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COMPOSITES

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TRIBOLOGICAL WEAR OF METAL-POLYMER COMPOSITES IN THE PRESENCE OF ABRASIVES

During the operation of certain machines and equipment, like technological lines for the transportation of flue dust to landfill, mining equipment or road and agricultural machines, a specific type of intensive usage, called abrasive wear, takes place. The microcutting phenomenon of the surface layers of both partners of friction with hard particles of chemical compositions with different grain shape and properties, is another phenomenon that occurs at the time of abrasive wear. This requires the usage of hard materials, such as high-quality alloyed and carbon steel as well as heat and thermo-chemical treatment. The occurrence of the abrasive wear phenomenon of cooperating elements is unavoidable despite the application of the above-stated operations. The application of a chemically-hardened metal-polymer composite on the surface layer of elements, may be a good way to reduce costs, increase the durability of the used elements and simplify the method of element regeneration. When applied in the used element, the metal-polymer composite of specified composition and characteristics, which is able to create a surface layer with greater resistance to erosion, increases abrasive wear resistance in an abrasive environment.

The article presents the results of the abrasive wear resistance of chemically-hardened metal-polymer regenerative composites and a classic steel-bearing alloy construction joint. Amine compounds with different chemical structure and reactivity (such as triethylenetetramine, poliaminoamide and a reaction product between phenol-formaldehyde and secondary amine), were adopted as cross-linking agents. These cross-linking agents made it possible to obtain composites of very different mechanical properties. Cenospheres from flue dust, electrocorundum and silica of defined chemical and granulometric composition were adopted as abrasive material. Chemically-hardened metal-polymer composites were imposed on a steel roller, and machined to the desired size to cooperate with traditional construction materials, such as steel and bronze. The friction and wear tests were performed in conformal contact using a T-07 block-on-ring tester in the presence of the selected abrasive material. Tribological tests were conducted at a speed of 0.1 m/s and 1 MPa pressure, without the usage of any lubricant. High resistance to abrasive wear of the metal-polymer composites was proved, which means they can be used for the regeneration of machine elements that work in an abrasive environment.

Keywords: metal-polymer composite, regeneration, tribological characteristic, abrasive wear

ZUŻYCIE TRIBOLOGICZNE KOMPOZYTÓW METALOPOLIMEROWYCH W OBECNOŚCI MATERIAŁÓW ŚCIERNYCH

Przedstawiono wyniki badań odporności na zużycie ścierne regeneracyjnych chemoutwardzalnych kompozytów metalopolimerowych oraz klasycznego skojarzenia konstrukcyjnego stal - stop łożyskowy. Środkami sieciującymi kompozytów były związki aminowe o zróżnicowanej budowie chemicznej i reaktywności (trietylenotetraamina, poliaminoamid oraz produkt reakcji fenolu formaldehydu i drugorzędowej aminy), które umożliwiły uzyskanie kompozytów o bardzo zróżnicowanych właściwościach mechanicznych. Jako materiały ścierny zastosowano mikrosfery, stanowiące główny składnik pyłów dymnicowych, elektrokorund oraz krzemionkę o określonym składzie chemicznym i granulometrycznym. Kompozyty chemoutwardzalne nałożone na stalową rolkę i obrobione mechanicznie na żądany wymiar współpracowały z klasycznymi materiałami konstrukcyjnym, tj. stalą i brązem. Badania tarciowo-zużyciowe prowadzono na maszynie tribologicznej T-07 typu rolka - klocek w styku rozłożonym w obecności materiału ściernego. Testy tribologiczne prowadzono przy prędkości 0,1 m/s i naciskach 1 MPa, nie stosując przy tym środków smarnych. Wykazano, że testowane kompozyty metalopolimerowe charakteryzują się dużą odpornością na zużycie ścierne i mogą być z powodzeniem wykorzystane do regeneracji elementów maszyn pracujących w środowisku, w którym występują substancje ścierne.

