepared for comparison purposes. The spent elements were removed from the machine's working/shaping system. Considering their placement, they were described as top (Top) and bottom (Bottom). The unused material was described as new (New). Due to the fact that a lubricant is used for the working system, its samples were also taken (used and new – obtained from the machine user). The prepared oil samples were marked as fresh and used oil. The name of the oil was encoded due to industrial secret. Used oil was sampled from the lubrication area of the shaping system. As a spray lubrication system is used in the machine (constant supply of fresh oil), this means that the cooperating elements are lubricated in a continuous manner with a dose of pure oil, yet only on selected work sections. Oil mist allowance and products of wear (both metallic and non-metallic) are drained through small drainage channels into used oil tanks. Before the lubricant covers this route, however, it enters the friction area, where it is contaminated with products of the technological process. In this manner, with its initial chemical composition altered, it reacts with the metallic base, having an impact on the condition of its surface.

Before commencing the tests, the steel samples were subjected to the process of machining in order to acquire the desired shapes and dimensions (especially for tensile testing). Then they were washed in acetone by means of an ultrasonic cleaner for 10 min. and air-dried. Moreover, procedures to prepare inserts for tests of chemical composition, metallographic tests, and microscope observations were carried out. After thorough mixing and degassing, the oil samples were subjected to direct testing.

The tests were divided into several stages. First, tensile testing was carried out pursuant to PN-EN ISO 6892-1 [23] with a speed of 0.05 $m \cdot s^{-1}$ over a distance of 50 mm, by means of an MTS 858 Mini Bionix universal testing machine. Tests of chemical composition and microscope observations of selected characteristic spots of steel samples and an analysis of products of wear filtered from the oil were then carried out. Tests of chemical composition were performed by means of an ARL Quantris mass spectrometer by Thermo. Microscope observations were carried out by means of a Hitachi S-3000N N scanning microscope (with an x-ray microanalysis module – EDS by THERMO NORAN, NSS type).

Tests of physiochemical properties of lubricants were the last to be carried out. They were divided into tests of viscosity and tests lubricating properties. Viscosity tests were performed by means of a RheoStress 6000 rheometer by Thermo HAAKE. Tests of lubricating properties were carried out on a four-ball machine pursuant to the methodology laid down in PN-76/C-04147 [24].

4. Research results

Fig. 2 compiles selected results of tensile testing. The performed analysis showed that unused material is characterized by the best mechanical properties, which seems obvious. As far as samples taken from exploited materials are concerned, it can be noted that the tested properties are arranged in a certain order. Samples taken from the top drive are characterized by slightly reduced parameters of mechanical properties than samples from the bottom drive, both batches having worse mechanical characteristics than the new sample. This state is probably the result of the process of exploitation and the accompanying factors. Information obtained from the machine's user shows that the temperature of the working area of the machine is approx. 270°C. Considering the friction resistances (occurring in the system between the cooperating elements) and the conditions of externally-applied parameters, significant local temperature fluctuations may occur, by as much as several tens degrees Celsius (and in the special cases of the so-called flash temperature, even up to 1000°C).

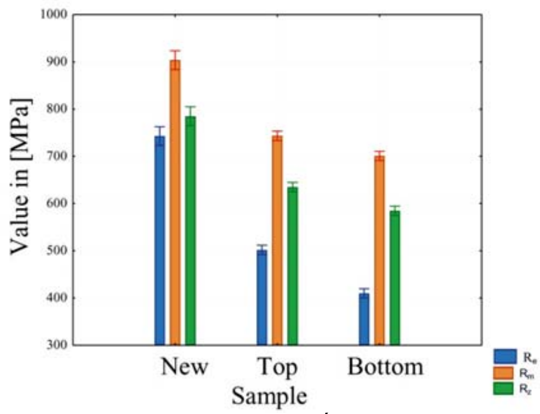

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Fig. 2. Statistical analysis of the obtained results of tensile testing

Rys. 2. Statystyczna obróbka uzyskanych wyników badań próby rozciągania

The result of this is that conditions beneficial for the process of material drainage appear, similarly to classic heat treatment processes. This in turn leads to a reduction of hardness and other mechanical properties of the material. Obviously, this is not a rule and does not apply to all steels, but can be expected in the case of traditional steel materials.

