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THE INFLUENCE OF THE FRICTION PAIR LOAD ON TRIBOLOGICAL CHARACTERISTICS OF POLYMER COMPOSITES IN RECIPROCATING MOTION

WPŁYW OBCIĄŻENIA WĘZŁA TARCIA NA CHARAKTERYSTYKI TRIBOLOGICZNE KOMPOZYTÓW POLIMEROWYCH W RUCHU POSTĘPOWO-ZWROTNYM

Key words:

machine tools, guides, polymer composite, reciprocating motion, friction, wear, scanning electron microscopy

Słowa kluczowe:

obrabiarki, układy prowadnicowe, kompozyt polimerowy, ruch postępowo-zwrotny, tarcie, zużycie, skaningowa mikroskopia elektronowa (SEM)

Abstract

This paper presents the influence of the friction pair load on the wear and friction coefficient of polymer composites in reciprocating motion. The tested polymer composites are used in regeneration purposes of supports in cutting

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tools. Tribological characteristics were evaluated for composites modified with graphite and molybdenum disulphide as the additives (modifiers). The tests were performed by the use of T-17 tribotester under conditions of various loads (100, 150, 200 N), with a frequency of 1 Hz, and the 20 000 cycles of 25 mm amplitude. The friction pairs were lubricated with standard machine oil. For comparison purposes, the tribological characteristics of steel-steel configuration were performed. The mechanism of friction pair wear was evaluated by the analysis with scanning electron microscopy (SEM). The results have shown that the increase in the load of friction pair affects the friction coefficient only restrainedly. The polymer regeneration composites designed for flat guide rails in cutting machines proved to be more useful and resistant than the steel-steel combination.

INTRODUCTION

Cutting tools for metal processing are basic machine production equipment. Both economic and ecological aspects limit the production of new units. Constant modernization and amendments of cutting tools and machines bring numerous benefits, especially in reasonable maintenance costs as well as better customization of the unit to the actual process conditions. The innovative character of the company as well as its rapid development was previously a result of the purchase of up-to-date units. Now the same benefits may be obtained through regeneration and refurbishing of used units, called retrofitting. The majority of modifications cover the modern solutions in tool positioning systems. The present market share of refurbished cutting tools and machines is about 20 – 25% [**L. 1**].

The cutting tool as a complex unit does not age and wear evenly. Large and massive bodies of the machines became more stable in terms of dimensions and shape. Thus, the breaking up of these components is not reasonable. The most effective approaches are refurbishing and modernization. Information provided by manufacturers have shown the decrease in the worldwide production of new units and the simultaneous increase in modernization and re-use of older ones. The essential part of this process is associated with both the new control systems but also the regeneration of guide rails, which normally exposed to considerable loads. The tribological wear of these rails increases in time and changes the movement of cutting tool. That leads to decreased accuracy of the whole machine [**L. 2–5**].

The regeneration of the guide rails may be performed by the use of metal-polymer composite of defined composition and properties. The optimal addition of powder and fibrous fillers as well as lubricating additives provides beneficial tribological characteristics, limitation, or even elimination of stick-slip phenomenon, with an increase in mechanical resistance and a decrease of the static friction coefficient [**L. 6–8**].

The aim of this paper was to examine the influence of various loads of the friction pair on its wear and the change in the friction coefficient of polymer regeneration composites under reciprocating movement.

MATERIALS AND METHODS

The metal-polymer composites to be tested were composed of chemically cured epoxy resin (100 parts by weight), iron (Fe) powder of defined structure (250 parts by weight), polyaramide fibres (1 part by weight), and solid lubricants – graphite and molybdenum disulphide (separately or in a mixture). The lubricating additives expose chemical volume, and they do not affect hardening of the composite and are properly wetted by liquid polymer base. Based on mechanical properties, static friction coefficient and static-dynamic friction characteristics (stick-slip effect) [**L. 7**], the composites of 10 and 20 parts by weight of solid lubricants were chosen for the tests in reciprocating movement (**Table 1**).