Słowa kluczowe: kompozyt metalopolimerowy, charakterystyki tribologiczne, regeneracja, zużycie ścierne

INTRODUCTION

During the operation of some kinds of machines and devices, such as conveyors for the transportation of flue dust to landfills, mining equipment or road and agricultural machines, a characteristic type of intensive wear takes place. This is known as abrasive wear which results from the presence of hard particles of various liquids and compositions in the operating area. In the above listed types of devices, the use of expensive sealed or coated bearings is not justified. It is so, particularly in the case of belt conveyors for the transportation of spoil in the mining industry or some simple agricultural machines. In such cases, the phenomenon of micro-cutting of the surface layers of both partners of friction with hard particles that have different chemical composition, grain shape and properties can be observed [1-4]. The intensity of material wear is then repeatedly higher than that at the time of the occurrence of other forms of wear, i.e. adhesive, fatigue or oxidational wear [5-7]. The operation of technical devices at the time of the interaction of abrasives makes it necessary to apply suitable and usually expensive materials with high hardness obtained with the application of thermal or thermal-chemical treatment. However, in many cases, quick repair of the used elements is crucial. One of such means of repair is the application of chemically-hardened metal-polymer composites onto the surfaces. Such composites will then form a characteristic protective coating with increased resistance and will not result in excessive wear of the partner element. It is assumed that such an effect is possible to be obtained through the application of a properly shaped metal-polymer composite in which the particles of the abrasive can be adhered, which in turn guarantees resistance to non-dilatational strain (high hardness) and thermal, destruction (the result of incorporating metal powders). Exploratory research has indicated that metal-polymer, composites with lower hardness than metal, show high wear resistance in a friction combination in the presence of an abrasive [8]. The advantages of these composites are the possibility to shape their composition depending on the assumed usage and the fact that their mechanical and tribological properties depend mainly on the proportion and characteristics of their basic components: warp, fillers and functional additives, and in the case of composites on the basis of a chemically-hardened warp - a kind of chemical structure and reactivity of a cross-linking agent [9].

The aim of the work was to test the usability of metal-polymer composites as regeneration materials for the surfaces of slide bearings subject to abrasive wear resulting from the presence of cenospheres, electrocorund and silica.

SUBJECT AND METHODOLOGY

Chemically-hardened composites on the basis of Epidian-5 epoxy resin warp, and filled with iron powder (300 PBW), graphite (5 PBW) and limited polyamide fabrics (2 PBW) were the subject matter of the conducted tests. Three types of amine hardeners were used to cross-link the composites. They were:

- Triethylenetetramine: density at 20°C - 0.985 g/cm^3, amine number - 490 mg KOH/g, amount of hardener - 12 PBW in 100 PBW of resin,
- polyaminoamide: density at 20°C - 1.15÷1.20 g/cm^3, amine number - 280 mg KOH/g, amount of hardener - 50 PBW in 100 PBW of resin, viscosity at 25°C ca. 30000 mPa·s,
- TFF - product of interreaction between formaldehyde phenol and secondary polyamine: density at 20°C - 1.1 g/cm^3, amine number - 610 mg KOH/g, amount of hardener - 26 PBW in 100 PBW of resin, viscosity at 25°C ca. 10000 mPa·s.

The composites were hardened at room temperature for 7 seven days. Depending on the hardener used, the composites obtained were marked with the following symbols:

KM-1 - composite cross-linked with aliphatic amine - triethylenetetramine,

KM-2 - composite cross-linked with product of interreaction between formaldehyde phenol and secondary polyamine (TFF),

KM-3 - composite cross-linked polyaminoamide.

Table 1 presents the selected strength characteristics of the chemical hardeners of the composite materials that were the subject matter of the research.

TABLE 1. **Strength properties of tested composites**

TABELA 1. **Właściwości wytrzymałościowe badanych kompozytów**

Composite symbol	KM-1	KM-2	KM-3
Brinell hardness, MPa	260	304	121
Compression strength, MPa	97	92	79

Kinds of abrasive materials applied in tests

The cenosphere, which is the main component of smoke-box ashes created in the process of hard coal burning in power stations, was used as abrasive material applied in the tests. Figure 1 presents the images of cenosphere and the EDS spectrum determining the basic elements of the chemical composition of the cenosphere.

The cenospheres used as the abrasives have the shape of balls filled with gas - mainly carbon dioxide. As visible in the EDS spectrum, allowing one to determine the composition elements of the tested abrasive, the main components of cenospheres are silica and aluminium oxide - the visible strips characteristic for silicon, aluminum and oxygen reveal their presence. The trace amount of magnesium, potassium, calcium and iron are also visible in the X-ray spectrum.

