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Tribological properties of aluminium matrix composites reinforcement with intermetallic

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Properties

ABSTRACT

Purpose: In the investigations, two types of material were taken for the cooperation with the composite Al + intermetallic phases. One of the materials were composites based on the AlMg12Si alloy, reinforced with ceramic particles (SiC, Al_2O_3), and the other was spheroidal cast iron.

Design/methodology/approach: For the investigations of wear under technically dry friction conditions the pin-on-disc measuring system was applied.

Findings: It has been shown that Al based composites reinforced with intermetallic phases are characterized by considerable resistance to tribological wear under technically dry friction conditions in a cooperation with composites based on the Al alloy (AlSi12CuNiMg) . The tribological systems in which composites of the Al +intermetallic phases type are used, are characterized by a stable course of the friction coefficient value as a function of friction distance, irrespective of the type of material cooperating with them.

Practical implications: In the case of cooperation of $Al-Al_2O_3-Al_3Ti-Al_3Fe$ composites with aluminium alloy based composites, one should take into account the changes in friction conditions resulting from plastic deformation of the friction surface of the composite Al + intermetallic phases.

Originality/value: Thanks to conducted researches it was stated that there is a possibilty of application of heterophase reinforcement that use the mixture of intermetalic phases as a effective method of aluminium alloys resistance improving the wear in dry sliding conditions.

Keywords: AMCs composites; Intermetallic phases; Tribological properties; Friction coefficient; Wear

1. Introduction

In the production of modern composites with the use of the in situ method, chemical reactions which take place between the introduced reagent and the metal matrix components are taken advantage of. In a majority of processes, a liquid aluminium matrix is applied. In authors' own investigations, it was assumed that by means of a properly controlled reaction of aluminium with ilmenite, a composite of a heterophase composition, $Al-Al_2O_3-Al_3Ti-Al_3Fe$, can be produced in a two-stage process. Suspension technology was selected as the composite fabrication method (stage I), followed by a synthesis under controlled conditions (stage II) [1-7]. Stage I is called the precursor-composite production stage (Al-particles FeO · TiO2). For the fabrication of the composite, aluminium of A0 grade produced by ZM Skawina was used together with ilmenite powder of a grain size of 71-80μm.

2. Purpose and scope of tribological investigations

The purpose of the investigations conducted was to evaluate the tribological properties of friction couples, where one of its components was made of an Al-based composite material reinforced with intermetallic phases in the form of fine dispersion particles.

The scope of the research encompassed:

- the determination of the friction coefficient value under technically dry friction conditions;
- the determination of the wear value under technically dry friction conditions;
- an evaluation of the left wear-out trace based on profilographometric investigations.

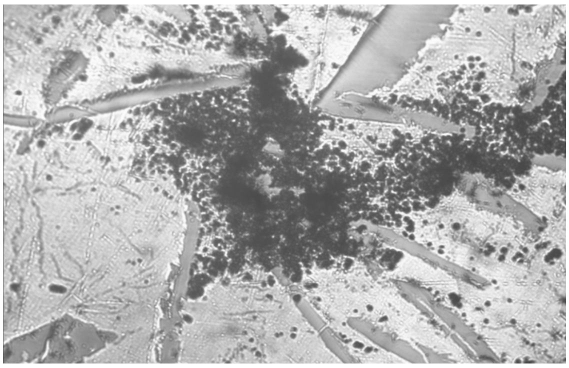

Fig. 1. Composite structure after holding at a temperature of 1000°C

The tribological investigations were conducted on a tribological pin-on-disc tester T-01M, manufactured in series by the Institute of Technology and Operation in Radom. The test stand consisted of: the T-01M tester, a/d converter, a control and data registration system based on a PC with suitable software. A scheme and view of the test stand are presented in Figure 2.

The investigations were focused on the determination of the degree of wear measured by mass decrement, and the friction coefficient value. The research was conducted in accordance with the technological instruction recommendations as well as ASTM G99 and DIN 50324 standards.