Table 1. The mass share of low-friction additives in the composites
Tabela 1. Udział wagowy dodatków niskotarciowych w podstawowym składzie kompozytów

Low-friction additive					
Graphite		Molybdenum disulphide		Graphite + molybdenum disulphide	
The mass share of additives for 100 parts by weight of epoxy base					
10	20	10	20	10	20
Sample ID					
G-10	G-20	M-10	M-20	GM-10	GM-20

Dispersion of fibrous and powder fillers in the liquid epoxy base was carried out in a low-speed laboratory mixer, providing high cutting forces between the compounds. For cross-linking purposes, the aliphatic polyamine (triethylenetetramine) was in 12 parts per weight. The cross-linking process occurred at room temperature.

METHODOLOGY OF TRIBOLOGICAL TESTS

The friction-wear characteristics of polymer regeneration composites in reciprocating motion were specified by the use of a T-17 tribotester (**Fig. 1**).

The major part of the mentioned tribotester is a friction pair (**Fig. 1b**) composed of a stationary steel mandrel that is pressed with the force F to the plate covered with the composite to be tested. The plate containing the tested composite performs reciprocating motion with a defined amplitude and frequency.

Each test plate was prepared by covering with composite and its subsequent curing and grinding to fit the tribotester. T-17 is equipped with a computer system for data acquisition. The evaluation of resistance to wear of the polymer regeneration composites was carried out based on linear wear observed in the friction pair.

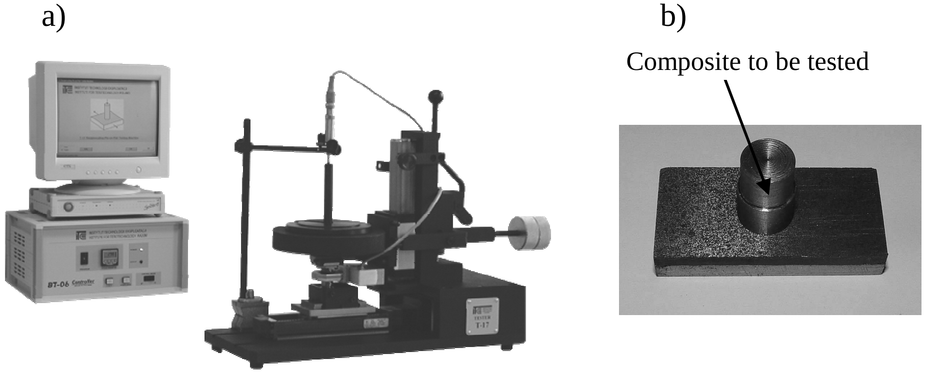

Fig. 1. The view of T-17 tribotester (a) and tribosystem (b)
Rys. 1. Widok testera tribologicznego T-17 (a) i skojarzenia badawczego (b)

The methodology of tribological tests can be summarized as follows: interaction between steel plate (size: 36 × 17 mm) containing metal-organic composite to be tested (layer of 2 mm in thickness), with the steel mandrel (ϕ 9 mm, hardness 30–40 HRC). The measurements were performed under the following conditions: sliding, reciprocating motion, constant load, amplitude of 25 mm, frequency 1 Hz, number of cycles: 20 000, and lubrication with machine oil AN 46. The tests were carried out under different loads: 100, 150 and 200 N, which are typical for the guiding systems of cutting tools. During each test, the following parameters were acquired: friction force, temperature of the friction pair, cycle number, and linear wear of the friction pair. As a reference, the characteristics of the steel–steel tribosystem were investigated under similar conditions.

Due to the impossibility of precise assessment of the friction coefficient during the test, the following procedure was applied to evaluate this parameter: test duration 300 s, number of cycles 300, sampling frequency 10 Hz, and no average filters. The friction coefficient was calculated by multiplying momentary values of friction force and the load. The minimum and maximum values were included. The result was the average of absolute values of the momentary friction coefficient.

METHODOLOGY OF SEM ANALYSES

To evaluate the condition of composite surfaces, a Hitachi S 2460N scanning electron microscope was applied. The unit allows for operation under low vacuum conditions. The energy dispersion detector (EDS) by Noran was coupled with the microscope and equipped with Norvar window and SiLi crystal of 133 eV resolution. The following exposure parameters were applied: accelerating voltage 15 kV, high vacuum, SE detector, and a magnification of 50×.

RESULTS

Figures 2–5 show the exemplary tribological characteristics of combinations steel-composite and steel-steel under a load of 150 N.

