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A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S

Volume 60 2015 Issue 1

DOI: 10.1515/amm-2015-0018

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TRIBOLOGICAL PROPERTIES AND A WEAR MODEL OF ALUMINIUM MATRIX COMPOSITES – SiC PARTICLES DESIGNED FOR METAL FORMING

WŁAŚCIWOŚCI TRIBOLOGICZNE I MODEL ZUŻYCIA KOMPOZYTÓW O OSNOWIE STOPU ALUMINIUM WZMACNIANYCH CZĄSTKAMI SiC PRZEZNACZONYCH DO PRZERÓBKI PLASTYCZNEJ

Aluminium based metal matrix composites are well known for their good wear resistance, high specific strength, stiffness and hardness. They have been applied in the aerospace, military and, especially, in the automotive industries. This paper presents the results of tests with regard to the application of a mixture of particles in aluminium matrix (AlCu2SiMn) composites where a mixture of SiC ceramic particles was used. The aim of the research was to determine the tribological properties as well as the phenomena and mechanisms which accompany the tribological wear of composites under dry friction conditions. The tribological investigations were conducted on a pin-on-block tester. The results of the tests show the composite obtained can be applied for sliding elements. Based on microscopic examinations and profilometry of the composites AlCu2SiMn+SiC surfaces at interaction the relationship between the size of reinforcing particles and the geometry of the surface layer of the composite was described. The study made it possible to develop a model of tribological wear of composites depending on the size of reinforcing particles.

Keywords: tribology, metal matrix composites, wear

Kompozyty z osnową stopów aluminium, są dobrze znane z ich dobrej odporności na zużycie, wysokiej wytrzymałości, sztywności i twardości. Znalazły one zastosowanie w przemyśle lotniczym, wojskowym, ale zwłaszcza w przemyśle motoryzacyjnym. W artykule przedstawiono wyniki badań tribologicznych kompozytów o osnowie stopu AlCu2SiMn wzmacnianego cząstkami węglika krzemu (SiC) o rozmiarze ziaren od 25 do 50 μm. Celem badań było określenie właściwości tribologicznych oraz zjawisk i mechanizmów, które towarzyszą zużycie tribologicznemu kompozytów w warunkach tarcia suchego. Badania tribologiczne przeprowadzono na testerze pin-on-blok. Wyniki predysponują badane kompozyty do zastosowania na elementy ślizgowe. Na podstawie przeprowadzonych badań mikroskopowych i profilografometrycznych, powierzchni kompozytów po współpracy, opisano zależność pomiędzy wielkością cząstek zbrojących a geometrią warstwy wierzchniej kompozytu. Przeprowadzone badania pozwoliły na opracowanie modelu zużycia trybologicznego kompozytu w zależności od rozmiaru cząstek zbrojących.

1. Introduction

Advancements in the technology of material manufacturing and forming enable designing and producing machine parts that show properties closely related to work conditions. For machine parts, such as: brake backing plates, cylinders, pump and compressor elements, slides or gear elements, exposed to intense tribological wear, light metal alloy-, aluminium-, titanium- or magnesium-matrix composites are of increasing use. Knowledge on the composites and their reactions in complex operation systems, frequently extremely difficult, should be expanded to determine, in a comprehensive manner, a set of factors that affect the nature of material operation. While designing a composite intended for tribological operation, both external factors (i.e. load, operating temperature, lubrication type or no lubrication, motion-related velocity, oscillations) and structural features, such as: matrix and reinforcing phase types as well as reinforcement fraction, size and morphology, should be considered [1-3]. Each of these factors directly or indirectly affects the tribological pair. The ceramic particle reinforced aluminium alloy-matrix composites are among materials that are most commonly applied for designing modern, high-loaded friction pairs [4-8]. They are mainly obtained using casting methods which involve simultaneous stirring of and introducing adequately prepared reinforcing particles into the aluminium bath [1-5]. A quality of thus-obtained composite materials is sometimes unsatisfactory due to poor particle wetting by the metal, additional defects of the interface and porosity that appears during the process of stirring and casting. The use of aluminium alloys that are intended for plastic work enables application of such processing techniques as forging, compression moulding, pressing or rolling for forming composite materials obtained by means of suspension methods [2, 8]. A potential of composite plastic

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work extends the range of composite material application and ensures that structural inhomogeneities and casting defects are eliminated.

