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The Influence of Graphite Addition on the Abrasive Wear of AlMg10 Alloy Matrix Composites Reinforced with SiC Particles

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Abstract

The presented work deals with the influence of the addition of soft graphite particles on the abrasive wear of composite reinforced with hard SiC particles. The discussed hybrid composites were produced by stirring the liquid alloy and simultaneous adding the mixture of particles. The adequately prepared suspension was gravity cast into a metal die. Both the composite castings obtained in this way and the comparative castings produced of the pure matrix alloy were examined for the abrasive wear behaviour. Photomacrographs of the sliding surfaces of the examined composites were taken, and also the hardness measurements were carried out. It was found that even a small addition of C_{gr} particles influences positively the tribological properties of the examined composite materials, protecting the abraded surface from the destructive action of silicon carbide particles. The work presents also the results of hardness measurements which confirm that the composite material hardness increases with an increase in the volume fraction of hard reinforcing particles.

Keywords: Composites, Abrasive wear, Hard SiC particles, Soft C_{gr} particles, Hardness of composite materials

1. Introduction

During recent years, much attention is paid to the research work directed towards the development of new materials of improved functional properties. Metal matrix composites reinforced with ceramic particles are beyond doubt within this class. These materials are, in the first place, characterised by the advantageous tribological properties [1,2]. Since the introduction of ceramic particles into various alloys generally deteriorates their mechanical properties, mainly plasticity, the emphasis is put on some other material features, including the broad possibilities of wear rate reduction and the improvement of tribological properties [3,4].

Two groups of the abrasion resistant composites are distinguished in scientific literature, depending on the type of matrix and reinforcement [5,6]: the first one includes composites with low abrasive wear and the high coefficient of friction, the second one is constituted by the composites with low abrasive wear and the low coefficient of friction. The first group is composed of materials reinforced with hard particles, e.g. carbides, nitrides, or oxides, while the second one consists of composites reinforced with soft particles, such as graphite, mica or lead.

The kinetics of wear of the metal matrix composites depends on their hardness. Scientific reports inform that the abrasive wear rate of metal matrix composites grows rapidly if the hardness of abrading particles is at least 20% greater than the hardness of the abraded surface [7]. Large particles of irregular shape and sharp edges make the wear process faster than small and rounded particles [3]. It is also reported that, in the case of metal matrix composites, the more effective solution for the wear rate reduction is an introduction of greater number of small reinforcing particles rather than increasing their size [8,9]. The properly developed, strong bond between the particle and the matrix is crucial for the abrasive wear resistance of metal matrix composite materials. A phenomenon of pushing the hard particles, e.g. SiC, into the soft matrix, e.g. aluminium alloy, is observed during the abrasive wear examinations. This process, however, do not lower the abrasive wear resistance of composites. On the contrary, it can cause the strengthening of matrix in microregions directly beneath the carbide. The strengthened regions prevent the ceramic particles from being pushed further into the matrix alloy [10]. Also the detrimental phenomena can occur during the abrasion process, e.g. the particle pullout. This phenomenon results in the significant increase in abrasive wear and leads to a great damage of the sliding surfaces. It occurs due to the weak bond between a reinforcing particle and the matrix.

The most recent group of composite materials designed to achieve the high abrasive wear resistance are the so-called hybrid composites. These materials, produced so far as the aluminium matrix ones, contain both the soft lubricating particles (e.g. graphite) and hard strengthening particles (e.g. SiC) [11-15]. Examinations of their abrasive wear show that the introduction of e.g. graphite particles reduces the heat generated due to friction at the material surface, reduces the counter surface wear, and leads to the generation of the so-called tribological layers consisting of carbon, various types of oxides, and other matrix microadditions. These layers exhibit high hardness and smoothness, so that they can serve as protection against the damage of the cooperating counter surface.

