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The Influence of Graphite Type on the Abrasive Wear of AlMg10 Matrix Composites

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Abstract

The presented work discuss the influence of various types of graphite additions on the abrasive wear of AlMg10 matrix alloy composites. Flake graphite, electrographite, and short graphite fibre were used as a composite reinforcement. Composites containing 10 vol. % of graphite particles were produced by mechanical mixing of the liquid alloy with simultaneous introduction of the reinforcement. Composite suspensions were gravity cast into metal moulds. The achieved castings were tested for the abrasive wear. Also the pure matrix alloy was examined. Microphotographs of the produced materials were taken, the specimens were also examined after the abrasion test by observing the microsections perpendicular to the abraded surface. The carried out experiments allow to state that even the little addition of graphite influences beneficially the tribological properties of composite under small loads applied to the frictional pair. It was found that under the increased load (30 N) the least abrasive wear is exhibited by the composite reinforced with graphite fibre, the largest one occurring for the composite reinforced with electrographite. The composite reinforced with electrographite, however, exhibited the mass loss less by 25% than the pure matrix alloy.

Keywords: Cast composites, Abrasion-resistant alloys, Graphite particles, Aluminium-magnesium alloys, Electrographite

1. Introduction

Metal matrix composites (MMCs) reinforced with ceramic particles are worth particular attention within the group of composite materials which are still growing in popularity among the designers of machines and devices for many branches of industry. The reason for this interest is, first of all, that they exhibit the so far unknown properties, which exceeds the properties of conventional alloys [1-6]. Modern technology is eager to apply the mixtures of high strength, or the high-temperature resistant, or abrasion resistant materials, with metal alloys. However, the production technology necessary for achieving MMCs is rather complicated and a great many of these materials require the multi-stage production. The basic operation of such a technology is the preparation of the stable and uniform suspension. Ceramic particles are, as a rule, not wetted or poorly wetted by molten metal. Moreover, the composite components often exhibit different densities, so that – taking into account the influence of the crystallization front on the reinforcing particles – there exists a danger of generating the non-uniform arrangement of the particles in metal matrix, which should be avoided. Finally, the suspension of ceramic particles in liquid metal transforms into the resulting composite due to the matrix solidification process [7, 8].

The scientific literature distinguishes two basic groups of the abrasion resistant composites, the first of them includes composites containing soft lubricating particles, such as graphite or mica, while the second one comprises materials with hard particles, e.g. SiC or Al_2O_3. Composites reinforced with hard particles are characterised by the extremely high abrasion resistance and a high coefficient of friction, whereas these containing soft particles exhibit slightly lower abrasion resistance than the ones with hard particles, and the low coefficient of friction [9-13]. Many authors point out that the abrasion resistance of MMCs is influenced by the size of particles, as well as by the volume fraction of the material reinforcing the metal matrix. Therefore one can unequivocally say that the properties of composite material results both from the properties of its components, and from the proportions between their respective fractions, as well as from their arrangement in the metal matrix. [14, 15]. Scientific reports draw also attention to the significance of the proper selection of the matrix material with respect to its wetting capacity towards the ceramic particles. Much attention is also paid to the investigation of the influence of the size and the ceramic particle fraction on the abrasive wear of these materials. [16]. However, the selection of the type of ceramic particles represents the area which is not so extensively explored, despite of the fact that many types of e.g. silicon carbide or graphite particles are commercially available, varying with chemical composition and with their purity.

The present work concerns with MMCs containing graphite particles. These materials are characterised not only by the high abrasion resistance and the low coefficient of friction. They are also seizure resistant [17-19], exhibit the high thermal conductivity and the low density. This rather favourable set of properties shows that these materials can satisfactorily replace the so far applied conventional bearing alloys.

2. Methods and results of investigation

The type of the reinforcing phases applied in MMCs is important with respect to their wetting and the expected properties of the final material. Taking this into account, the work tries to determine the influence of the graphite type on the abrasive wear of AG10 (AlMg10) alloy matrix composites. The high content of magnesium in the alloy provides for its high wetting capability, thus enabling introduction of graphite into the matrix without the precedent preparation of graphite surface.

Graphite in the form either of electrographite (powdered graphite electrodes), or chemically refined flake graphite (carbon content of 99.5-99.9%), or eventually graphite fibre containing 99% of graphite. Graphite particles were fractionated by sieving, and the particles of size within the 100-160 μm range were used for preparing composites. The diameter of a single carbon fibre was 7 μm, and its length was equal to 2 mm. Both the particles and fibre were annealed at the temperature of 250°C in order to eliminate the possible moisture. The examined composites contained either 5 vol. % or 15 vol. % of the reinforcement.