2. Experimental part

The subjects of investigations were composite materials with the aluminium alloy matrix, AlCu2SiMn, reinforced with silicon carbide particles, SiC, sized 10 μm, 25 μm, 50 μm and a combination of these particles (Table 1). The composites were obtained using the mechanical stirring method and formed by means of the open die forging technique. The open die forging was performed with a forging hammer in two perpendicular directions. The material was previously pre-heated up to 500°C. The forging process involved two stages. During the first stage, a draft of ε =10% was obtained, while in the second stage, it was ε = 20%. The phase compositions and labels of the materials for tribological tests are presented in Table 1.

TABLE 1
Phase compositions of the investigated AlCu2SiMn+SiC composites

Label	Diameters of the reinforcing particles, μm	Volume fractions of the reinforcing particles, %
S25	25	15
S50	50	15
SM	25; 50; 10	5 + 5 + 5

Based on the investigations of AlCu2SiMn+15%SiC composite structure following plastic work, even distribution of the particles in the matrix and no agglomerates were observed (Fig. 1). No discontinuities at the matrix-reinforcement interface were found, which proves good bonding. Moreover, there were no signs of the forging-induced particle-matrix interface destruction or particle crushing.

In order to determine the tribological properties, cuboid samples, sized 35×15×10 mm, were obtained from the forged composites. The surfaces of investigated samples were polished. Based on the profilometric measurements, baseline geometry of the composite material surfaces before the sliding process was determined. In Figure 2, an image of the S50 composite surface after polishing is shown. In this case and for the other materials, reinforcement particles protruding from the matrix at a height of 3 to 5 μm were observed.

Thus prepared composite surface was subjected to the abrasion test under conditions of dry sliding using a tribology pin-on-block tester. A pin-shaped counter sample, φ = 3 mm and 20 mm in length, was made of EN-GJ200 cast iron. The test parameters were as follows: friction force = 5 MPa, sliding velocity = 0.5 m/s, sliding distance = 5000 m. During the test, changes of the friction coefficient values were constantly measured. The test stand and test parameters are presented in Figure 3. A wear trace that appeared on the composite surface was subjected to microscopic and profilographometric analyses. For the profilographometric analysis, a MicroProf 3000, FRT optical profilometer was used.