In order to verify the above assertions, measurements of hardness and microhardness of samples were carried out using a single specific method in order to make a direct comparison of their levels (without the need to use conversion or scale comparison). The measurements were carried out on the cylindrical surface and the facing surface of the samples (over a cross-section), and repeated three times (fig. 3). The results of hardness measurement do not confirm the thesis, i.e. operating conditions of the elements do not have a significant influence on the reduction in hardness of the material. A slight reduction in hardness can be noted on the cylindrical surface of the exploited elements in relation to the new sample (fig. 3a), a significant or rapid reduction in hardness not occurring here.

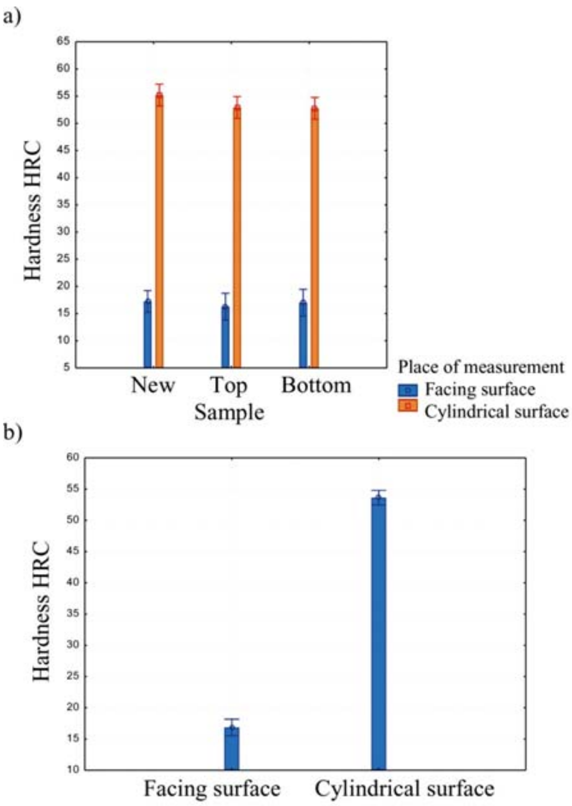

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Fig. 3. Hardness measurement results: a) comparison of hardness of tested samples, b) comparison of hardness on facing and cylindrical surfaces for all the tested samples
Rys. 3. Wyniki pomiaru twardości: a) porównanie twardości badanych próbek, b) porównanie twardości na powierzchni czołowej i walcowej dla wszystkich badanych próbek

Coming back to mechanical tests and considering the results of hardness measurements, it can be surmised that the state of mechanical properties of exploited materials may be the result of a "redesign" of the internal structure, or the crystallographic network, e.g. arrangement/ orientation and accumulation of dislocations, caused by strong cyclic mechanical impacts (rolling under Hertzian contact stress). Orientation and accumulation of dislocations may lead to the appearance of local "holes and notches", reducing the mechanical properties of the material (this issue, however, was not analysed). At the same time, (wholly different) cyclic Hertzian contact stress impacts have a positive effect on hardening of the surface of elements due to the phenomenon of material strengthening during the exploitation process. An additional factor includes heat treatment of brand new materials. Fig. 4 illustrates a selected macrophotograph of a structure with a clearly defined surface layer (New sample). It can be only assumed that during the technological process the samples were subjected to heat treatment, e.g. surface hardening.

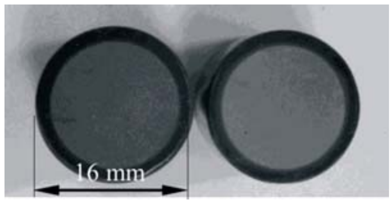

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Fig. 4. A cross section of samples after etching (new sample)
Rys. 4. Widok przekroju poprzecznego próbek po trawieniu (próbka nowa)

Owing to this, an increased abrasive wear resistance of the material. In this context it can be stated that significant differences in hardness measurements on the cylindrical surface and over a cross-section of the sample below the surface layer were noted. It turns out that the surface layer is characterized by hardness similar to tool steel, whereas the core of the material is ductile and soft (which also corresponds to surface hardening). The results shown in fig. 5 indicate a change in microhardness of the cylindrical surface and its subsurface areas for the operated elements in comparison with the new sample. Due to heat treatment, it is understandable that the surface layer of rolls is characterized by greater hardness than the core of the material. One puzzling fact is that greater microhardness of the surface layer was obtained for after-exploitation samples in comparison with the new sample. It is probable that the increase in microhardness of the material is caused by the aforementioned strengthening phenomenon.

