Examining of abrasion resistance of hybrid composites reinforced with SiC and C<sub>gr</sub> particles

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Received 15.07.2008; accepted in revised form 28.07.2008

Abstract

The presented work discusses the influence of the type and volume percentage of particulate reinforcement consisting of mixed silicon carbide and graphite on the abrasion wear of hybrid composites with AlMg10 matrix. Also the macro photos of frictional surfaces have been shown and the results of hardness measurements have been presented. The performed examinations have allowed for stating that the mixture of SiC and C<sub>gr</sub> particles changes in favour the tribological properties of the matrix alloy. It has been also proved that introducing hard reinforcing particles along with soft lubricating ones allows for achieving the material exhibiting high abrasion resistance, and moreover, the graphite particles protect the abraded surface from the destructive action of silicon carbide particles. Also hardness measurements have been performed and the resulting conclusion is that the composite hardness increases with an increase in volume fraction of the reinforcing particles.

Keywords: Hybrid composites, Abrasion wear, Composite hardness, Aluminium alloy

1. Introduction

The necessity of searching for new materials, especially for machine-building, automotive, and aircraft industry, exhibiting improved service performance and prolonged life expectancy, has forced the research workers to examine intensively the abrasion resistance of metal composite materials [1]. Two sorts of abrasion resistant composites can be distinguished with regard to the reinforcement and matrix types [2,3]: first of them are composites exhibiting both high abrasion resistance and high coefficient of friction, while the second type comprises composites exhibiting high abrasion resistance but low coefficient of friction. The first group consists mostly of composites reinforces with hard particles like oxides, carbides, or nitrides; the second one includes composites reinforced with soft particles like graphite, mica, or lead. The rate of abrasive wear of composites grows rapidly if the hardness of abrading particles is by at least 20% greater than the hardness of the abraded surface [4]. Large and angular particles cause greater composite wear than the small and rounded ones [5]. According to the authors of Ref. [6], introducing larger volume fraction of particles is more beneficial than increasing their size. Significantly less matrix material loss occur if there exist a strong bonding between the ceramic particles and the matrix. Frequently the pushing-in of hard particles e.g. silicon carbide into the soft aluminium alloy matrix is observed during the abrasion process. This phenomenon, however, should not affect negatively the increase of abrasion resistance of composites. This process can first of all result in matrix strengthening within microregions directly beneath the carbide. Such strengthened regions stop ceramic particles from being further pushed into the matrix [7,8]. Mechanisms of wear comprise also plastic flow and cracking. Increasing material
hardness would reduce the plastic flow, but then the danger of cracking can grow. The fracture toughness should also be taken into account while abrasive wear of composite material is concerned. The high material hardness should be composed with the high fracture toughness to achieve a metal matrix composite of the best abrasion resistance. A dangerous phenomenon occurring in metal matrix composites during abrasion is the process of pullout of the reinforcing particles. It results mainly from the interaction at the particle/matrix interface. This phenomenon brings about the rapid increase in abrasive wear of composites and can lead to the severe destruction of the abraded surfaces. Recently [9-12] experiments have been started for the new type of abrasion resistant composites, the so called hybrid composites. These composites, produced very often with aluminium matrix, contain simultaneously two or even more types of reinforcement. These can be SiC fibre and whiskers, carbon fibre, abrasiveing particles (e.g. graphite) and hard reinforcing particles (e.g. SiC). Tribological examinations of such materials have shown that introducing, for example, graphite particles, reduces the heat of friction at the 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 can serve as protection against surface damage.

2. Methodics and the examination results

The purpose of the work has been determining of influence of silicon carbide and graphite particles on the abrasive wear of gravity cast composites with AlMg10 matrix.

The range of experiment included achieving of hybrid composites containing uniformly distributed reinforcement in the form of mixed hard (SiC) and soft (Cgr) particles in the AlMg10 (also called AG10) alloy, determining of abrasive wear of these materials, and an attempt to explain the phenomena taking place during abrading of the examined composites. The four types of hybrid composites have been produced, with various fractions of silicon carbide and graphite, to perform investigation. The first of them has contained 5% SiC + 2% Cgr, the second one 5% SiC + 5% Cgr, the next 15% SiC + 2% Cgr, and the last 15% SiC + 5% Cgr. For a purpose of comparison also the specimens of pure matrix alloy (AG10) have been cast. The hybrid composites containing the mixture of SiC and Cgr particles have been produced in the two-stage process using mechanical mixing of components. Metal has been melted in the induction crucible furnace and overheated up to 680°C. The process has been conducted under the protective atmosphere of argon because of the high susceptibility to oxidation of the matrix alloy. The alloy after melting has been cooled to the temperature of about 570°C. Then the mixture of reinforcing particles has been introduced to the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. Then the mixture of reinforcing particles has been introduced to the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state. After the solidification and cooling of cast material it has been melted again to achieve the alloy in its semi-solid state.