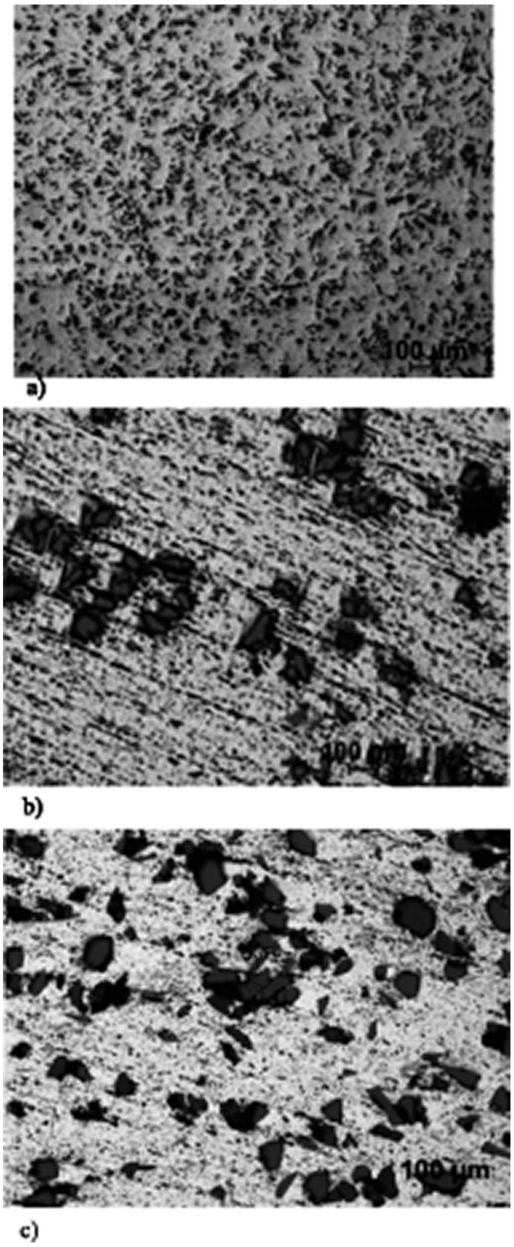

Fig. 1. Distributions of particles in the composite following the plastic work

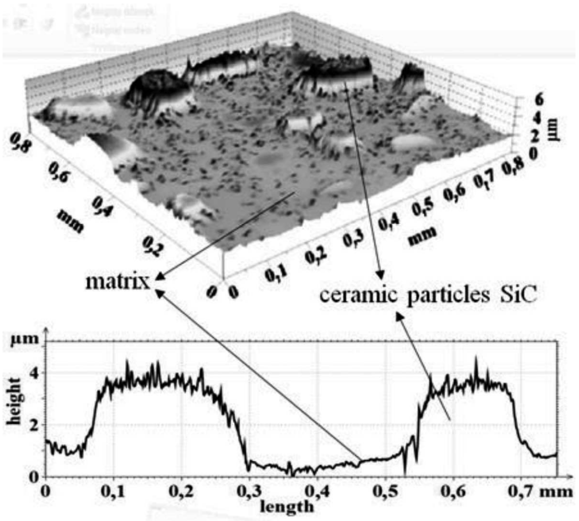

Fig. 2. Geometry of the S50 composite surface after polishing

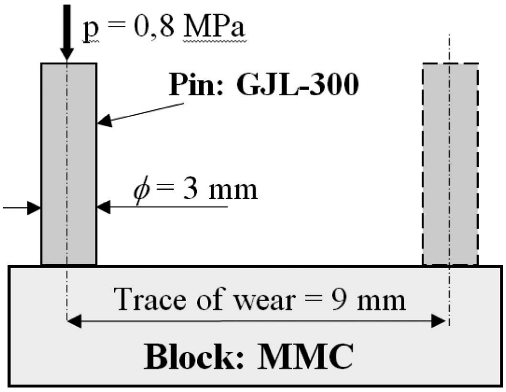

Fig. 3. The tribological test stand

3. Results

Based on the investigations, it is seen that the friction coefficient in tested tribological system increases with the increase in the size of reinforcing SiC particles (Fig. 4). Following the running-in phase (about 250 m for all composite types), the friction coefficient stabilised and remained stable until the end of the test. For the composites reinforced with particles sized 50 μm in diameter, a mean friction coefficient was 0.4 and it was the highest value for all the investigated materials. The smallest friction coefficient of 0.27 was observed for the composite reinforced with particles sized up to 25 μm in diameter.

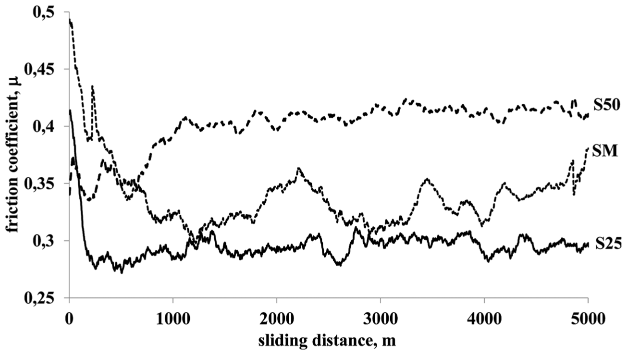

Fig. 4. Changes of the friction coefficient versus the sliding distance under conditions of dry sliding

The profilometric tests enabled quantitative and qualitative analyses of the wear trace that formed on investigated composite surfaces. A wear trace of the composite reinforced with particles sized 10 μm in diameter is presented in Figure 5a. It shows a mild wear process. In the surface, no clear signs of reinforcing particle pullout were observed. The wear trace is regular, which is proved by Ra=2.25 μm.

