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Tribological properties of heterophase composites with an aluminium matrix

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Properties

ABSTRACT

Purpose: The paper presents the investigation results of tribological properties of composites with an aluminium matrix, which contain various types of reinforcing particles.

Design/methodology/approach: Tribological tests were carried out on composites containing SiC or Al_2O_3 reinforcing particles (homophase composites) and composites reinforced with a mixture of SiC or Al_2O_3 particles with an additive of glass carbon (heterophase composites) as a frictional properties modifier.

Findings: The results of friction and wear coefficients' investigation allowed the determination of how the addition of glass carbon can influence tribological characteristics. The replacement of the part of the reinforcement with glass carbon particles led to a reduction of both the friction and wear coefficients of heterophase composites and of the grey cast iron cooperating with them.

Practical implications: The results obtained allow us to claim that it is possible to change the tribological properties of composites as a result of using reinforcing particles with various physical and mechanical characteristics.

Originality/value: The utilization of heterophase reinforcement enables, to a large extent, the broadening of the possibilities of designing the tribological properties of friction couples.

Keywords: MMCs composites; Heterophase composites; Ceramic particles (SiC or Al_2O_3); Glass carbon; Tribological properties

1. Introduction

Alluminium alloys reinforced with SiC and Al_2O_3 particles have been researched extensively for many years and are used more and more widely in the industry. They find applications in machine building, for elements subject to intense wear under extreme operating conditions [1-6]. The growing demand, especially in the car and aircraft industry, gives rise to constant search for the possibilities of improving the utilitarian properties, including the tribological ones, in order to learn more about the mechanisms of wear and tear and operational possibilities of machine parts made of composites. The use of traditional reinforcing particles of the SiC or Al_2O_3 type contributes to improvement of physical and mechanical properties and reduces the weight of structural elements (pistons, connecting rods), yet the wear of such elements decreases significantly. A negative effect of using ceramic particles is the increase in wear of materials cooperating with them. Particles characterized by a low friction coefficient and lubricating properties, like graphite, are used to prevent this. As a result, so-called hybrid composites are obtained by adding two kinds of reinforcing phase to the matrix, for example SiC and graphite. The composite reinforced with 20% of SiC with a 10% addition of graphite [7] in cooperation with steel under dry friction conditions has shown almost ten times lower wear when compared to the composite with SiC only. After using cylinder sleeves made of a heterophase composite (12% short fibers of Al_2O_3, 9% of graphite), their wear reduced and the efficiency of cooling improved considerably, which allowed a reduction of the wall thickness by about 30 % [8]. The application of heterophase reinforcement composed of two types of reinforcing particles (Al_2O_3 or SiC ceramics with glass carbon additives) constitutes an alternative to the solutions described in the literature, where emphasis is placed on heterophase reinforcement based on a mixture of fibers and reinforcing particles [9,10].

This paper presents the results of tests as regards the application of a mixture of particles in aluminium matrix composites, in which the mixture of traditional types of ceramics and carbon of an amorphous structure (glass carbon) were applied. The purpose of applying Al_2O_3 and SiC particles in the mixture was to ensure high wear resistance, whilst carbon particles were used to lower the friction coefficient and prevent wear of the material cooperating with the composite.

2. Methodology and research materials

The target of the research was to determine the tribological properties as well as the phenomena and mechanisms which accompany the tribological wear of composites with heterophase reinforcement under dry friction conditions.

The scope of the research was connected both with the technology of production of aluminium composites with heterophase reinforcement consisting of ceramic particles and glass carbon by mechanical mixing as well as obtaining the material for the tests in the process of centrifugal casting of composite suspensions, and with determining the tribological properties of the cast iron/composite couple under technically dry friction, with the determination of the mechanisms which accompany the destruction of the outer layer of composites as a result of tribological processes.

The tests were carried out on composite materials with a casting AlSi12CuNiMg aluminum alloy matrix. The composite materials discussed were reinforced with ceramic particles of SiC, Al_2O_3 or a mixture of SiC, Al_2O_3 particles containing, additionally, glass carbon (Cs) with the same mass fraction of 30-wt. %. The composites were obtained by the method of mechanical mixing and then, formed into sleeves, using the centrifugal casting technology [11-14]. This technology made it possible to form an outer composite layer, ca. 7 mm thick. The composition of the materials investigated is presented in Table 1. Two types of composites with heterophase reinforcement of two types of particles (Al_2O_3+Cs; SiC+Cs) were used in the tests and, for the sake of comparison, composites containing one type of Al_2O_3 or SiC particles, or glass carbon, were used.