Examination of tribological properties for the produced composites has been performed by means of a T-05 tribological tester made by the Institute for Sustainable Technologies, Radom. This testing device is intended for examining abrasion resistance of metals and plastics and for examining of seizing resistance of low friction coatings. Fig. 1 schematically illustrates the principle of operation of the T-05 wear tester.

Examination has been done by measuring the composite specimen mass loss corresponding to the specified wear path at the following characteristic parameters:
- specimen load – 50 N;
- wear path – 1,500 m;
- motion type – sliding with constant velocity of 5 r.p.s.;
- specimen type – flat cubicoid specimen of dimensions 10.00×15.75×6.35 mm with concentrated contact area.

Measurements have been taken after every 500 m of wear path to examine precisely the kinetics of abrasion. The weight of specimens has been determined by means of a laboratory scales with 0.00001 g accuracy.

Fig. 2 graphically presents the curves characterising the wearing process of the examined materials.

Fig. 1. Principle of operation of the T-05 tester; 1 – specimen, 2 – counter surface, 3 – spherical pivot, 4 – specimen fixture, 5 – tensometric bridge

Fig. 2. Abrasion wear of the examined hybrid composites
The differences in the character of abrasion wear can be also seen between depths, widths and surface defects along the wear track. Macro photos of the frictional surfaces of examined composites have been taken to illustrate these differences. They are shown in subsequent figures (Figs 3-7).

Fig. 3. Macro photo of frictional surface of the pure AG10 matrix alloy, magn. 100×

Fig. 4. Macro photo of frictional surface of AG10 + (5% SiC and 2% C\textsubscript{gr}), magn. 100×

Fig. 5. Macro photo of frictional surface of AG10 + (5% SiC and 5% C\textsubscript{gr}), magn. 100×

Fig. 6. Macro photo of frictional surface of AG10 + (15% SiC and 2% C\textsubscript{gr}), magn. 100×

Fig. 7. Macro photo of frictional surface of AG10 + (15% SiC and 5% C\textsubscript{gr}), magn. 100×

The quality of composite material is determined first of all by its structure. The uniformity of particle distribution within the matrix provides for achieving a set of desired properties of such a material. The following figures (8, 9) present the exemplary microstructures of examined composites.

Fig. 8. An exemplary microstructure of AG10 + (5% SiC and 2% C\textsubscript{gr}), magn. 100×

Fig. 9. An exemplary microstructure of AG10 + (15% SiC and 5% C\textsubscript{gr}), magn. 100×

Authors of numerous publications search for the relationship between the material hardness and its abrasion wear. The measurements concerning hardness have been performed to confirm such a relationship. Both the pure matrix and the composites has been examined by Brinell method according to the PN-93/H-04350 Polish Standard. A ball indenter with 5 mm diameter has been applied. The results of examination are plotted in Fig. 10.

Fig. 10. Hardness bar chart of the examined materials
3. Conclusions

The properly selected parameters of production of hybrid composites have allowed for obtaining the composites of the expected structure (Figs 8 and 9). Exemplary microstructures of examined composites show the uniform distribution of particles within the matrix volume, with neither particle clusters, though otherwise characteristic for particulate composites, nor porosity, nor non-metallic inclusions. Examination of abrasion wear has consists in measurement of the sampler wear along the wear path (3,000 m). The wear has been assessed by weighting the specimens. The measurement results concerning the wear along the wear path are presented in Fig. 2. Hybrid composites with AG10 alloy matrix reinforced both with hard, material-strengthening SiC particles and soft, lubricating C particles has proved to be really the materials of high wear resistance. Relationships illustrated in Fig. 2 have allowed for stating that hybrid composites of AG10 alloy reinforced with silicon carbide and graphite particles exhibit less abrasion wear than the examined pure AG10 matrix alloy. It has been also observed that the less abrasion wear occurs when the percentage of silicon carbide increases. The results indicate also that the less graphite content, the greater is the abrasive wear of the examined materials. The results of abrasion wear examination have been also confirmed by observations of the frictional surfaces. Great differences have been found regarding the frictional surface appearance. Fig. 3 presents the frictional surface of the pure AG10 matrix, where deep and wide grooves can be seen. Generally, smaller and minor damages of the frictional surfaces has been observed for specimens with increased graphite volume fraction. Results of hardness measurements have been shown in Fig. 10. The influence of SiC particles on the composite hardness is clearly visible. The addition of 15% SiC has caused the increase in hardness by about 15%. It is also noticeable that increasing graphite content reduces composite hardness. For composites with total particle fraction of 8 or 10% the hardness has even fallen slightly beneath the value for the pure matrix alloy. It can be generally stated that the hardness decreases with an increase of the abrasion wear. The presented examination results show that production of composites which beside hard particles of silicon carbide contain also the soft, lubricating graphite particles, protecting the abraded surface from destructive action of SiC particles, seems to be fairly reasonable.

References