2. Methods and results of investigation

The purpose of the presented work was to determine the influence of variable fraction of graphite particles on the abrasive wear of AlMg10 alloy matrix composites reinforced with silicon carbide particles, produced by gravity casting method.

The scope of research work included first of all production of composite castings containing the uniformly distributed particulate reinforcement consisting of the mixture of hard SiC particles (average grain size 100 μm) and soft C_{gr} particles (average grain size also 100 μm) embedded in AlMg10 alloy matrix. Next the abrasive wear of the examined materials was determined and their hardness was measured.

Hard and soft ceramic particles mixed in various volume proportions were introduced into the liquid aluminium alloy matrix (973 K) and intensively stirred by means of mechanical impellers at the rate of 400 rpm for 2 minutes. A turbine mixer was chosen for this purpose due to the possibility of achieving high mixing power. Mixers of this type are used for homogenization of highly viscous liquids. They generate an advantageous velocity field within the mixing tank which allows for achieving uniform suspension. They agitate axial flow of the liquid and give rise to the strong suction effect, able to lift particles up from the bottom of crucible. The diameter of impellers was equal to 0.05 m and their four pitched blades were inclined at 45° angle. The impeller was placed in the crucible axis, at one third of the liquid depth counted from the bottom.

Composite castings were ∅40 mm rods gravity cast into metal dies. Five types of hybrid composites containing graphite and silicon carbide mixed in various proportions and one composite with silicon carbide only were produced for the purpose of examination. The reinforcement content in the produced composites was therefore as follows: 10% SiC, 9% SiC+1% C_{gr}, 8% SiC+2% C_{gr}, 7% SiC+3% C_{gr}, 6% SiC+4% C_{gr}, 5% SiC+5% C_{gr}. Additionally, for the purpose of comparison, examinations of pure, non-reinforced matrix alloy were carried out.

The specimens used for abrasion tests of dimensions 10.00 × 15.75 × 6.35 mm were cut out of the middle part of cast rods and abraded against a counter surface being a steel roll of 35 mm diameter and the hardness equal to 58-63 HRC. The T-05 tester was used for examinations. In order to determine the abrasive wear kinetics for the examined composites and the matrix alloy, the mass losses after the subsequent stages of wear were determined after every 500 m of sliding distance by weighing specimens by means of laboratory scales with an accuracy of 0.00001 g. Parameters of abrasion test were selected as follows:

– type of movement → sliding at constant angular velocity of 250 rpm;
– load (P) → 50 N;
– sliding distance → 3000 m.

Also the specimens for metallographic examination were cut out of the produced castings and the photographs of microstructures were taken to ensure that ceramic particles were uniformly distributed within the metal matrix volume, which is essential for achieving suitable properties of composite material. Figuress 1 and 2 present the exemplary microstructures of the produced hybrid composites. Structure AlMg10 alloy consist of α and β (Al_3Mg_2) phase.

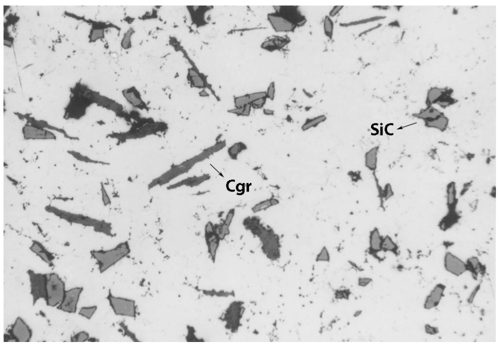

Fig. 1. Exemplary microstructure of AlMg10 + 8% SiC+2% C_{gr} composite, magn. 100×

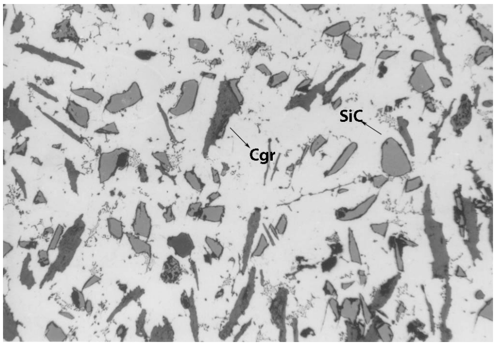

Fig. 2. Exemplary microstructure AlMg10 + 5% SiC +5% Cgr composite, magn. 100×

Figure 3 is a graphic representation of abrasive wear kinetics of the examined materials.