Tribological investigations were carried out under technically dry friction on a T-01M pin-on-disk tester. As counter-specimen materials, pins of *f* 6x20 mm were used. They were made of grey cast iron EN-GJL-300, being the most often used material for brake discs in motor vehicles. The research on friction and wear coefficients was carried out under technically dry friction conditions with a constant pressure of 1.3 MPa, constant slide speed of 0.8 m/s and friction distance of 5000 m.

During the research, the friction coefficient value was continuously recorded and wear was determined as mass decrement after the completed test cycle.

Table 1
Composition and designation of composites used in the investigations

Designation	Reinforcement particles	Mass fraction of 30-wt. %	Particles size, μm
A50	Al_2O_3	30	50
A50C	Al_2O_3 +Cs	30(25+5)	50+100
S50	SiC	30	50
S50Cs	SiC+Cs	30(25+5)	50+100
Cs	Cs	30	100

3. The results of tribological investigations

The results of the tribological tests carried out on the T-01 tester, are presented in Figures 1-3 in the form of diagrams of changes of the friction coefficient as a function of friction distance.

The introduction of vitrous carbon particles into the aluminium matrix resulted in a reduction of the friction coefficient value (Fig. 1). The results of the tests predispose the AlSi12CuNiMg-Cs composite obtained to its application for sliding elements, though the hardness of the Cs particles (4200 μHV) is similar to the hardness of SiC particles (3800 μHV). Among the composites reinforced with single-phase particles (Fig. 3), the highest value of the friction coefficient was about 0.5, recorded in the composite reinforced with Al_2O_3. particles. In composites reinforced with SiC particles (Fig. 2) changes in the tribological properties are similar in nature to the changes in composites reinforced with alumina particles. On the other hand, replacement of part of the alumina particles in the A50Cs composite with glass carbon caused a decrease in the friction coefficient from 0.45 to 0.37. Similar changes of the properties were obtained while modifying the composite containing SiC - S50Cs particles by using glass carbon.

Consequently, glass carbon, which is characterized by good sliding properties, contributed to a 20-25 % reduction of the friction coefficient in heterophase composites. Moreover, as can be seen in Figures 2 and 3, the application of glass carbon particles allows the elimination of the stage of grinding-in, characteristic of the initial stage of friction couple cooperation.

The results of wear measurements in the tested couples are shown in Table 2. The results indicate explicitly that an addition of glass carbon reduces wear almost by half, both in the group of composites reinforced with Al_2O_3 particle and with SiC particles.

Table 2.
Mass wear of composites and cast iron

Designation	Mass loss composites , g	Mass loss cast iron, g
A50	0,09	0,011
A50Cs	0,055	0,009
S50	0,05	0,010
S50Cs	0,021	0,004

As a result of using the reinforcement with glass carbon particles, the wear of counter-specimen (cast iron pin) decreases as well.

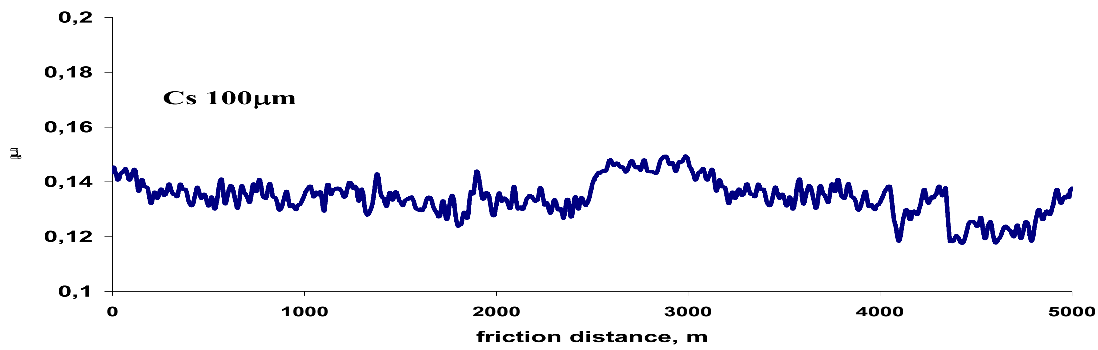

Fig. 1 The diagram of changes of the friction coefficient as a function of friction distance for composite reinforced with glass carbon