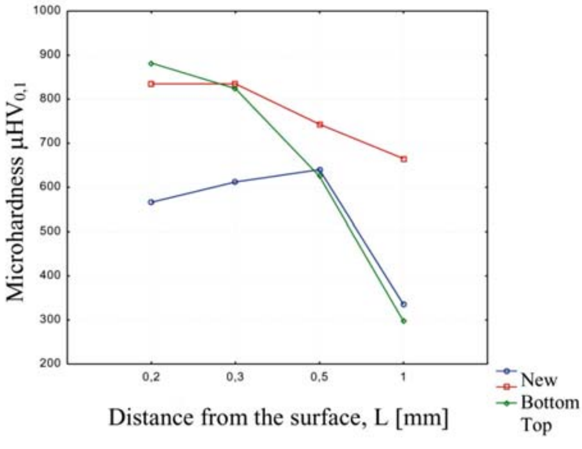

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Fig. 5. Results of microhardness measurements in transverse microsections
Rys. 5. Wyniki pomiarów mikrotwardości na zgładach poprzecznych

Fig. 6 shows a photograph of a transverse microsection of a selected steel sample with marked points of microhardness measurement. The photograph also shows a clear difference in the structure of the surface layer and the core of the material.

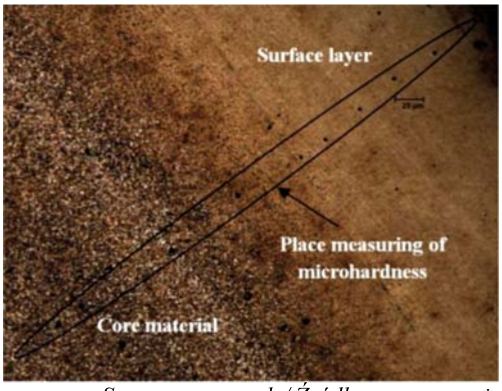

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Fig. 6. Microphotograph of a transverse microsection of a selected steel sample with marked area of microhardness measurement

Rys. 6. Makrofotografia zgładu poprzecznego wybranej próbki stalowej z zaznaczonym obszarem pomiaru mikrotwardości

Table 1 compiles the results of tests of chemical composition for the tested samples. In the case of top and bottom elements, eight samples were taken for the tests. The table shows the results for the new sample and the compositions of samples (top and bottom) for which maximum and minimum carbon contents were obtained.

Table 1. Results of tests of chemical composition

Tab. 1. Wyniki badań składu chemicznego

Element, [% mass] Sample	C	Mn	Si	P	S	Ni	Cr	Cu	Al	Sn	Ca
New	**0.63**	**0.49**	**0.24**	**0.002**	**0.013**	**0.18**	**0.1**	**0.05**	**0.015**	**0.003**	**0.002**
Top	0.67	0.47	0.26	0.002	0.023	0.12	0.11	0.012	0.032	0.001	0.002
Bottom	0.59	0.48	0.26	0.002	0.015	0.16	0.14	0.012	0.019	0.0009	0.0008
Average	**0.63**	**0.475**	**0.26**	**0.002**	**0.019**	**0.14**	**0.12**	**0.012**	**0.025**	**0.00095**	**0.0014**
Bottom	0.66	0.48	0.30	0.002	0.012	0.19	0.20	0.09	0.017	0.008	0.0015
Bottom	0.63	0.47	0.28	0.002	0.016	0.16	0.13	0.014	0.018	0.001	0.001
Average	**0.64**	**0.475**	**0.29**	**0.002**	**0.014**	**0.17**	**0.16**	**0.05**	**0.017**	**0.0045**	**0.0012**
C60 EN10279-1	**0.57-0.65**	**0.60-0.90**	**max. 0.40**	**max. 0.045**	**max. 0.045**	-	-	-	-	-	-