The problem of abrasive wear is a much broader problem and it also concerns the machines and mining industry devices, where the abrasives have sharp edges, greater hardness and a chemical composition similar to that of electrorund. Figure 2 presents the image from a scanning microscope and the element composition of electrorund. On the basis of the obtained microscope picture, it is possible to state that the particles of this abrasive have a completely different shape than the abovementioned cenospheres. The grains of this material have sharp edges and their shape is irregular. The radiation spectrum shows that it is mainly aluminum oxide with trace amounts of silicon.

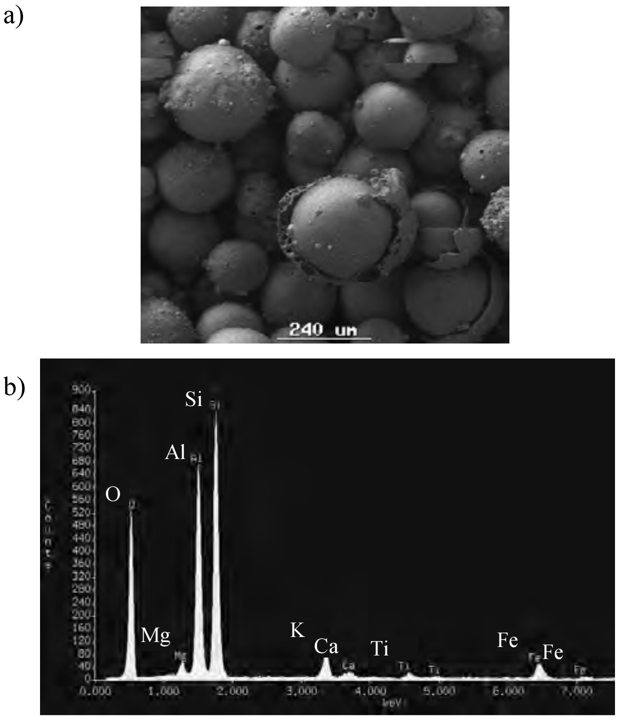

Fig. 1. SEM image of cenospheres (100x) (a); EDS spectrum of surface of cenospheres (b)

Rys. 1. Obraz mikroskopowy mikrosfer (pow. 100x) (a) i widmo EDS z powierzchni mikrosfer (b)

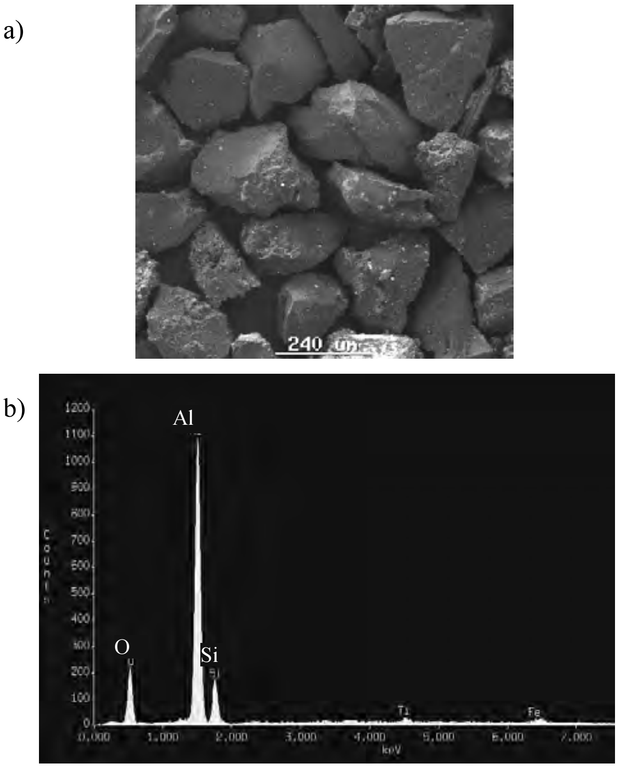

Fig. 2. SEM image of electrocorundum (100x) (a); EDS spectrum of electrocorundum surface (b)

Rys. 2. Obraz mikroskopowy elektrokorundu (pow. 100x) (a) i widmo EDS z powierzchni elektrokorundu (b)

Intensive wear can also be observed in the machines and devices used in earthworks and agriculture. The main component of the abrasive that can be found in this environment is silica, whose microscope image and EDS spectrum showing its chemical composition is presented in Figure 3.