3. Investigation of tribological wear under technically dry friction conditions

A scheme of the pin-on-disc measuring system applied for the investigations of wear is presented in Figure 2.

From the first meters of the friction distance, the friction coefficient value is almost constant and amounts to ca. $\mu = 0,3$; it is the average value for the whole measurement.

When observing the change of the friction coefficient throughout the distance, the coefficient can be described as stable.

Mass decrement for the specimen (pin) and counter specimen (disc) was determined from the difference between the initial and final mass (after covering a distance of 5000 m).

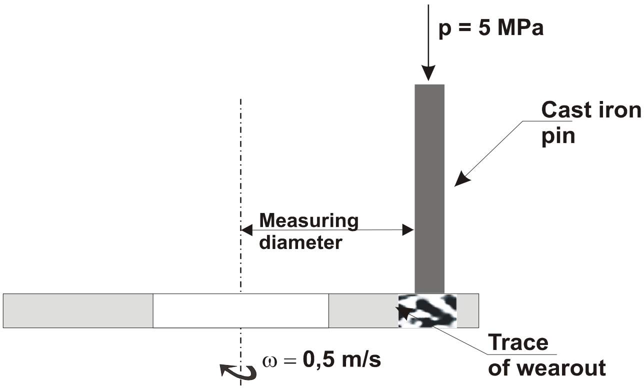

Fig. 2. Scheme of the pin-on-disc measuring system applied for the investigations of wear under technically dry friction conditions

4. Investigation of the wear-out trace

Investigations of the wear-out trace formed on the surface of specimens aimed at describing the qualitative and quantitative nature of composites' wear. In profilographometric investigations, a contact method was applied, with the head of the profilographometer with a diamond tip moving along the investigated surface. The results of the profilographometric investigations after digital processing allowed the determination of so-called wear-out trace topography maps.

The sets of friction couples taken for the investigations and the parameters of the specimens (unit pressure, friction distance and speed) are presented in Table 1 [8-12]. In all cases, the pin diameter was 6 mm.

4.1. Measurement of the system friction coefficient. Pin composite Al + intermetallic phases – disc composite AlSi12CuNiMg + 15%Al_2O_3 (50μm)

Figure 3 shows the friction coefficient value as a function of distance for the analyzed couple. For the investigated couple, in the initial phase of the test (distance of up to 500m), it is impossible to identify the grinding-in stage, characterized by instability of the friction coefficient.

Table 1.
Juxtaposition of the friction couples subjected to investigations.

DISC	PIN	Speed m/s	Distance, m	Unit pressure MPa
AlSi12CuNiMg+15%SiC(50μm)	Al+intermetallic phases	0,7	5000	1,25
AlSi12CuNiMg+15%Al_2O_3(50μm)	Al+intermetallic phases	0,7	5000	1,25
Cast iron	Al+intermetallic phases	0,7	5000	1,25

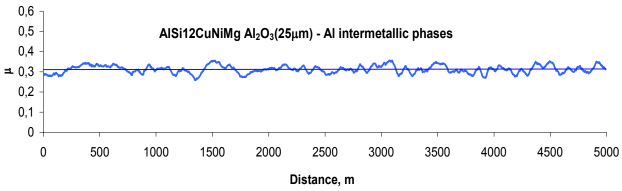

Fig. 3. The results of the friction coefficient value measurement for the friction couple. composite Al + intermetallic phases – composite AlSi12CuNiMg + 15% Al_2O_3 (50µm), during cooperation under technically dry friction conditions

The trace formed as a result of friction on the cooperating elements is shown in Fig. 4. There are visible traces of wear in the form of scratches in the movement direction on the working surface of the pin made of the composite: Al + intermetallic phases.

a) b)