The wear trace analysis for the composite reinforced with particles sized 25 μm in diameter (Fig. 5b) suggests a mild wear nature as in the previous case. However, the parameter of surface roughness increases to Ra=2.27 μm, which is a negligibly small increment compared to the composite reinforced with particles sized 10 μm in diameter. The wear trace of the composite reinforced with particles sized 50 μm in diameter, presented in Fig. 5c, is different from the previous ones – deeper, irregular wear signs (grooves) can be identified. This trace could be caused by pullout of the reinforcing particles; such a particle is an element that cuts the composite and cast iron counter sample surfaces. A comparison of results of surface geometry measurements and the tribological characteristics of investigated materials shows that increased sizes of the reinforcing particles are accompanied by a higher level of the surface development, a higher friction coefficient and an enhanced wear process.

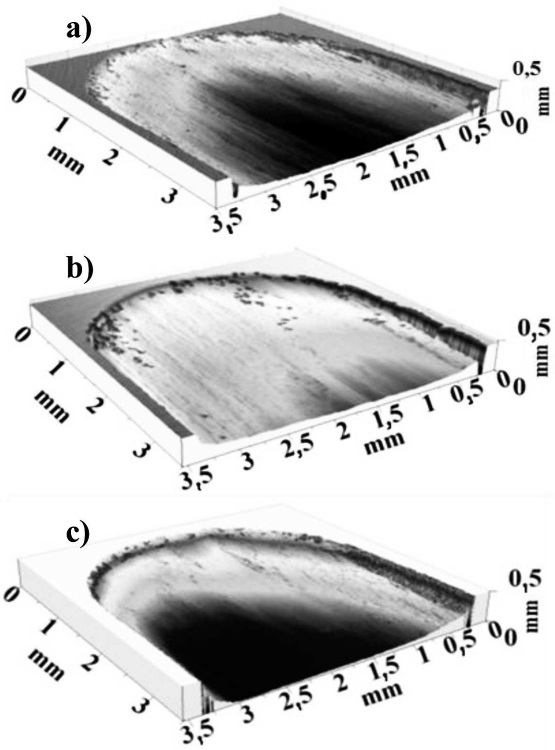

Fig. 5. 3D images of the wear trace: a) S10 composite, b) S25 composite, c) S50 composite

4. A model of composite wear

Based on the performed tribological tests, microscopic observations and profilographometric measurements, an attempt was made to present a model mechanism of wear for the SiC-particle reinforced composite under dry sliding conditions. The model refers to consecutive wear stages from the running-in to the established interaction. It presents characteristic friction-related effects, such as pullout of the reinforcing particles, plastic deformation of the matrix, abrasive wear of the cast iron sample and crushing of the particles during interaction. Moreover, differences in the wear nature, resulting from the sizes of investigated particles, were presented. A model of the composite with particles sized up to 50 μm, shown in Figure 6, involves four stages:

Stage I: initial interaction – the cast iron surface rests on the protruding (after polishing) reinforcing particles. Initial ploughing of the cast iron surface (running-in).

Stage II: due to "adjustment" during the running-in process, the contact area of interacting surfaces increases. At this stage, decrease and stabilisation of the friction coefficient are observed. Irregularities on the surface of cast iron counter sample interact with the reinforcement and the matrix, which results in their gradual abrasive wear.