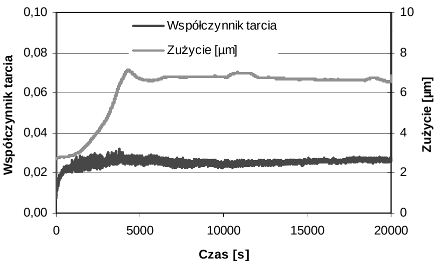

Fig. 2. The changes of friction coefficient and wear for the system G-20 composite – steel, friction pair load 150 N

Rys. 2. Przebieg zmian współczynnika tarcia i zużycia skojarzenia kompozyt G-20 – stal, obciążenie węzła 150 N

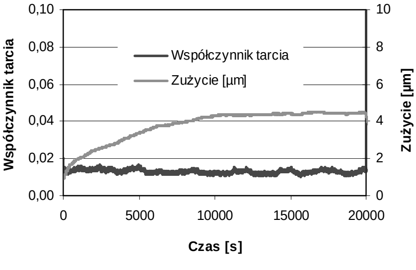

Fig. 3. The changes of friction coefficient and wear for the system M-20 composite – steel, friction pair load 150 N

Rys. 3. Przebieg zmian współczynnika tarcia i zużycia skojarzenia kompozyt M-20-stal, obciążenie węzła 150 N

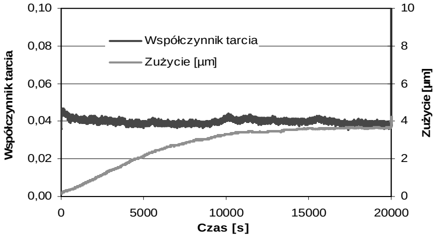

Fig. 4. The changes of friction coefficient and wear for the system GM-20 composite – steel, friction pair load 150 N

Rys. 4. Przebieg zmian współczynnika tarcia i zużycia skojarzenia kompozyt GM-20 – stal, obciążenie węzła 150 N

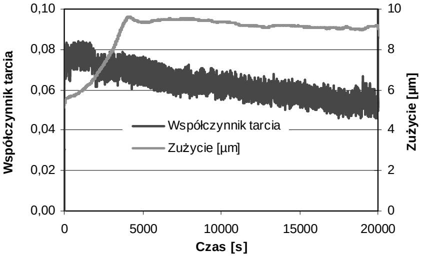

Fig. 5. The changes of friction coefficient and wear for the system steel – steel, friction pair load 150 N

Rys. 5. Przebieg zmian współczynnika tarcia i zużycia skojarzenia kompozyt stal – stal, obciążenie węzła 150 N

The friction characteristics obtained for the tested composite–steel tribosystems revealed stable and minimal changes of friction coefficient. In contrast, the steel–steel tribosystems show no stability and considerable alteration of the friction coefficient during the test.

Figures 6–11 show the average linear wear of tested systems (composite–steel, steel–steel) and the friction coefficient. The results were obtained for different loads of friction pairs.