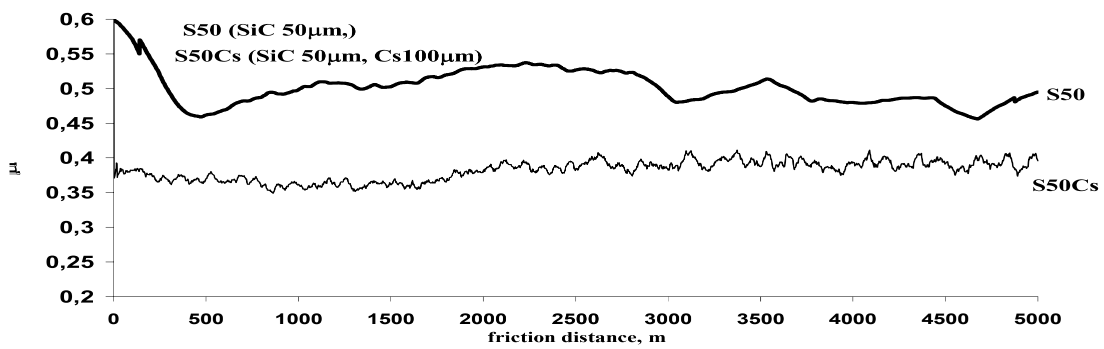

Fig. 2. The diagram of changes of the friction coefficient as a function of friction distance for composite reinforced with SiC heterophase composite

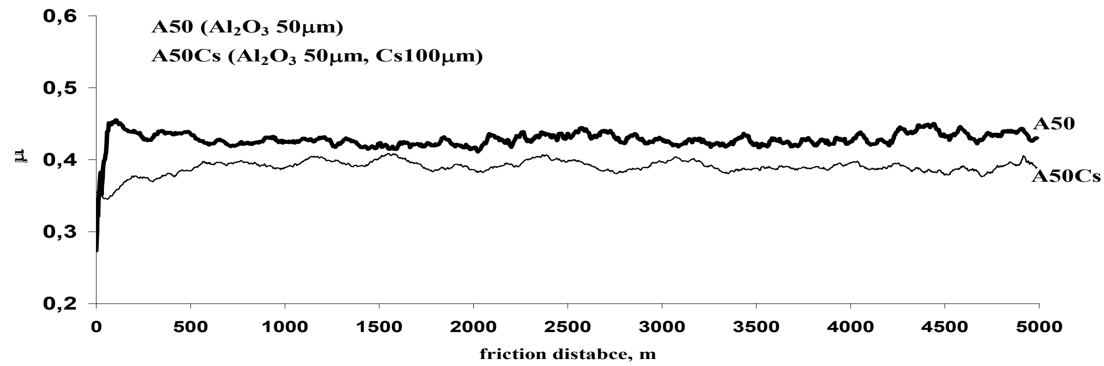

Fig. 3. The diagram of changes of the friction coefficient as a function of friction distance for composite reinforced with alumina and heterophase composite

4. The friction face structure

The microscopic examination of the composites' surfaces after friction made it possible to trace in a qualitative way the mechanisms responsible for tribological effects induced by the presence of Al_2O_3 and SiC reinforcing particles modified with an addition of glass carbon. Both in composites with homogenous particles and in those with a mixture of particles, the dominant wear mechanism is abrasion, whose effects are grooves and scratches created on the surface of outer layer (Fig. 4).

Hard reinforcing particles give rise to damage to the outer layer of a friction partner, thus increasing roughness of the cast iron surface. This in turn results in damage to and destruction of the reinforcing particles (Fig. 5). The damaged (crushed) particles are located between the cooperating partners and, by operating as a loose abrasive, they additionally damage the composite surface.