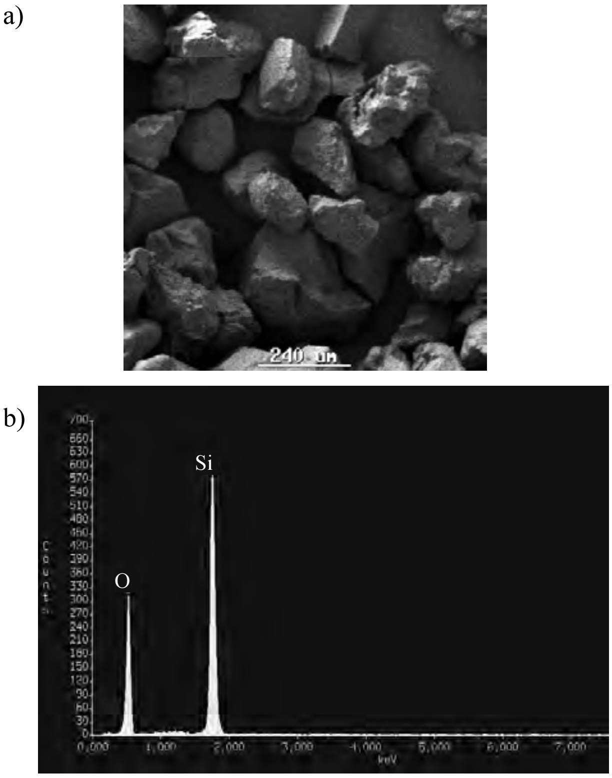

Fig. 3. SEM image of silica (100x) (a); EDS spectrum of silica surface (b)

Rys. 3. Obraz mikroskopowy krzemionki (pow. 100x) (a) i widmo EDS z powierzchni krzemionki (b)

On the basis of the obtained image, it is possible to say that the grains of this kind of abrasive have an irregular shape resembling an oval, and their edges are sharp as in the case of electrorund. The X-ray radiation spectrum indicates that it is pure silicon dioxide.

SEM-EDS TEST CONDITIONS

The changes in the chemical composition of the working surface have been determined with the use of an electron scanning microscope. An X-ray radiation microanalyzer with energy dispersion spectroscopy (EDS) was used to identify the individual elements found in the micro-image of the sample (qualitative analysis).

The following work parameters were applied at the time of the observation:

Zoom	100x
Acceleration Voltage	10 kV
Distance	15 mm
Vacuum type	high

Methodology of tribological tests

The friction-wear tests on chemically-hardened metal-polymer regeneration composites were carried out on a T-07 tribotester of the roller-block type, which is presented in Figure 4. The gravity means of feeding the abrasive from the container equipped with a dosing device, was applied.

Steel rollers coated with a hardened and mechanically processed layer of chemically-hardened composites (KM-1, KM-2, KM-3) cut to the requested dimension in the shape of blocks, counter samples made of bearing bronze, were applied in the tests. For comparison purposes, the tribological characteristics for ŁH-15 bearing steel (hardness 56÷60 HRC) - bronze (hardness 85÷88 HRB) combination were determined. For each combination, there were at least three research tracks carried out in the presence of the selected abrasives.

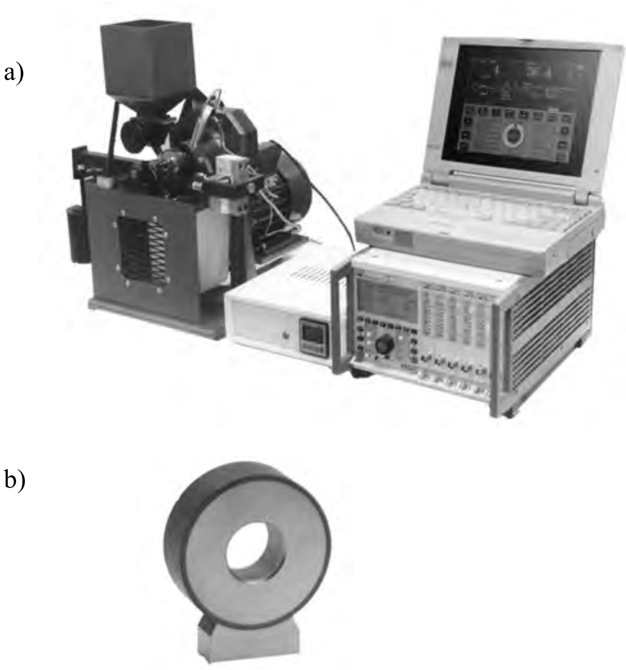

Fig. 4. Device for tribological tests: a) view of device, b) view of exemplary friction couple

Rys. 4. Urządzenie do badań tribologicznych: a) widok stanowiska badawczego, b) widok modelowego węzła tarcia

As in real operating conditions, many machines and devices work at a considerably low skid speed and low unit pressures, therefore, the following conditions for conducting friction-wear tests were adopted: contact type - distributed, average skid speed - 0.1 m/s, unit pressure p = 1 MPa, average friction path - 1000 m, volume of the abrasive - ca. 300 ml (per one research track), dry friction. During the tribological tests, the force of friction, rotary speed and mass temperature of the block were measured. The wear of the tested elements was determined on the basis of weight measurements before and after the tribological experiment.