The introduction of both electrographite and graphite fibre into the liquid matrix alloy was difficult to manage, therefore the composite suspension were produced in the following way: The AlMg10 matrix alloy was overheated up to 650°C, then after removing impurities from the metal surface it was cooled to the liquid-solid state and the proper amount of graphite particles was added. After doing this, the suspension was overheated up to 670°C to achieve the suitable castability. Then it was cast into metal moulds to form rod-shaped castings of 20 mm diameter. The specimens for metallographic examination and for abrasive wear tests were cut out of these castings. Also the castings made of pure matrix alloy were produced in the same way for the purpose of comparison. The whole melting and mixing process was performed under the protective argon atmosphere.

Figure 1 presents the microstructure of AlMg10 alloy revealing the primary crystals of α-phase, characteristic for this alloy (bright areas), and the precipitates of the secondary β-phase (dark areas).

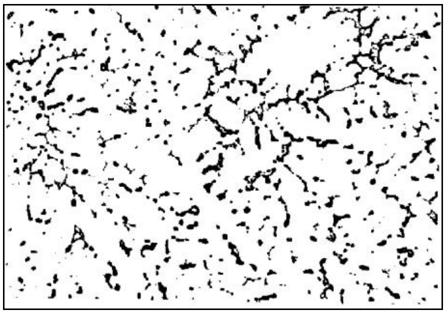

Fig. 1. Microstructure of AG10 (AlMg10) alloy cast in metal mould. Etched with 3% HF, magn. 100×

The following Figures show the exemplary microstructures of composites reinforced with graphite of various types.

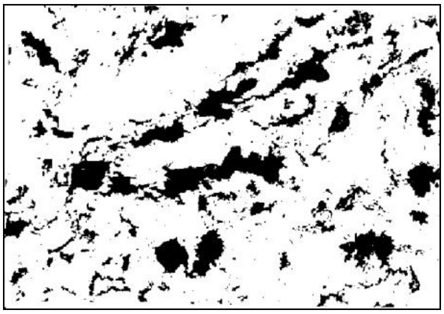

Fig. 2. Microstructure of AG10/10%Cgr composite with electrographite, magn. 100×

Fig. 3. Microstructure of AG10/10%Cgr composite with flake graphite, magn.100×

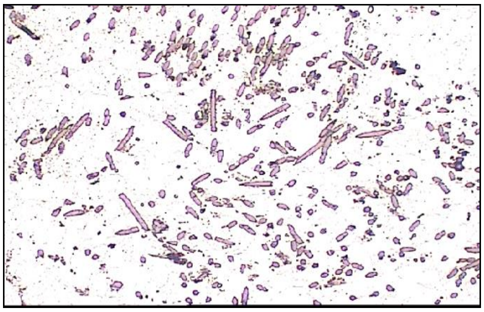

Fig. 4. Microstructure of AG10/10%Cgr composite with graphite fibre, magn. 100×

Figure 2 presents the microstructure of the composite containing electrographite. The composite exhibit not quite uniform arrangement of the particles within the volume of matrix. There were observed clusters of graphite particles as well as multiple voids in the spaces between particles. This unfavourable result can be attributed to the fact that the particles were electrically charged, this causing their joining into clusters, which are not dispersed during the mixing operation. The following figure (Fig. 3) shows the composite containing flake graphite. This material is characterised by the uniform arrangement of the reinforcing phase within the alloy matrix. The defects characteristic for the composite with electrographite, i.e. clusters of particles, gas porosity, or large aggregations of oxides, were not observed here. Figure 4 depicts the microstructure of the composite containing graphite fibre. For that case, the proper preparation of composite suspension resulted in the production of composite with graphite fibres uniformly distributed within the volume of matrix.

After performing the microstructural examination of the obtained composites, their abrasive wear was tested. The tests of the tribological properties were carried out by means of the T-05 tester at the following parameters of examination:

- specimen load: 5 or 30 N;
- sliding distance: 3000 m;
- sliding speed: 5 rotations per second (300 rpm);
- frequency: 50 Hz;
- environment: air, ambient temperature about 20°C;
- specimen: with concave sliding surface, width of 6.35 mm, area contact at the area equal to 100 mm^2;
- counter-surface test specimen: steel roll of 35 mm diameter, made of NC10 steel of hardness equal to 60 HRC.

The evaluation of the abrasive wear was carried out by the determination of mass loss along the specified sliding distance. The mass loss measurements were taken every 500 m in order to determine exactly the kinetics of the abrasion process.

Figure 5 represents the results of abrasive wear tests for both the examined composites and the matrix alloy under the load of 5 N, while Figure 6 shows the results for the load value of 30 N.