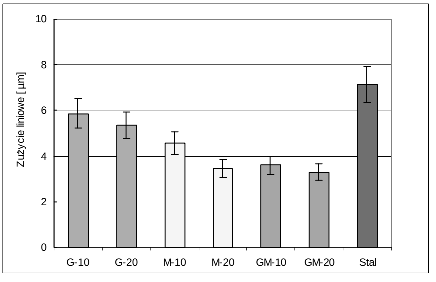

Fig. 6. The linear wear of tested materials, friction pair load 100 N

Rys. 6. Zużycie liniowe badanych materiałów, obciążenie 100 N

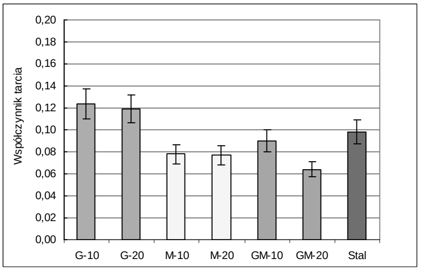

Fig. 7. The friction coefficient of tested materials, friction pair load 100 N

Rys. 7. Współczynnik tarcia badanych materiałów, obciążenie 100 N

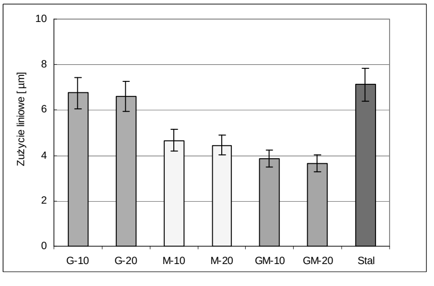

Fig. 8. The linear wear of tested materials, friction pair load 150 N

Rys. 8. Zużycie liniowe badanych materiałów, obciążenie 150 N

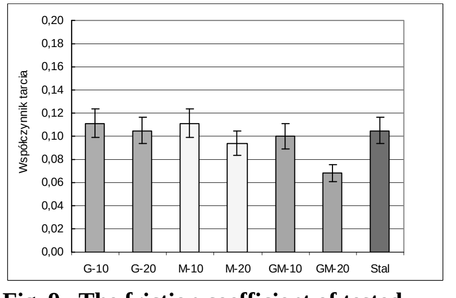

Fig. 9. The friction coefficient of tested materials, friction pair load 150 N

Rys. 9. Współczynnik tarcia badanych materiałów, obciążenie 150 N

Based on the obtained test results, it was concluded that the 50% and 100% increase in load of friction pair does not affect the relation with the final linear wear of the tested friction pair. Composites containing inorganic, laminar lubricant additive (molybdenum sulphide) separately or combined with graphite exhibit increased resistance to wear in comparison to those containing only graphite (**Figs. 6, 8, 10**). For each applied load (100, 150 and 200 N), less wear is observed in composite–steel tribosystems rather than steel-steel. The composites containing mixed additives exhibit high resistance to wear, and the greater content thereof (GM-20) the greater is the resulting resistance of the composite. Their combinations with steel in the friction pair show about half the linear wear than with the composites containing only graphite as well as the steel-steel systems. Doubling the load of the friction pair does not cause a considerable increase in the wear. Similarly to the tests conducted under 100 and 150 N, the stabilization of wear under 200 N for this composite occurs in the middle of the test run.

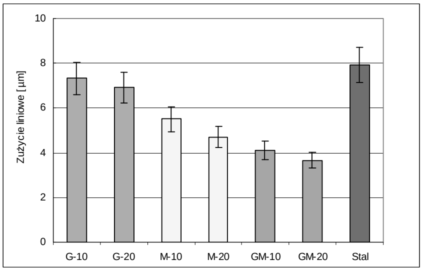

Fig. 10. The linear wear of tested materials, friction pair load 200 N

Rys. 10. Zużycie liniowe badanych materiałów, obciążenie 200 N

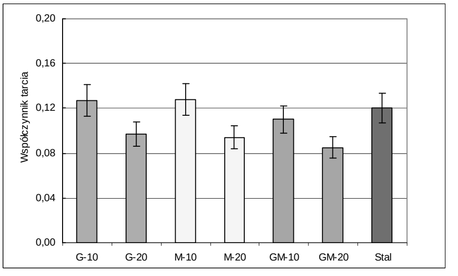

Fig. 11. The friction coefficient of tested materials, friction pair load 200 N

Rys. 11. Współczynnik tarcia badanych materiałów, obciążenie 200 N

Considering the influence of the friction pair load on the friction coefficient (**Figs. 8, 10, 12**), some tribosystems revealed an increase in this parameter accordingly to the load. As far as the load of 200 N is concerned, the composites containing 20 parts by weight of solid lubricants (separately or together) revealed the 20–30% decrease in resistance to motion in comparison to those with 10 parts by weight. The results have shown that the changes of friction coefficient are more vulnerable to the content of the lubricant rather than its chemical composition. **Figures 6–11** present the tribological characteristics of tested tribosystems and revealed the most beneficial effects of simultaneous use of molybdenum sulphide and graphite.

MICROSTRUCTURE OF THE COMPOSITES

The surface morphology of composites after each tribological test run was evaluated via SEM analysis. **Figure 12** depicts the surface of test plates (with composites) and the control plate (steel) after friction tests. The right-handed area of each image features the result of friction, whereas the rest of the sample is unaffected.

