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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 59 2014 Issue 2

DOI: 10.2478/amm-2014-0116

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MECHANICAL AND TRIBOLOGICAL PROPERTIES OF METAL MATRIX COMPOSITES REINFORCED WITH SHORT CARBON FIBRE

WŁAŚCIWOŚCI MECHANICZNE I TRYBOLOGICZNE KOMPOZYTÓW METALOWYCH ZBROJONYCH KRÓTKIMI WŁÓKNAMI WĘGLOWYMI

The paper constitutes the culmination of the foregoing investigations concerning the influence of short carbon fibre on the enhancement of AlMg10 alloy properties. The presented work brings forward the results of examinations of mechanical and tribological properties of metal matrix composites (MMCs) based on this alloy. Composites were produced by two methods: either by gravity casting or by squeeze casting in semi-solid state of a composite suspension previously obtained through mixing of its components. The volume fraction of the reinforcing phase varied and took the value of 5, or 10, or finally 15 vol. %. Specimens cut out of the experimental castings were examined with respect both to their mechanical properties, i.e. the tensile strength and unit elongation, and to their tribological behaviour. A series of examinations of the mechanical properties proved a slight increase in tensile strength and a minor decrease in unit elongation of the examined composite materials both for gravity cast and squeeze cast specimens, as compared with the properties of pure matrix alloy. The introduction of short carbon fibre into the matrix alloy resulted also in the increased abrasive wear resistance of the examined composites in comparison to the non-reinforced matrix.

Keywords: aluminium alloys, metal composites, carbon fibre, mechanical properties

Artykuł stanowi podsumowanie dotychczasowych badań na temat wpływu krótkich włókien węglowych na poprawę właściwości stopu AlMg10. W prezentowanej pracy przedstawiono wyniki badań właściwości mechanicznych i trybologicznych kompozytów metalowych. Kompozyty zostały wytworzone dwoma metodami: poprzez odlewanie grawitacyjne wytworzonej uprzednio na drodze mieszania zawiesiny kompozytowej oraz poprzez prasowanie w stanie ciekło-stałym tejże zawiesiny o zmiennym udziale objętościowym krótkich włókien węglowych. Ilość zbrojenia wynosiła odpowiednio 5,10 i 15% obj. Badania właściwości mechanicznych polegały na określeniu wytrzymałości na rozciąganie badanych materiałów oraz wydłużenia. Po przeprowadzeniu szeregu badań właściwości mechanicznych kompozytów wykazano nieznaczny wzrost wytrzymałości na rozciąganie oraz spadek wydłużenia kompozytów w porównaniu z właściwościami stopu osnowy zarówno w przypadku próbek prasowanych jaki i odlewanych grawitacyjnie. Wprowadzenie krótkich włókien węglowych do osnowy ze stopu AlMg10 spowodowało również zmniejszenie zużycia ściernego badanych kompozytów w porównaniu z nieuzbrojoną osnową.

1. Introduction

At present a group of materials known as metal matrix composites (MMCs) exhibits the most dynamic development and is highly appreciated by specialists in almost every field of application. MMCs reinforced with short ceramic fibre are produced by a variety of methods, among which the most popular are suspension casting, infiltration of the prepared preforms, or the squeeze casting in the semi-solid state [1-3]. Short fibre is distributed randomly within the matrix during the production process, so the alloy is not strengthened as efficiently as in the case of properly oriented reinforcement of continuous fibre, providing the maximum strength of the material [4,5]. On the other hand, the random orientation of fibre greatly increases cracking resistance of a composite material. It is essential for materials composed of the ductile matrix and short ceramic fibre with high tensile strength that the bond between the matrix and an individual fibre should be sufficiently strong to enable the transfer of the load between the matrix and the fibre. Mechanical properties of fibrous composite materials depend not only on the properties of their components themselves, but, most of all, on the efficiency of transferring the load from the matrix to the fibrous reinforcement [6]. The main reason of the non-uniformity in distribution of reinforcing phases lies in the composite production technology. There are some difficulties to overcome resulting e.g. from poor wettability of the non-metallic phases with liquid metals, or the non-optimised mixing process, or in some cases from the specific crystallization of such complex systems [7]. The poor wettability of carbon fibre with the liquid matrix alloy is frequently improved by special treatment, mainly by either covering the fibre with metal layers or modifying of matrix alloy

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[8,9]. Such treatment, however, is rather expensive, therefore the more economic and uncomplicated methods of production are incessantly searched for. One of such possibilities is an application of a squeeze casting technology to the composite suspension in semi-solid state. This modern method of production of composites reinforced with short fibre consists in the introduction of metal in the semi-solid state into the heated die and the subsequent mechanical applying of pressure by means of the pressing die (punch) [10]. High values of pressure applied in this method and rapid cooling result in the refined matrix structure and the decreased porosity of casting, by the same increasing mechanical properties of composite material [4,11].