RESEARCH RESULTS AND THEIR ANALYSIS

The results of the conducted friction-wear tests of various material combinations are presented in Figures 5 and 6.

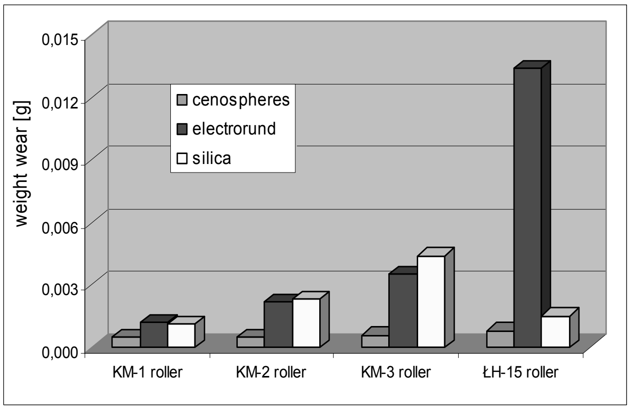

Fig. 5. Mass wear of rollers running in presence of various types of abrasives

Rys. 5. Zużycie wagowe rolek pracujących w obecności różnych rodzajów materiałów ściernych

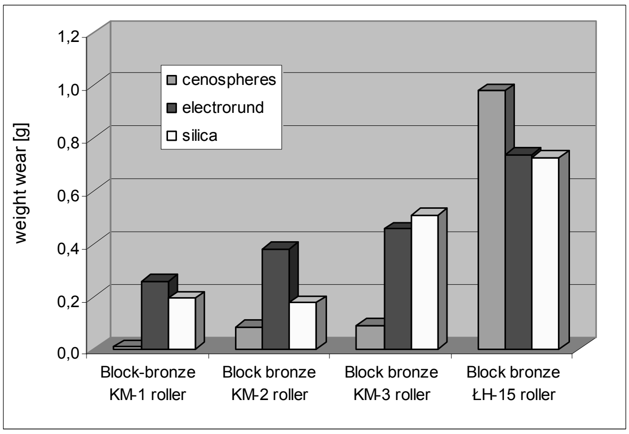

Fig. 6. Mass wear of cooperating blocks in presence of various types of abrasives

Rys. 6. Zużycie wagowe klocków współpracujących w obecności różnych materiałów ściernych

It is possible to state, on the basis of the obtained characteristics for the tested material combinations, that the weight wear of the rollers (Fig. 5) depends on the kind of chemically-hardened metal-polymer composite applied onto the surface. The lowest wear, regardless of the type of the abrasive used, was obtained for the KM-1 composite cross-linked with aliphatic amine, which, among all other regeneration composites tested, can be characterized by average hardness and the highest resistance to compression. The abrasive wear for this composite, in the presence of cenospheres and silica is comparable to the wear of the roller made of bearing steel (ŁH-15) - a material with great hardness. In the presence of electrorund, however, the wear of the steel component is several times higher than the wear of the composite materials.

The analysis of the results of the wear tests - presented in Figure 6, indicates that the lowest wear value of the counter sample in the presence of the abrasives applied, was obtained for the combination of KM-1 and bronze. The greatest wear of the block, regardless of the type of chemically-hardened regeneration composite, was observed in the presence of electrorund. It should be noted that greatest wear of the counter samples from the bearing alloys, in the presence of the applied abrasives, was observed at the time of their cooperation with the roller made of ŁH-15 bearing steel. The erosion properties of the abrasives used in the experiment cause the abrasive wear of the counter sample (block) to be, in all cases, significantly higher than the abrasive wear of the roller coated with the regeneration composite layer and the steel roller. Comparing the joint abrasive wear of the tested material combinations, it can be stated that KM-1 - bronze combinations (the combination in which the chemically-hardened composite has, out of all the composite materials tested, average hardness and greatest compression strength) has the greatest wear resistance, whereas the KM-3 - bronze combination (the combination with lowest hardness and compression strength) has, at the same time, the lowest wear resistance. The observed differences in the composites' resistance to the influence of abrasives directly results from the physico-chemical and mechanical phenomena occurring in the tribological combination, which can then be applied to the force of friction and the heat generated in the combination.