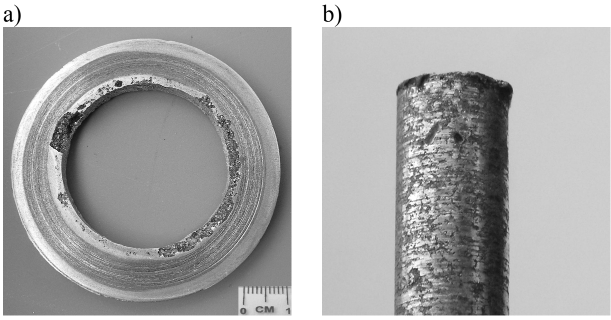

Fig. 4. View of the friction couple elements: a) disc: composite AlSi12CuNiMg + 15%Al_2O_3 (50µm); b) pin – composite Al + intermetallic phases

As a result of friction of the investigated couple, few products of wear in the form of silvery powder were created. On the worn out surface of the pin, a 0.8 mm increase of the diameter was observed. In this way, a "flange" was formed by plastic deformation. This effect may influence the stabilization of the friction coefficient. An increase in the pin diameter induces a reduction of the unit pressure in a friction contact by increasing the contact surface of elements subject to friction. A view of the deformation formed is presented in Figure 5.

4.2. Measurement of the system friction coefficient. Pin composite Al + intermetallic phases – disc composite AlSi12CuNiMg + 15%SiC (50µm)

In the other couple subjected to investigations, the disc material was changed. A composite that was used was based on the AlSi12CuNiMg alloy reinforced with silicon carbide particles. Like in the previous case, in the initial phase of the friction elements cooperation, no distinct grinding-in period was identified. The friction coefficient has a stable course with its average value amounting to µ = 0,3. The course of the friction coefficient value as a function of 5000m friction distance is presented in Figure 6. Only slightly, i.e. by 0.05, did the minimum value of the friction coefficient decreased, μ_{min} = 0,22, in relation to the value recorded in the previous test.

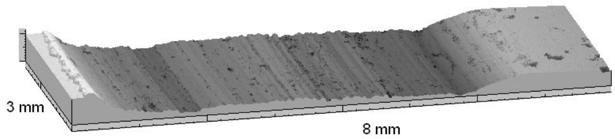

Fig. 5. Topography of the surface of AlSi12CuNiMg + 15% Al_2O_3 (50µm) composite after cooperation with the composite Al + intermetallic phases under technically dry friction conditions

The traces formed on the surfaces of the pin and disc as a result of wear look similar to those in the previous test. In the working part of the pin, like previously, an increase in the diameter was observed; in this case, it was an increase by 0.7mm. The view of traces of the friction surfaces wear is shown in Figure 7.

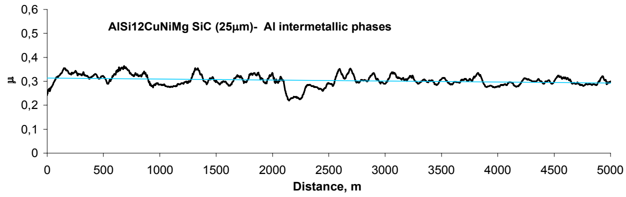

Fig. 6. The results of the measurement of the friction coefficient value for the friction couple: Al + intermetallic phases – composite AlSi12CuNiMg + 15% SiC (50µm), during cooperation under technically dry friction conditions

a) b)

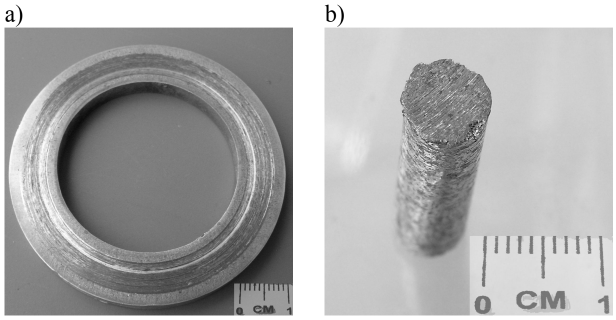

Fig. 7. View of the friction couple elements: a) disc – composite AlSi12CuNiMg + 15% SiC (50µm), b) pin – composite Al + intermetallic phases