MMCs have found a broad range of application as structural material for various machines and devices. Composites reinforced with carbon fibre are applied in many industrial branches ranging from aviation, chemistry, automotive industry, electrical industry to sport or health care industry. The unique set of mechanical and thermal properties, which is possible to achieve, makes such materials well suited for elevated temperature applications as well [12]. Many composite elements have to work under conditions which require for the sufficient abrasion resistance. Therefore it is important that the fraction of reinforcement is correctly selected in order to stabilize the frictional wear of composite elements under the existing conditions at a possibly low level.

2. Methods and results of investigation

The investigation was started with producing composites based on the AlMg10 matrix alloy reinforced with short carbon fibre of 7 μm diameter and 4 mm length, the volume fraction of the reinforcing phase being 5, 10 or 15%. Composites were produced from the prepared composite suspension either by gravity die casting or by semi-solid squeeze casting. To produce the suspension, the charge of matrix alloy was melted in a crucible induction furnace and overheated to the temperature of 930 K, then the short carbon fibre (CF) was added by means of a dosing spout and the components were thoroughly stirred. One part of suspension was gravity cast into a die with a cylindrical cavity 15 mm in diameter, and the other was cooled in crucible to the semi-solid state. The material in the semi-solid state was squeeze cast in a cuboidal die of dimensions 100×50×15 mm by means of a hydraulic press PHM-250C under the 100 MPa pressure. This pressure value was maintained by 20 s.

Standard specimens intended for examination of the tensile strength R_m and the unit elongation A_5 were cut out of the obtained castings and tested by means of ZWICK-1488 tensile testing machine. Also there were prepared specimens of 25 mm length and 3 mm diameter for abrasive wear tests, which were performed using T-01M tester. Finally, specimens for microstructural examination were cut out of the achieved castings.

Fig. 1 presents the microstructure of the gravity cast AlMg10 matrix alloy, while Fig. 2 depicts the squeeze cast material. Further figures show exemplary microstructures of composites containing short carbon fibre: Fig. 3 concerns the gravity cast composite, Fig. 4 – the squeeze cast one.

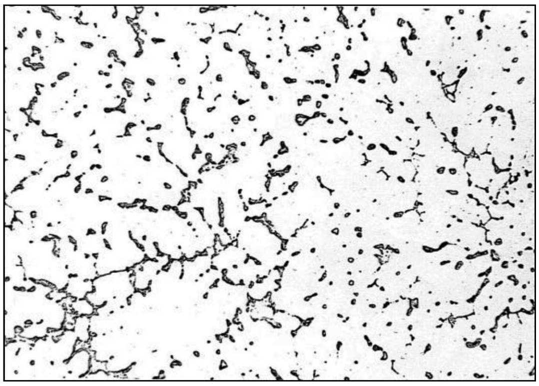

Fig. 1. Microstructure of gravity cast AlMg10 alloy; magn. 100×, etched with 4%HF

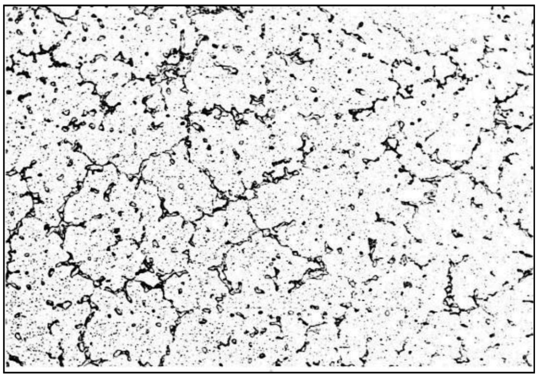

Fig. 2. Microstructure of squeeze cast AlMg10 alloy; magn. 100×, etched with 4%HF

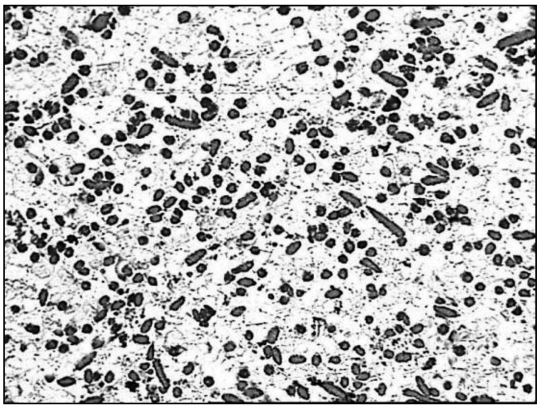

Fig. 3. Exemplary microstructure of gravity cast AlMg10/10% CF composite; magn. 100×, etched with 4%HF