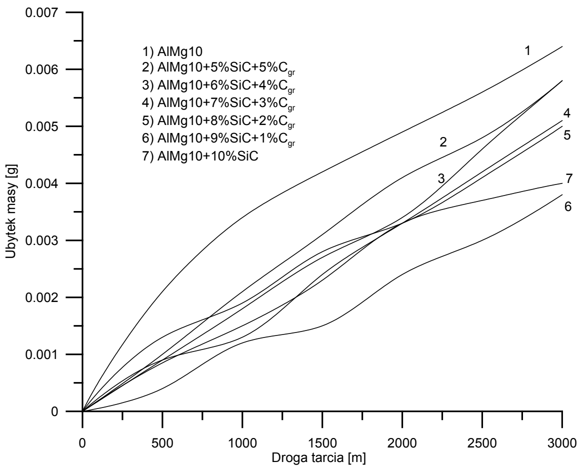

Fig. 3. Abrasive wear of the examined composites

Changes in the character of abrasive wear of hybrid composites can also be observed while examining the size of wear tracks, which are presented on the exemplary photographs (Fig. 4).

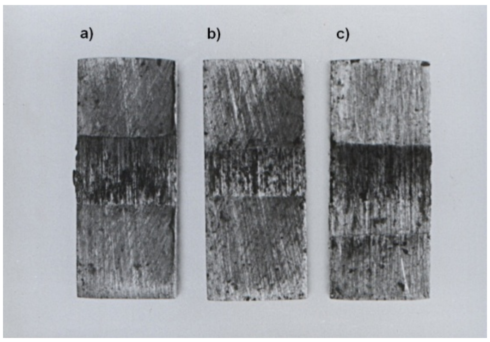

Fig. 4. Exemplary wear tracks for the examined composites: a) AlMg10+5% SiC+5% C_{gr} composite, b)AlMg10+9% SiC+1% C_{gr} composite, c) AlMg10 alloy

The subsequent Figures (5-7) show exemplary macrographs of sliding surfaces of the examined composites. These macrographs show also changes in the character of friction taking place when the graphite content is increased. They allow for observation of traces of the work of ceramic particles at the sliding surfaces of the examined materials. Such observations made for hybrid composites revealed the phenomenon of spreading the abraded graphite particles over the sliding surface and lubricating the exposed SiC particles.

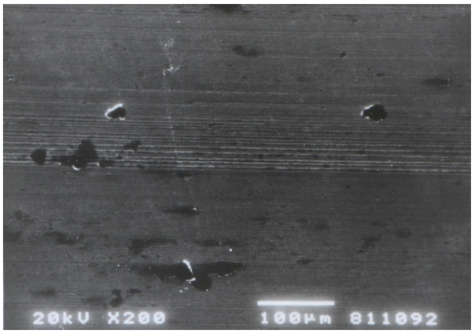

Fig. 5. Photomacrograph of sliding surface of the AlMg10 + (9% SiC and 1% C_{gr}) composite, magn. 100×

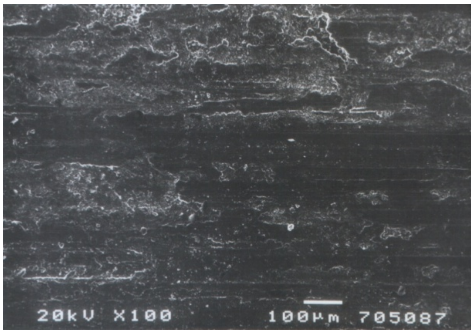

Fig. 6. Photomacrograph of sliding surface of the AlMg10 + (5% SiC and 5% C_{gr}) composite, magn. 100×