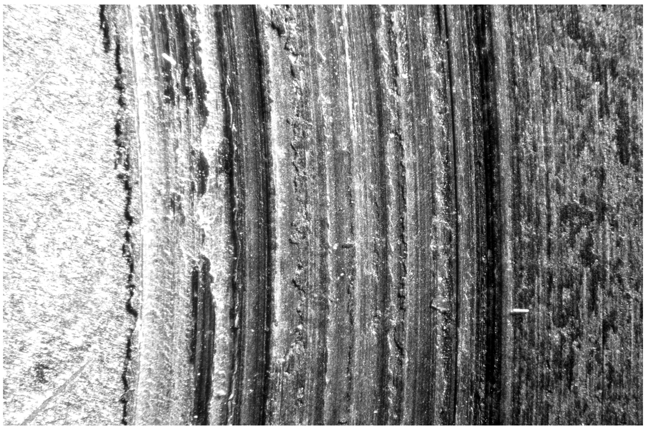

Fig. 4. Grooves and scratches on the surface of the composite

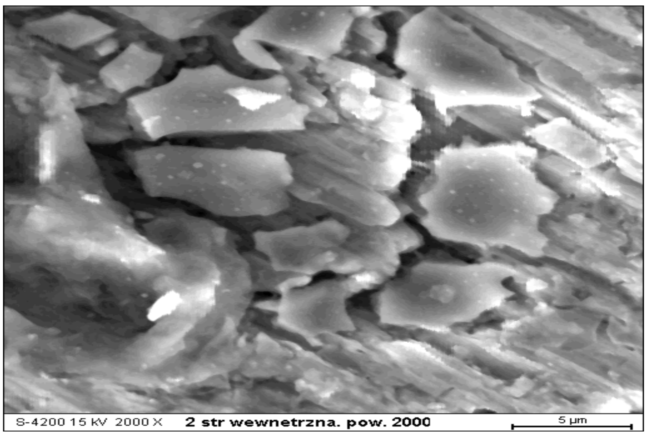

Fig. 5. The view of the damaged (crushed) particle (Al_2O_3)

Therefore, in composites containing hard SiC or Al_2O_3 particles, wear processes are enhanced even more as a result of crushing of the reinforcing particles (e.g. in the case of the AlSi12CuNiMg-Al_2O_3 composite).

Figures 6 and 7 show a trace of wear, which occurred as a result of the Al_2O_3 particle destruction. After its crushing, the particle gets stuck into the matrix material, thus damaging the outer layer. Also, in the case of the composites containing glass carbon, wear occurs as a result of carbon particles destruction. Carbon particles, however, are not subject to destruction as a result of cracking or crushing into small sharp pieces. The process of their destruction is connected more with delamination (Fig.8). Pieces of carbon particles break off from the matrix and they tend to sediment on the surface of the composite and cast iron, where they form a lubricating layer which separates the cooperating elements.

The effect of distribution of disintegrated glass carbon and its deposition on the fiction surface occurs both in the composite reinforced with silicon carbide and alumina. Such a layer is not formed in the case of friction of composites without glass carbon additions. In Figure 9, there are traces of wear visible in the form of ridging and microshearing within the area of the AlSi12CuNiMg-Al_2O_3+Cs composite friction which does not contain any glass carbon particles.