Source: own work / Źródło: opracowanie własne

Tests of chemical composition indicate its very high similarity in all the analysed cases, with slight discrepancies. Small differences in the contents of Cu, Al, Sn, and Ca admixtures between the Top, Bottom, and New samples can be observed. Data analysis shows a high degree of chemical composition similarity to steel (C60). However, considering the obtained discrepancies, these differences can be treated as diversity in chemical composition on the one hand, remembering about measurement errors and possible local discrepancies of the chemical composition on the other. As is known, even analysis of the same spot can yield slightly different results. As mentioned before, data analysis indicates a high degree of similarity of chemical composition to grade 60 steel (C60). This composition, however, does not fully match the normative composition of C60 steel. It can be supposed that the analysed material is consisted of steel prepared especially for constructing elements of this type. Yet its composition is close to the composition of C60 steel. Considering the recommendations of the machine's manufacturer on the grade of steel, it has to be remembered that using a theoretically identical material is in fact tantamount to using a substitute, which may in turn result in a reduction of durability and reliability of the exploited machine.

Fig. 7 shows the results of tests performed by means of a four-ball machine. The graph shown in fig. 7b illustrates the relationship between diameters of defects that appear on the surfaces of the balls of the machine, load, and the used lubricant. The appearance of an example friction trace on the surface of the ball is illustrated in fig. 7a. The data shown in fig. 7b apply to the determination of the maximum non-seizure point (P_n), seizure point (P_t), and weld point (P_z). A comparison of these values for the tested oil samples leads to the conclusion that the highest value of weld point was obtained for used oil (P_z= 250 kG), which unexpectedly indicates its better lubricating properties at high loads. Greater loads are needed for the cooperating surfaces in order to weld in the case of used oil in comparison with fresh oil. For fresh oil the obtained value was P_z= 200 kG. The values of P_n and P_t were the same for both substances – P_n= 80 kG, P_t= 100 kG. It is only worth adding that despite the values of P_n and P_t being the same, shorter diameters of wear defects were obtained for used oil, both in the case of P_n and P_t (fig. 7b).

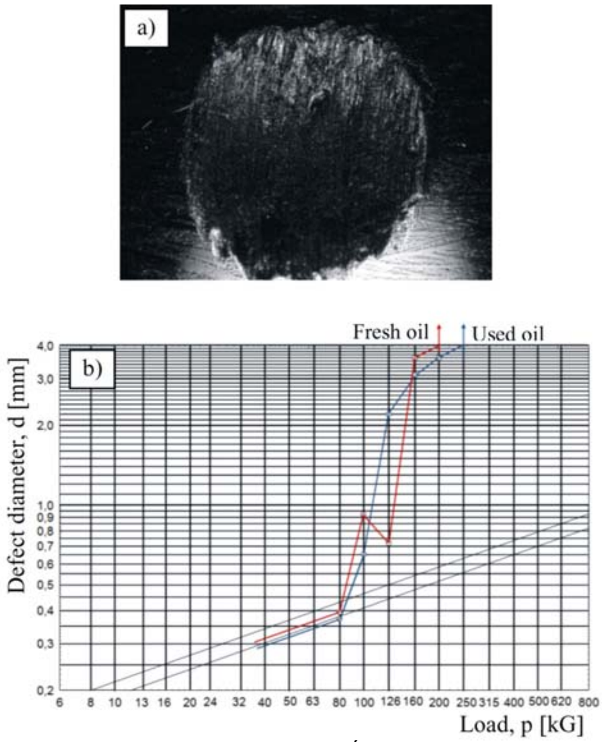

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Fig. 7. Test results obtained by means of a four-ball machine: a) friction trace on the surface of a ball from the four-ball machine (fresh oil, load 126 [kg], magn. x 50, b) graph of defect diameter-load relationship, for oil samples; P_n- maximum non-seizure point, P_t- seizure point, P_z- weld point

Rys. 7. Wyniki badań uzyskane za pomocą aparatu czterokulowego dla otrzymanych próbek oleju: a) ślad tarcia na powierzchni kulki z aparatu czterokulowego (olej świeży, obciążenie 126 [kg], pow. x 50, b) wykres zależności średnica skazy – obciążenie, dla próbek olejów; P_n- największe obciążenie niezacierające, P_t- obciążenie zatarcia, P_z- obciążenie zespawania

Although both used and fresh oil are characterized by the highest non-seizure point at a level of P_n= 80 kG, in the case of used oil, the cooperating elements wear less intensively.