The analysis presented in Figures 7-10 of the examples of the progress of the friction force and the temperature of the model friction couple allows one to observe that the combinations in which classic structural materials - bearing steel and bronze - were applied, have the lowest resistance to motion, and in consequence, the lowest temperature of the friction couple. This results from the fact that steel has better thermal conductivity than composites with polymer warp. However, that does not correspond to the wear value of the cooperating elements, which is at least several times higher than in the case of metal-polymer composites - the bronze combination. The least advantageous course of such recorded parameters as the lack of stability and constant increase of friction force and the temperature of the friction couple were obtained for the KM-3 composite in cooperation with the block made of bearing alloy. Such a course of recorded tribological parameters adversely influenced the wear value of both the roller and the counter sample, which is significantly higher than in the case of the KM-1 and KM-2 composites, particularly in the presence of elecrorund and silica. It can be assumed that the low hardness of this composite facilitates an excessive temporary concentration of the abrasive on the surface, causing increased wear of the counter sample.

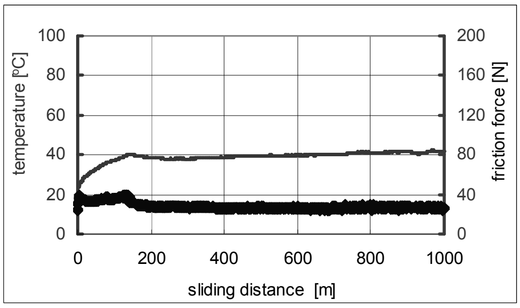

Fig. 7. Friction force and temperature of friction couple for ŁH15 steel - bronze.

Rys. 7. Przykładowy przebieg zmian siły tarcia i temperatury węzła dla skojarzenia stal ŁH-15 - brąz

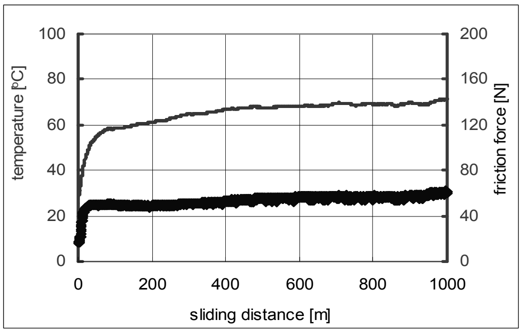

Fig. 8. Friction force and temperature of friction couple for KM-1 composite - bronze

Rys. 8. Przykładowy przebieg zmian siły tarcia i temperatury węzła dla skojarzenia kompozyt KM-1 - brąz

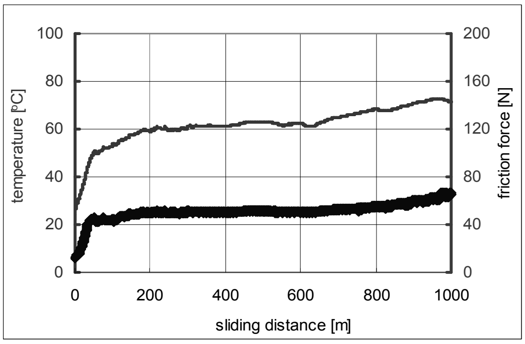

Fig. 9. Friction force and temperature of friction couple for KM-2 composite - bronze

Rys. 9. Przykładowy przebieg zmian siły tarcia i temperatury węzła dla skojarzenia kompozyt KM-2 - brąz

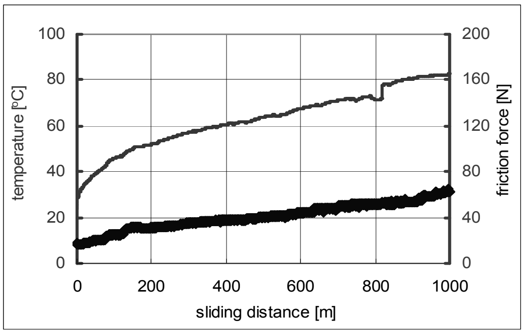

Fig. 10. Friction force and temperature of friction couple for KM-3 composite - bronze