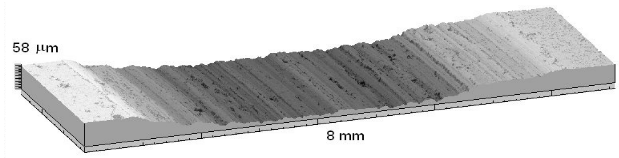

Fig. 8. Topography of the surface of AlSi12CuNiMg + 15% SiC (50µm) composite after cooperation with the composite Al + intermetallic phases under technically dry friction conditions

4.3. Measurement of the system friction coefficient. Pin composite Al + intermetallic phases – disc – spheroidal cast iron

For this test, the composite Al + intermetallic phases obtained by casting techniques was used as the pin material. This material is identical, as regards its composition and production technology, to that used for the pins cooperating with composites based on the AlSi12CuNiMg alloy. The results of the investigation of the friction coefficient changes as a function of distance are presented in Figure 9.

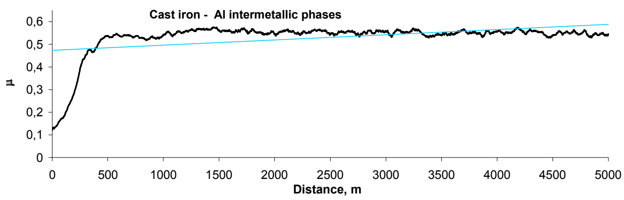

Fig. 9. The results of the measurement of the friction coefficient and wear values for the friction couple: cast iron – composite Al + intermetallic phases, during cooperation under technically dry friction conditions

a) b)

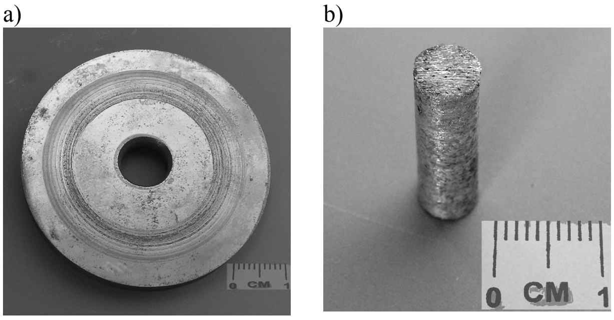

Fig. 10. View of the friction couple elements: a) disc – spheroidal cast iron, b) pin – composite Al + intermetallic phases

No irregular furrows or traces left after material pull-out were found, which could have been expected when observing the course of the friction coefficient. Contrary to the earlier presented effects of cooperation between the pin made of the composite Al + intermetallic phases and AlSi12CuNiMg composites reinforced with ceramic particles, no deformation effect was visible on the pin surface. Like in the previous case, during the cooperation with a cast iron disc, the pin maintained its initial diameter, Fig. 11.

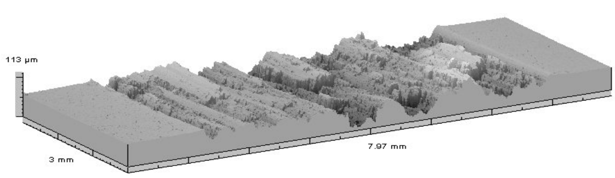

Fig. 11. Topography of the surface of composite Al + intermetallic phases after cooperation with spheroidal cast iron under technically dry friction conditions

4.4. Measurement of wear

The mass decrement in the tribological system elements recorded during the investigations were then used to plot a diagram (Fig. 12). The greatest wear was recorded for a disc made of the composite AlSi12CuNiMg + 15%Al_2O_3 (50μm). In the remaining cases, the wear was almost by half smaller and, taking into account the accuracy of the measuring method, it can be deemed identical. When comparing the obtained results of wear measurement of composite pins subject to wear under technically dry friction conditions, the greatest wear was observed for a pin made of the Al + intermetallic phases composite after its cooperation with cast iron. Much lower (almost by 10 times) mass decrement was recorded for the other two pins; in both cases, after their cooperation with AlSi12CuNiMg alloy based composites.