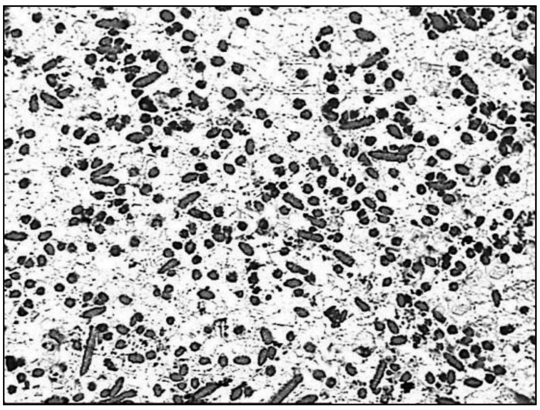

Fig. 4. Exemplary microstructure of squeeze cast AlMg10/10% CF composite; magn. 100×, etched with 4%HF

Fig. 1 shows a typical microstructure of AlMg10 alloy solidified in a metal die, characterised by occurring of α solid solution crystals and the Al_8Mg_5 intermetallic phase generated during the eutectic transformation. Fig. 2 presents the microstructure of squeeze cast AlMg10 alloy. Exerting of pressure during the material solidification implied advantageous changes in the matrix alloy microstructure. The microstructure of the examined specimens is refined in comparison with the gravity cast alloy. This refinement is caused by the increased rate of heat exchange, i.e. by shorter solidification time of castings achieved by this method. Microstructural analysis of the examined composites reveals that the application of the semi-solid squeeze casting method did not changed radically the arrangement of short carbon fibre. The appropriate preparation of composite suspension resulted in the uniform distribution of carbon fibre within the volume of matrix both for gravity cast and squeeze cast composites.

Fig. 5 presents the results of tensile tests performed for the examined materials, and Fig. 6 illustrates the results of examination of the unit elongation.

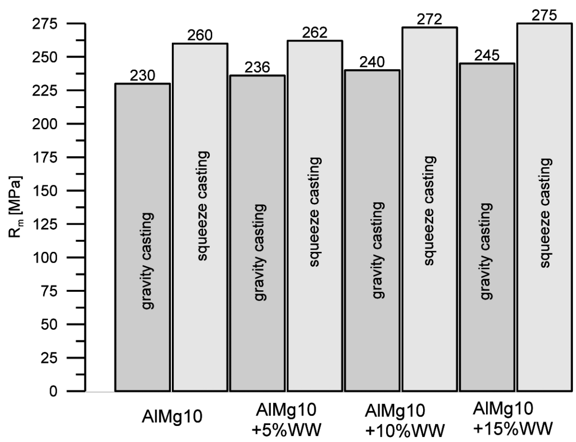

Fig. 5. Tensile strength of the examined materials

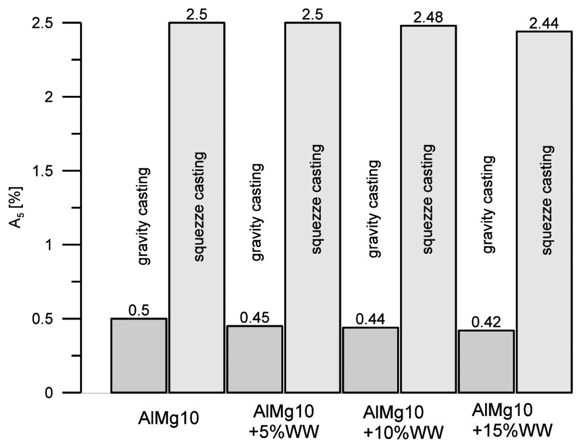

Fig. 6. Unit elongation of the examined materials

The performed examinations of mechanical properties show distinctly that the application of the semi-solid squeeze casting method results in the improvement of mechanical properties of castings. The squeezed castings, both made of pure matrix alloy and of the composite material, exhibit unit elongation about five times greater than the gravity cast ones, though the introduction of fibre caused a slight decrease in its value. The tensile strength of squeezed casting is also improved and reaches the level of 260 or even 270 MPa, the increased content of carbon fibre contributing slightly to the increment in results.