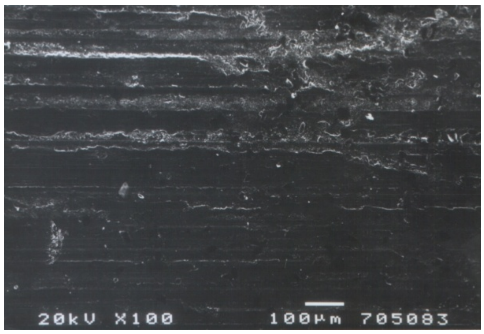

Fig. 7. Photomacrograph of sliding surface of the AlMg10 + (7% SiC and 3% C_{gr}) composite, magn. 100×

Authors of many scientific reports state that the magnitude of abrasive wear depends on the hardness of materials [11], therefore the present work gives also the results of hardness measurements carried out for the examined materials, i.e. both for matrix alloy and for produced composites. The examinations were performed using Brinell's method according to PN-93/H-04350 Standard. The indenter was a ball of 5 mm diameter. The results are illustrated in Figure 8.

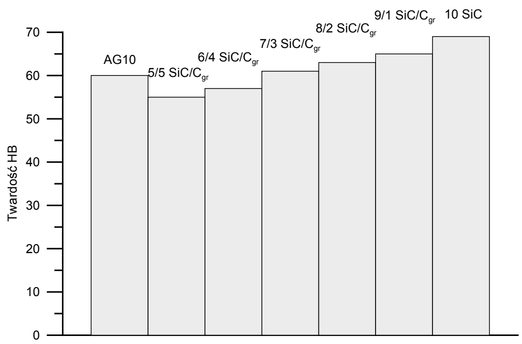

Fig. 8. Bar chart comparing hardness of examined materials

3. Summary and conclusions

Composite structure is decisive for its quality. Many problems are to be solved in order to achieve composite material with uniformly distributed ceramic particles. The development of production technology secures proper selection of process parameters and guarantees obtaining composites of suitable structure. The presented exemplary microstructures (Figs. 1,2) prove that the production parameters were chosen adequately, since both SiC and graphite particles are arranged uniformly, without clusters, and neither porosity nor the non-metallic inclusions are observed.

The presented results of abrasive wear tests of composites indicate a large increase in abrasive wear resistance of the material into which the ceramic particles were introduced. This phenomenon can be attributed mainly to the presence of hard silicon carbide particles at the sliding surface and to the action of their smoothed surfaces, against which the counter surface is sliding. Thus the matrix material loss is lessened. The presence of graphite particles exhibits smaller influence on the direct reduction of abrasive wear, expressed in terms of material mass loss, but they play an important part as a lubricant for the working surfaces of the matrix and the SiC particles themselves. It should be stressed that a significant diminution in effects of wear process was found at the counter surface working against hybrid composite specimen as compared with the counter surface used for examination of composites reinforced solely with hard SiC particles.

The results of abrasive wear tests were also confirmed by observation of wear tracks at the sliding surfaces. The sliding surface of the AlMg10 alloy matrix revealed many deep and wide scratches. As the content of graphite in composites was increased, modest and temperate damage at the composite surfaces was observed.

The results of hardness measurements shown in Fig. 8 show that SiC particles significantly influence the composite hardness. This figure illustrates also that the composite hardness decreases with an increase in graphite content. The results of both abrasive wear tests and hardness measurement confirm the supposition that larger abrasive wear occurs for composites exhibiting lower hardness. The results indicate also that the soft, lubricating graphite particles should be introduced into composites reinforced with hard silicon carbide particles in order to protect the counter surface, cooperating with such a composite and also abraded, from the destructive action of SiC particles.

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