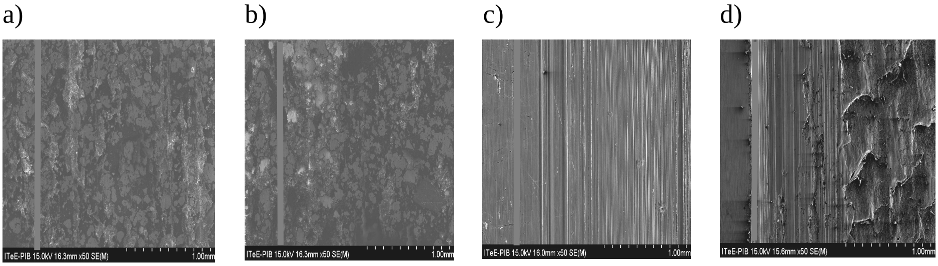

Fig. 12. SEM images of GM-20 composite after test run under the load of (a) 100 N and (b) 200 N and the control steel plate, tested in the same conditions (c and d, respectively)

Rys. 12. Obraz powierzchni płytki z warstwą kompozytu GM-20 po badaniach tribologicznych: a) obciążenie 100 N, b) obciążenie 200 N oraz płytki stalowej, c) obciążenie 100 N, d) obciążenie 200 N

There are no visible wear symptoms of metal-polymer composites. There are no significant differences between the left and right sides of the images. The load of the friction pair does not affect the surface appearance of the composites. Test plates covered with the composites designed for regeneration of guide rails of cutting tools is relatively smooth, with no visible symptoms of wear, ruptures, or scratches. The composite containing the mixture of molybdenum sulphide and graphite (GM-20) revealed no considerable differences between wear effects of 100 and 200 N (**Figs. 13a** and **b**), which confirms their similar anti-wear properties. Moreover, the SEM images revealed orderly arrangement of components in polymer matrix, which proves the appropriate dispersion of fillers and may contribute to the beneficial tribological characteristics. The steel-steel tribosystems are more susceptible to wear, which is clearly visible in **Figures 13c** and **d**. There is also a considerable difference between the effects of 100 and 200 N loads. The tribosystem loaded with 100 N revealed several scratches that may be a result of abrasion. Doubling the load (200 N) causes substantial change in the wear mechanism, where adhesion dominates. However, SEM analyses do not clearly identify the wear mechanisms occurring in composite tribosystems. However, it may be assumed that the presence of solid lubricants in the composite results in their transfer to the friction area and, therefore, in the mitigation of the wear effects of the contacting materials.

CONCLUSIONS

The major purpose of the developed metal-polymer composites is the regeneration of the guiding systems of cutting tools. On the basis of obtained test results, it was concluded that there is no significant influence of the load on both wear and resistance to motion. The wear of composite-steel tribosystems was considerably lower in comparison to the steel–steel setup. Additionally, for most composites, the resistance to motion was mitigated. The metal-polymer composites may be applied in a large variety of cutting tools in terms of their construction and support weight. Operational tests were conducted in a cutting tool, in which a 1-tonne support was subjected to regeneration with the above-mentioned composites. The cutting tool lifecycle may be considerably extended by using the regeneration of its crucial parts as guiding rails and supports in most cases.

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Streszczenie

W artykule przedstawiono wpływ obciążenia węzła tarcia na zużycie i współczynnik tarcia kompozytów polimerowych w ruchu postępowo--zwrotnym stosowanych do regeneracji suportów obrabiarek skrawających. Charakterystyki tribologiczne wyznaczono dla kompozytów z udziałem modyfikatorów tarcia grafitu i dwusiarczku molibdenu w układzie pojedynczym i binarnym. Badania przeprowadzono z użyciem testera T–17. Testy tribologiczne przeprowadzono w warunkach zmiennych obciążeń węzła tarcia 100, 150 i 200 N, typowych dla układów prowadnicowych obrabiarek, częstotliwość 1 Hz, amplituda 25 mm, liczba cykli 20 000, przy smarowaniu olejem maszynowym. Dla porównania w tych samych warunkach wyznaczono również charakterystyki tribologiczne skojarzenia stal–stal. Mechanizm zużywania pary trącej oceniono na podstawie obrazów powierzchni tarcia uzyskanych za pomocą

skaningowego mikroskopu elektronowego (SEM). Na podstawie uzyskanych wyników badań tribologicznych stwierdzono, że zwiększenie obciążenia węzła tarcia w umiarkowanym stopniu wpływa na zmiany współczynnika tarcia i zużycie kompozytów polimerowych. Polimerowe kompozyty regeneracyjne przeznaczone do regeneracji płaskich prowadnic obrabiarek skrawających w przyjętych warunkach badań charakteryzują się lepszymi właściwościami tribologicznymi niż skojarzenie stal–stal.