The work dealt also with the influence of the carbon fibre content on the abrasive wear of composites. Examinations of their tribological properties were carried out by means of T-01M testing device. The T-01M tester allows for performing tests in accordance to the ASTM G99 and the DIN 50324 Standards. Examinations were carried out for cylindrical specimen of 3 mm diameter made of the examined material and the steel counter-surface in a form of flat disc, 30 mm in diameter, made of NC10 steel of 58-63 HRC hardness. Test conditions were as follows: specimen load – 5 or 15 N, sliding distance – 3000 m, sliding rate – 303 rpm. The abrasive wear of composites was evaluated by determination of the specimen mass loss along the sliding distance. The maesurements were taken every 500 m in order to determine the kinetics of abrading process exactly. The obtained results of abrasion tests both for AlMg10 alloy and for composites reinforced with short carbon fibre are graphically represented in Figs. 7-9.

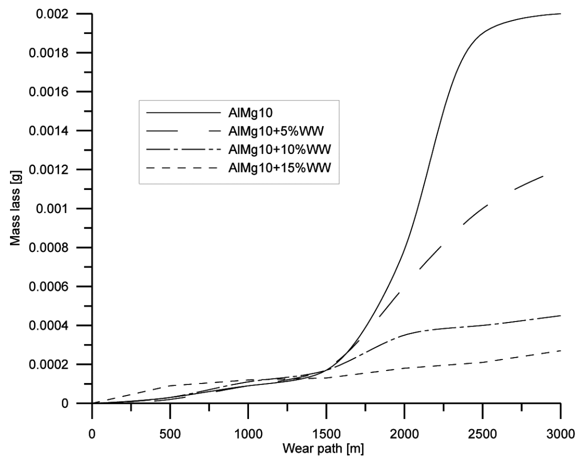

Fig. 7. Abrasive wear of the examined gravity cast materials (5N load)

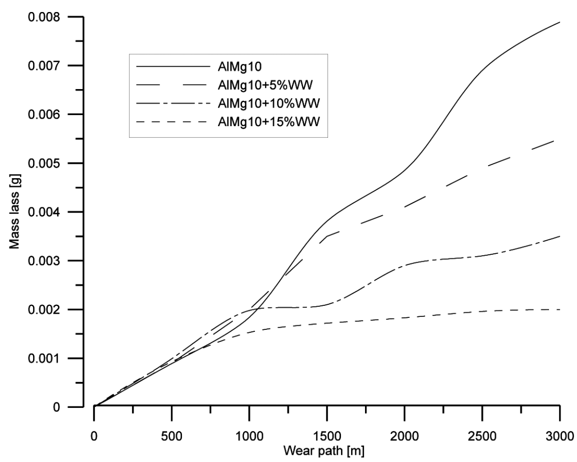

Fig. 8. Abrasive wear of the examined gravity cast materials (15N load)

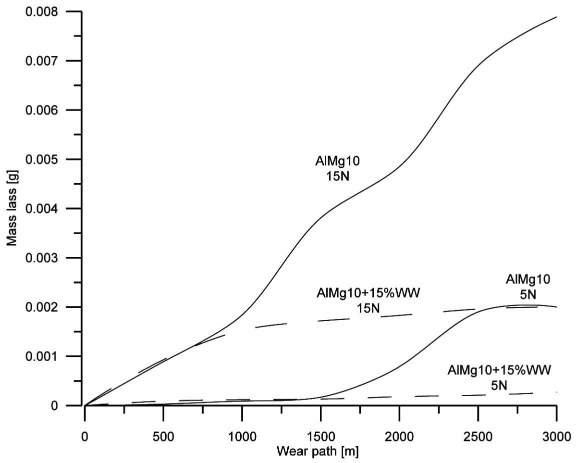

Fig. 9. Comparison of abrasive wear kinetics of pure matrix alloy and composite containing 15% CF under various load conditions (gravity cast materials)

Figs. 7 and 8 show the abrasive wear of gravity cast AlMg10 matrix alloy and gravity cast composites containing various fractions of carbon fibre under the load of 5 or 15 N, respectively. Figure 9 compares the mass loss curves for matrix alloy and for a selected composite material under these two load values in order to demonstrate the influence of load on the kinetics of abrasive wear. The figures show that the greatest mass loss occurs for pure AlMg10 matrix alloy, and the lowest one is observed for the composite containing 15% CF. It can be seen that the abrasive wear resistance rises with growing content of short carbon fibre for both values of the load. Nevertheless, the enlarged caused a significant increase in the mass loss rate, both for matrix alloy and the examined composite materials. Figures 10-12 show the results of abrasion test achieved for semi-solid squeeze cast specimens made either of AlMg10 matrix alloy or of composites reinforced with short carbon fibre.