The case is similar for seizure point. In the case of seizure of cooperating surfaces, used oil protects friction nodes against wear better than fresh oil. This may be caused by the oil being densified by products of wear, mainly wood fibres (polymer fibres), which may act as a lubricating additive, and by an increase in viscosity due to oil densification. As is commonly known, polymer additives are wildly used in lubricating oils on purpose as anti-friction and anti-wear compounds. This may be the reason for the unexpected situation as far as the tested lubricants are concerned. This effect prompted a more detailed analysis of the obtained oil samples. For this reason tests of viscosity of lubricants and a microscope analysis of products of wear filtered from used oil were performed. Fig. 8 below shows the results of viscosity measurements.

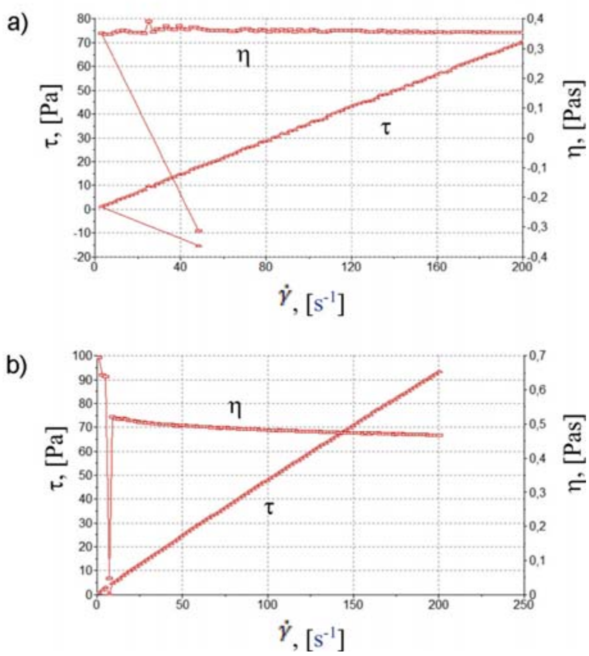

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Fig. 8. Results of viscosity measurements: a) fresh oil, b) used oil: η- dynamic viscosity, τ- shear stress, γ - shear speed

Rys. 8. Wyniki pomiaru lepkości: a) olej świeży, b) olej przepracowany: η- lepkość dynamiczna, τ- naprężenie ścinające, γ- prędkość ścinania

Tests of viscosity were carried out for 5 min. in a temperature of 30°C, at increasing shear speeds. The obtained viscosity measurement results confirm the higher viscosity of used oil - approx. 470 mPas after stabilizing. For fresh oil, the obtained value of dynamic viscosity was approx. 350 mPas. This may be confirmed by oil enrichment with polymer fibres (obtained from the technological process), which increase its viscosity and act as an additive. Fig. 9 contains an example photograph from the scanning microscope showing the filtered leftovers from used oil. The photo (fig. 9) shows irregularly arranged and agglutinated products in the form of fibres. In order to identify these products, tests of their chemical composition were performed in spots marked 1 to 4. Table 2 shows the elemental composition of products determined by means of a scanning microscope with an x-ray microanalysis module.

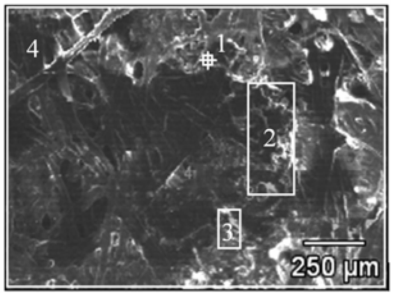

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Fig. 9. Microphotograph of filtered products of wear from used oil