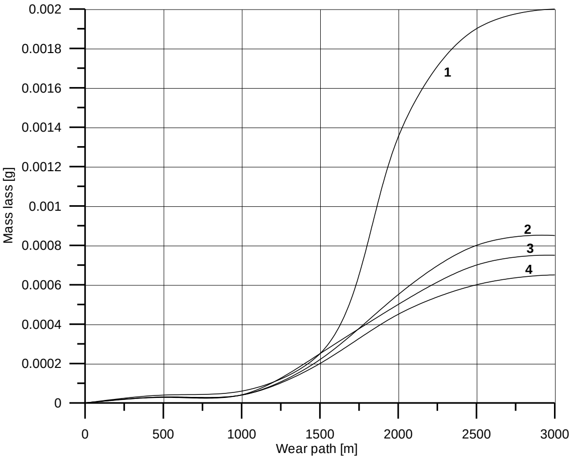

Fig. 5. Abrasive wear of the examined materials under the 5 N load: 1 – AlMg10 alloy, 2 – AlMg10/10% electrographite composite, 3 – AlMg10/10% flake graphite composite, 4 – AlMg10/10% GF

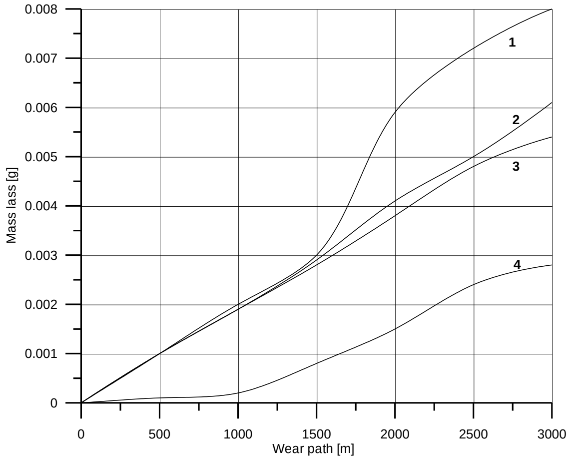

Fig. 6. Abrasive wear of the examined materials under the 30 N load: 1 – AlMg10 alloy, 2 – AlMg10/10% electrographite composite,3 – AlMg10/10% flake graphite composite, 4 – AlMg10/10% GF

The above presented plots clearly show that the smallest abrasive wear is revealed by the composite reinforced with 10% addition of graphite fibre, both for the applied load of 5 N and 30 N. The largest abrasive wear is found for the non-reinforced matrix alloy. The beneficial influence of graphite on the abrasive wear rate under the load of 5 N can be seen distinctly no matter which type of graphite was applied. The differences in mass losses are really diminutive. The importance of the type of reinforcing particles on the abrasive wear can be decidedly seen only under the load of 30 N. Here the advantageous influence of graphite addition on the abrasive wear was also observed for all the examined reinforcement types, but the electrographite was the least effective one, and the influence of carbon fibre – on the contrary – was still relatively large. While being examined under the 5 N load, all composites exhibited the final mass loss about three times less than the matrix alloy, whereas under the load of

30 N a similar result was achieved only for the composite containing graphite fibre. The final mass loss of the composite reinforced with electrographite was only by 25% less than the final mass loss of the non-reinforced matrix alloy.

3. Conclusion

The results of the carried out experiments seem to be somewhat surprising, all the more that the scientific reports often inform that the addition of carbon or graphite fibre to the Al matrix alloy influences beneficially its abrasive wear, but only when the addition does not exceed 3% [20]. The influence of flake graphite under the greater load, weaker than expected, is also astonishing. Such a result can be probably attributed to the methods of the composite suspension preparation and casting. As far as composites reinforced with electrographite are concerned, the generated reinforcement clusters were the reason of crumbling away of graphite particles from the abraded surface, so that the graphite was not smeared over the surface to that degree as in the case of composites reinforced with flake graphite or graphite fibre. Figure 7 shows the microstructure of the composite with electrographite for the cross-section perpendicular to the abraded surface, revealing the cavity left by the crumbled away graphite.

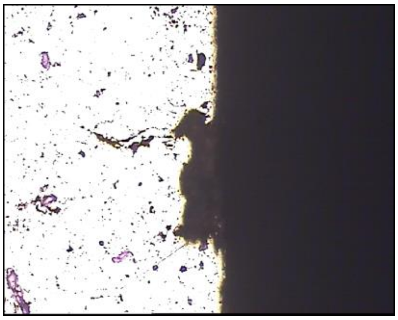

Fig. 7. Microstructure of AG10/10%Cgr composite with electrographite, the cross-section perpendicular to the sliding surface, magn. 100×

The process of fibre breaking and spreading them over the sliding surface was observed for composites containing carbon fibre. This process is likely to contribute to the protection of the matrix alloy against wear. On the other hand, the pulling out of fibre from the matrix was not observed, what can indicate the good fibre/matrix bonding. For the composites with flake graphite, the graphite was smeared over the sliding surface, what should have provided the satisfactory protection of the surface against the excessive wear due to friction. The phenomena mentioned in the work certainly require further analysis.

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