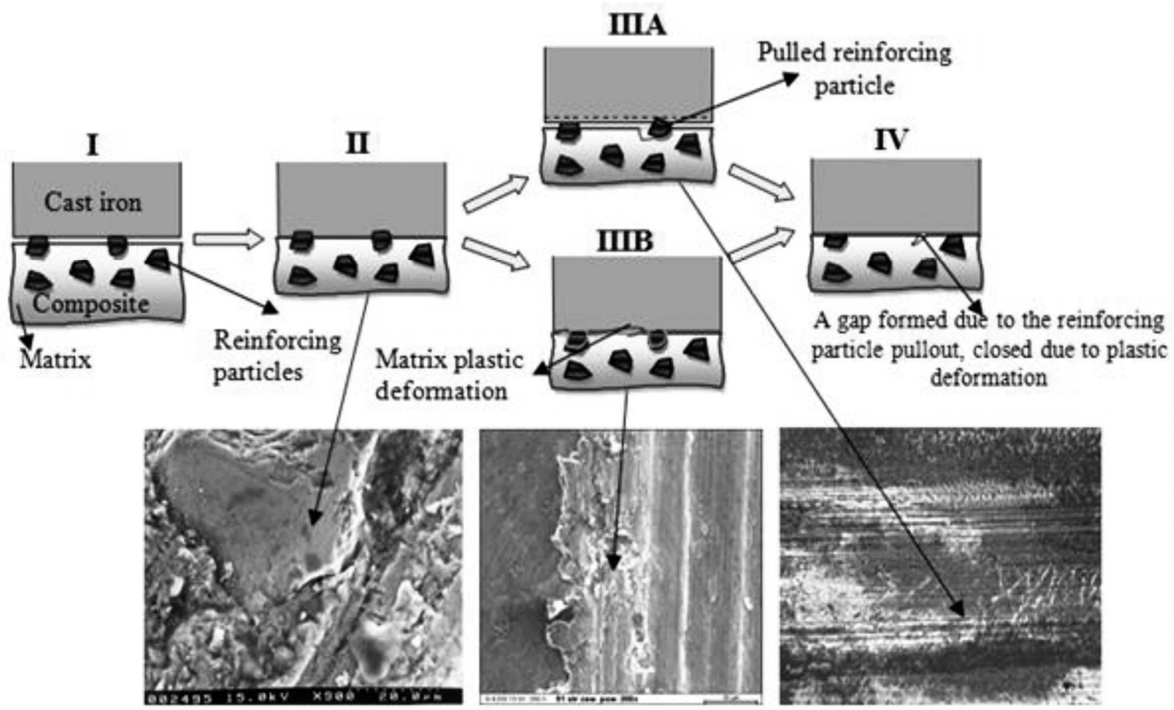

Fig. 6. A model of wear of the particle (up to 50 μm in diameter) reinforced composite during dry sliding