Rys. 10. Przykładowy przebieg zmian siły tarcia i temperatury węzła dla skojarzenia kompozyt KM-3 - brąz

Using an electron scanning microscope, the assessment of the condition of the surface of the counter samples of the KM-1 composite was conducted after the tribological experiment. Figure 11 delineates the image of the surface of the roller coated with the composite layer after the friction-wear tests, and the results of X-ray microanalysis of the surface for the presence of aluminum, silicon and the oxide of elements that are the main component of the applied cenospheres. The area to the right of the line (Fig. 11a) is the surface of the composite subject to friction, whereas the area to the left is the image of the composite outside the friction area.

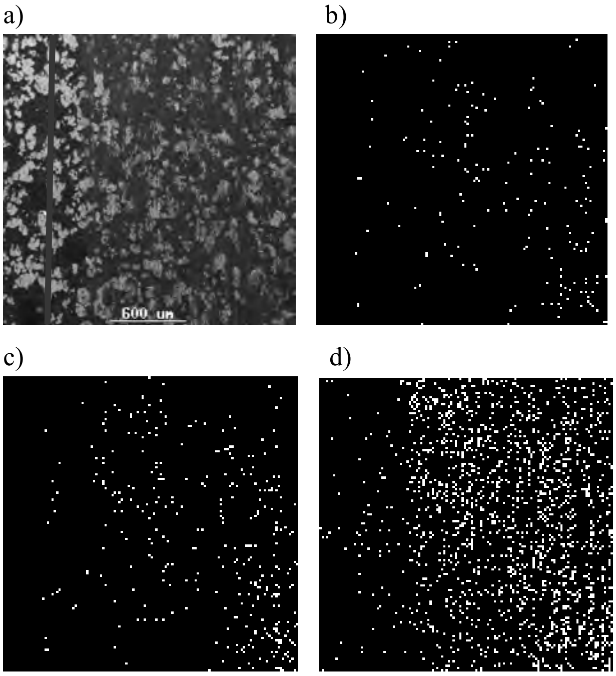

Fig. 10. SEM-EDS research results of surface of KM-1 composite after friction tests: a) microscope picture of composite, EDS signal for presence of: b) aluminum (Al), c) silicon (Si), d) oxygen (O)

Rys. 10. Wyniki badań SEM-EDS powierzchni kompozytu KM-1 po testach tarciowych: a) obraz mikroskopowy kompozytu, sygnał EDS na obecność: b) aluminium (Al), c) krzemu (Si), d) tlenu (O)

No symptoms of excessive wear of the chemically-hardened metal-polymer composite can be seen in the microscope image of the surface of the composite (Fig. 11a). The increased intensity of the presence of the composition elements of cenospheres on the surface of the composite subject to friction can be observed in the presented results of their X-ray microanalysis (Fig. 11b and 11c). The increased aluminum and silicon contents on the friction surface of the composite indicates that the grains of cenospheres form a protective layer and counteract the excessive wear of the metal-polymer regeneration composite. Simultaneously, the wear value of the bronze counter sample cooperating with the composite does not increase. As a result, the wear of the friction couple for the composite hardened with aliphatic amine is the lowest. The observations thus allow to us state that the material of the abrasive adheres to the surface of the composite, which in turn causes its additional reinforcement against wear.

SUMMARY

The research results indicate that the lowest abrasive wear loss, regardless of the kind of abrasive used, was achieved by the triethylenetetramine crosslinked composite, which out of all the regeneration materials tested, was characterised by average hardness and greatest compression resistance. The obtained results of the friction-wear tests showed new technological application possibilities for chemically-hardened metal-polymer composites, i.e. the regeneration of friction couples prone to tribological wear in the presence of abrasives. They can be applied to the regeneration of the parts of machines used in agriculture and mining. Chemically-hardened metal-polymer composites cross-linked with amine compounds at the time of cooperation with bearing alloys show great wear resistance in the presence of abrasives. It depends on the creation of the protective reinforcement layer in the metal-polymer composite. This layer increases the wear resistance of the composite and at the same time has a moderate influence on the cooperating alloy element. It can be assumed that it results from the application of triethylenetetramine as an abrasive, which allows one to obtain a material with sufficiently high resistance to deformation and the ability of quasi-permanent placement of the particles of the abrasive in the surface.

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