Rys. 9. Mikrofotografia odfiltrowanych produktów zużycia z oleju przepracowanego

Table 2. Chemical composition of products

Tab. 2. Skład chemiczny produktów

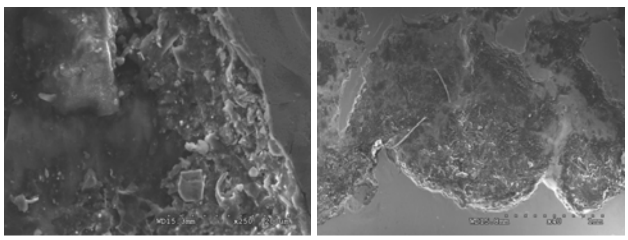
Element, [% mass] / Place of analysis	C	O	F	Al	S	Ca	Fe
Point 1	51.09	45.82	-	-	-	0.28	2.81
Point 2	58.44	39.35	-	-	-	0.15	2.05
Point 3	55.60	42.04	-	-	-	-	2.36
Point 4	94.35	-	2.83	0.06	0.32	0.10	2.33

Source: own work / Źródło: opracowanie własne

The chemical composition of products of wear indicates high contents of carbon and oxygen. In areas 1, 2 and 3 the content of carbon is approx. 50-60%, while in area 4 approx. 95%. Obviously such a high carbon content may be the result of the presence of lubricant leftovers. Areas 1, 2 and 3 contain mainly carbon and oxygen in amounts corresponding to the chemical composition of wood, which may signalize the presence of such a material. The insignificant iron content may be related to the presence of steel products.

As far as the results of physiochemical tests are concerned, it can be surmised that the machine user uses a lubricant with slightly reduced tribological characteristics, while the operating conditions in the working system of the machine may facilitate various forms of wear. Adding to this the reduced lubricant protection, ensuing effects may also be expected on the surfaces of working elements.

Tests in this area were carried out by means of a scanning microscope. Fig. 10 shows an example photograph from the surface of the cylindrical bottom sample. The presented photographs indicate fatigue wear of the adhesive-diffusive type. It should be emphasized that the aforementioned types of wear dominate on the observed surfaces. It seems that in order to reduce damage to surfaces as a result of this type of wear, the lubricant should be chosen more carefully.



a) b)

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Fig. 10. Examples of wear of the cylindrical surface of working elements: a) pitting wear, b) tearing/adhesive-diffusive pitting

Rys. 10. Przykłady zużycia powierzchni walcowej rolki: a) zużycie pittingowe, b) wyrwanie/wżery adhezyjno-dyfuzyjne

5. Conclusions

The performed tests and their analysis allowed to formulate the following general conclusions:

1. A significant diversity of mechanical properties of the tested steel samples was noted, the most beneficial mechanical properties having been observed for new material (New).
2. It is highly probable that the state of mechanical properties of the operated material is the result of the cyclic and fatigue character of the process (rolling under Hertzian contact stress), which leads to redesigning of crystallographic structures. Such course of the process may lead to "expansion" of oriented net dislocations and a reduction of mechanical properties. This phenomenon, however, was not studied, which would have required further more in-depth analyses.
3. An increase in hardness on cylindrical surfaces was noted in exploited samples, in comparison with the new sample. This may be the result of hardening of the material during the exploitation process of working elements.
4. An analysis of the chemical composition of samples taken from new material and exploited rolls indicates a similarity of composition to C60 steel. Certain discrepancies were observed as far as normative content was concerned.
5. Tests of lubricating properties of oil samples on a four-ball machine indicate unexpectedly beneficial lubricating characteristics of used oil in comparison with fresh oil. This is probably caused by the presence of polymer fibre type products (from the technological process) in used oil. Enriching the oil with products of wear results in an increase of its viscosity and may have a significant impact on its anti-friction and anti-wear protection, yet this may have an adverse effect on its other functions, e.g. moistening
6. Various forms of tribological wear were observed in microscope tests. The dominant types of wear are pitting type and adhesive-diffusive wear. The factors determining such a form of wear are relative stresses and speeds of the cooperating elements, which lead to cold and hot connections – type I and II couplings and cyclic, fatigue and dewedging action of oil.
7. All the performed tests and their analysis (including the analysis of operating conditions) indicate a significant impact of possible substitutes, oil and roll materials on durability and reliability of cooperating machine elements. Substitutes, in this particular case, are mainly materials used for working elements of kinematic nodes of the machine and lubricants.

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