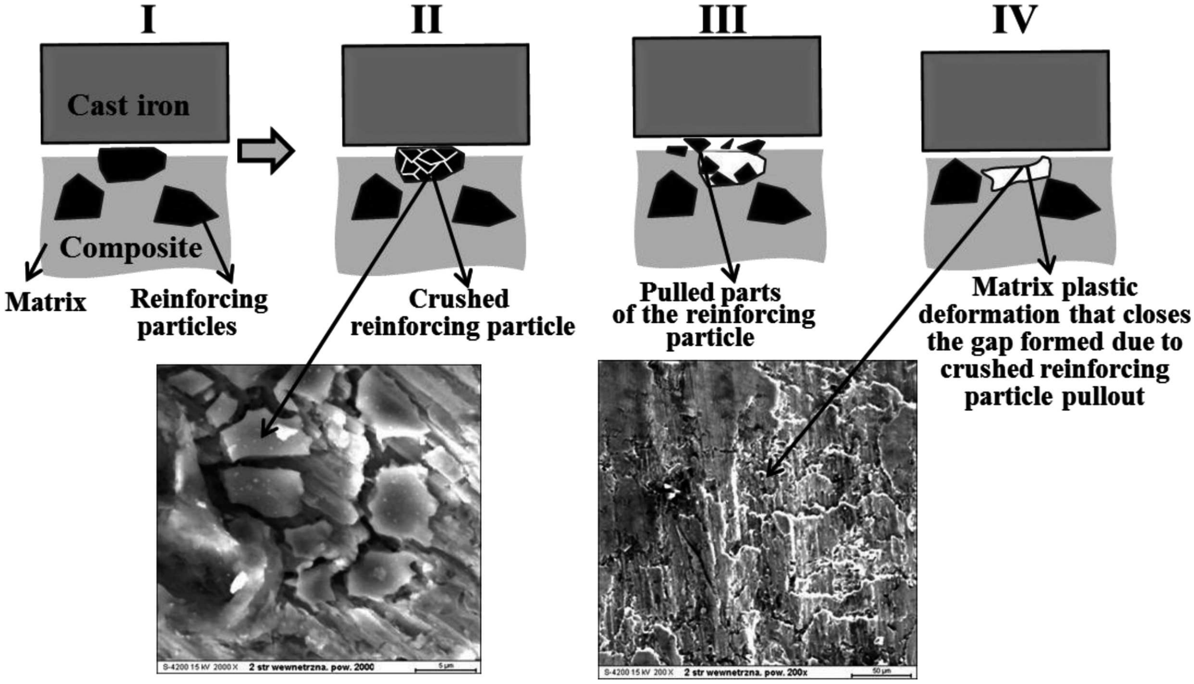

Fig. 7. A wear model for the composite materials reinforced with particles sized over 50 μm in diameter during dry sliding

Stage III: this stage should be divided into two types: A and B. For the type A, the reinforcing particle pullout and intensification of the wear process due to its additional interaction with the friction surfaces are observed. As a result, the particle may be embedded in the cast iron surface, which leads to increased abrasive wear of the composite, or it may freely move between the interacting surfaces. The moving particle may scratch any of the interacting surfaces or cause plastic deformation of the unreinforced parts of the matrix. Over time, the particle crushes and is eliminated. In the case of type B, the reinforcing particle is pressed into the matrix. This may result in adhesion of the composite matrix part to the cast iron, which leads to pullout or plastic deformation of the matrix identified as "smudging" on the friction surface.

Stage IV: it can be described as a return to the normal interaction following the previous stage disturbances. The characteristic effects for this stage are: gradual smoothing of the composite surface due to plastic deformation of the pullout-affected area and exposure of further reinforcing particles due to abrasive wear of the matrix.

The effects observed during the III and IV stages should be considered as typical of the set friction characteristics; they occur cyclically due to material wear during operation.

For the composites that are reinforced with particles sized less than 50 μm or with a combination of particles of various sizes, the wear model is presented in Figure 7.

In the model, together with the previously described effects, an additional wear mechanism, not observed for particles of smaller diameters, can be distinguished. It involves crushing big particles and occurs in the following stages:

Stage I: running-in of the interacting surfaces, abrasive wear of the cast iron and the composite.

Stage II: cracking of the reinforcing particles. The cracked particle remains in the matrix until it is released due to the surrounding matrix wear.

Stage III: releasing of the crushed particle parts that act as single pulled particles. Their interactions are presented in Stage III of the previous model.

Stage IV: smoothing of the pullout-affected area, plastic deformation and gradual abrasive wear of the matrix that leads to exposure of further particles.

The process of big particle-reinforced composite wear, described in this model, can be reduced when a combination of particles of various diameters is applied. In this case, friction forces that cause cracking of big particles affect the neighbouring, smaller particles, resulting in improvement of the wear process.

5. Summary

The results of investigations prove that an addition of ceramic particles, irrespective of the size of ceramic reinforcement, enhances the tribological properties of a system. It contributes to stabilization of the friction coefficient value. The application of ceramic (SiC) reinforcement is a solution which enables expanding the possibilities of designing the tribological properties of friction pairs.

Received: 20 February 2014.

Acknowledgements

Scientific work financed by National Science Centre, Project No POIG 01.02.-0015/08.

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