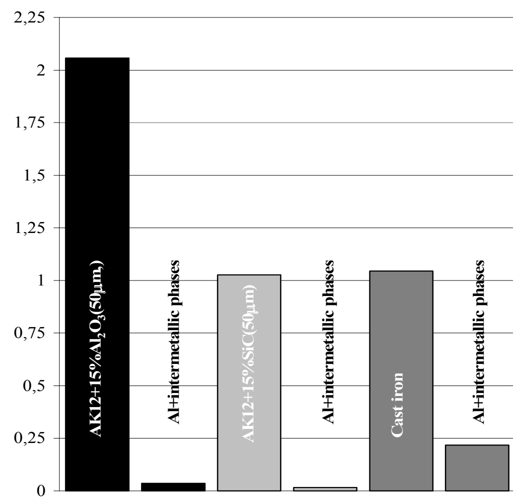

Fig. 12. Mass decrement of pins subjected to investigation under technically dry friction conditions

5. Summary

The results of the investigations carried out show a relationship between the nature of tribological wear of the Al + intermetallic phases type composites and the type of friction partner. In the investigations, two types of material were taken for the cooperation with the composite Al + intermetallic phases. One of the materials were composites based on the AlSi12CuNiMg alloy, reinforced with ceramic particles (SiC, Al_2O_3), and the other was spheroidal cast iron [13-15].

Comparing the results obtained during the investigation of wear and friction coefficient, it can be affirmed that both the friction coefficient value and the wear depend on the type of the material used. In the case of composites: AlSi12CuNiMg + ceramic particles, regardless of the type of composite, the tribological properties of the system are similar. The friction coefficient does not exceed $\mu = 0.3$ (measured as a mean value), however, the wear of the AlSi12CuNiMg-based composite itself is different. The composite AlSi12CuNiMg +Al_2O_3 is characterized by higher wear and lower resistance to wear in relation to the AlSi12CuNiMg + SiC. The difference is close to 100%. Likewise, the wear of the composite Al + intermetallic phases in the case of its cooperation with a composite reinforced with aluminium oxide is double as high as the wear during the cooperation with a composite reinforced with silicon carbide particles. Therefore, it can be assumed that the factor responsible for the tribological properties level in the compared couples is the type of the reinforcement used in AlSi12CuNiMg-based composites.

In spite of differences in the level of resistance to wear of the compared systems, their common characteristic feature must be stressed. Mainly, in both cases, plastic deformation of the pin occurred as a result of wear, which deformation contributed to an increase of the pin diameter in friction peripheries. This phenomenon was not present during the cooperation with spheroidal cast iron. For both systems, the increase in the diameter had a similar value of ca. 0.7 mm.

During the cooperation of the composite Al + intermetallic phases with spheroidal cast iron, a change was observed both of the friction coefficient and wear. The friction coefficient increased by 50%, achieving the value $\mu = 0.45$, whilst wear rose by almost 10 times.

6. Conclusions

Aluminium based composites reinforced with intermetallic phases are characterized by considerable resistance to tribological wear under technically dry friction condition in a cooperation with composites based on the AlSi12CuNiMg aluminium alloy.

1. The tribological systems in which composites of the Al +intermetallic phases type are used, are characterized by a stable course of the friction coefficient value as a function of friction distance, irrespective of the type of material cooperating with them.
2. In the case of cooperation of composites Al + intermetallic phases with AlSi12CuNiMg aluminium alloy based composites, one should take into account the changes of friction conditions resulting from plastic deformation of the friction surface of the composite Al + intermetallic phases.

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