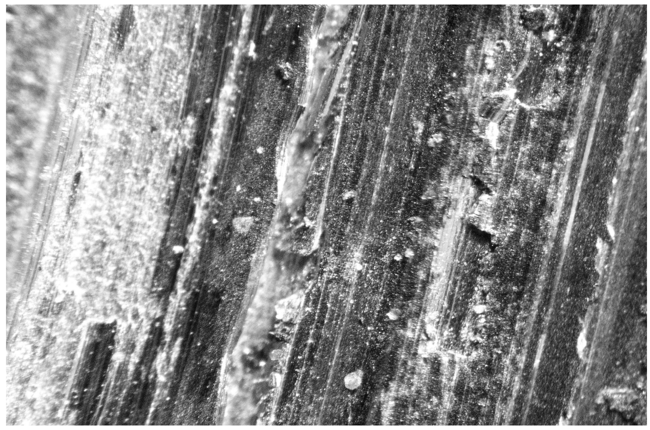

Fig. 6. A trace of wear, as a result of the Al_2O_3 particle destruction

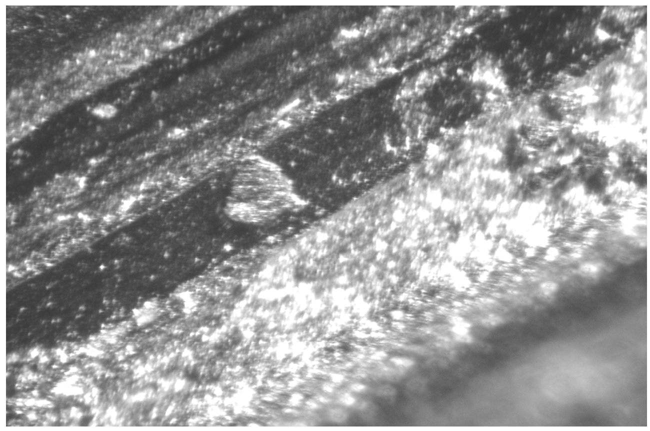

Fig. 7. A trace of wear, as a result of the Al_2O_3 particle destruction

The visible carbon particle has not been destroyed. It projects over the friction surface, whilst around it, no traces of wear can be seen. Both the reduction of the friction coefficient value and the decrease in wear of composites with an addition of glass carbon can be associated with the effect of sedimentation of wear products on the composite surface and with reducing the microshearing and ridging as a result of a different mechanism of reinforcement destruction.

The reduction of wear and of the friction coefficient by glass carbon can be explained by the difference of its physical and mechanical properties as compared with the SiC or Al_2O_3 particles. Glass carbon with an approximate hardness (ca. 300-350 MPa) is characterized by almost twice as low shearing resistance (ô = 30-50 MPa) as that of aluminium oxide [15]. According Bowden's hypothesis, this can be the result of reduction of friction and wear coefficients[16].

5. Summary

The results of the investigation prove that an addition of glass carbon, irrespective of the type of ceramic reinforcement, enhances the tribological properties of a system. It contributes to stabilization of the friction coefficient value as a function of friction distance and almost completely eliminates the stage of grinding-in period of the cooperating partners. In all the tested couples where glass carbon was present, a reduction of the friction coefficient value was recorded compared to the materials without such additions. The application of heterophase reinforcement is a solution which enables the broadening of the possibilities of designing the tribological properties of friction couples. It is currently possible to select such systems of reinforcement, where, when maintaining a high value and stability of the friction coefficient, the wear of cooperating partners can be reduced considerably.

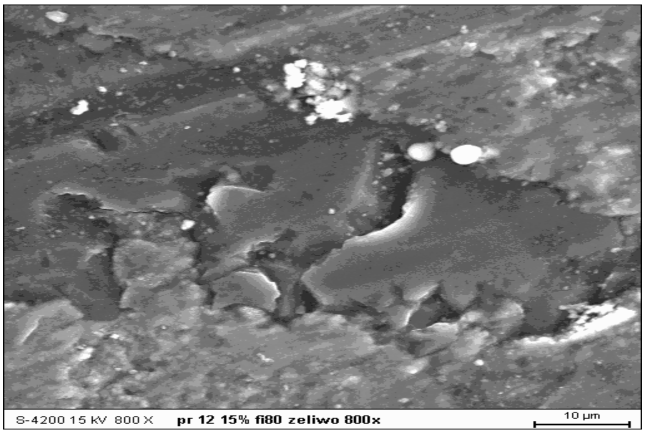

Fig. 8. The wives of particles delamination

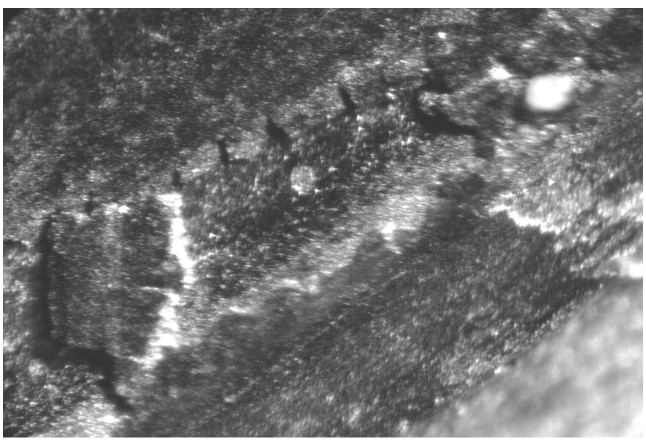

Fig. 9. Traces of wear within the area of the AlSi12CuNiMg-Al_2O_3+Cs without glass carbon particles

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