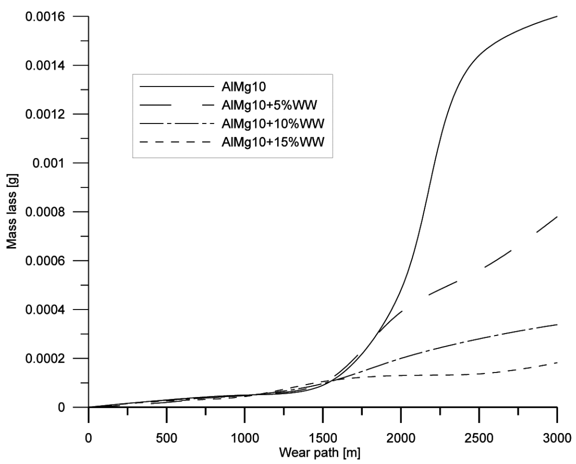

Fig. 10. Abrasive wear of the examined squeeze cast materials (5N load)

The introduction of short carbon fibre influences advantageously also the wear resistance of the squeeze cast AlMg10 alloy. Again, the abrasive wear resistance increases with an increase in carbon fibre content, and the enlarged load causes greater mass losses during the test. The results are interesting with regard to the fact that even the small amount of carbon fibre introduced into the matrix alloy reduces the mass loss by over 30% (see Fig. 11).

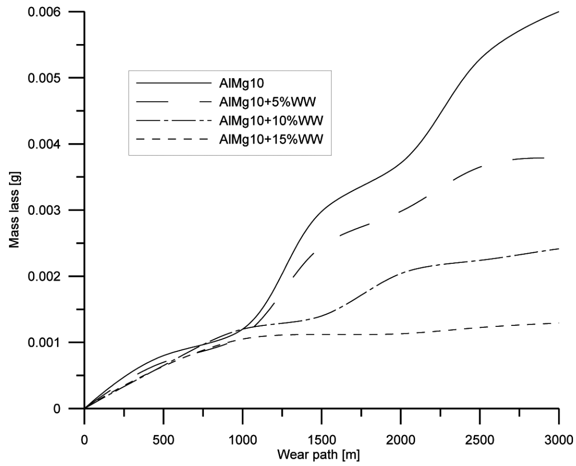

Fig. 11. Abrasive wear of the examined squeeze cast materials (15N load)

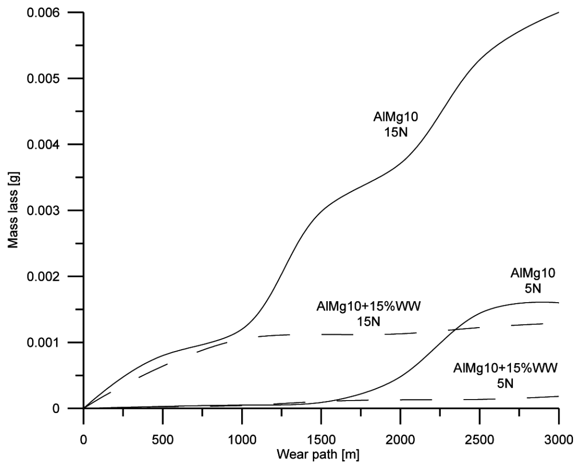

Fig. 12. Comparison of abrasive wear kinetics of pure matrix alloy and composite containing 15% CF under various load conditions (squeeze cast materials)

3. Conclusion

Application of the semi-solid squeeze casting method for production of AlMg10 alloy castings makes it possible to achieve the material with tensile strength a little higher than the strength of gravity cast alloy. The introduction of short carbon fibre into the AlMg10 metal matrix results in a slight increase in tensile strength R_m for both gravity and squeeze castings. The increase of carbon fibre content, however, leads to the minor decrease of unit elongation of the material. It is worth noticing that the obtained results of tribological tests indicate that even small addition of carbon fibre leads to the increase in the abrasive wear resistance of composite as compared with pure AlMg10 alloy, and this increment can be further enlarged by increasing the fibre fraction in the composite material. The technology of squeeze casting in semi-solid state enabled to achieve the increased abrasive wear resistance of both pure matrix alloy (by 20%) and composites reinforced with short carbon fibre (from 25% to even 35%). All of the examined materials exhibit a significant reduction of abrasive wear resistance when an increased load is applied to the sliding surfaces. The composite materials, however, seem to be more sensitive than pure matrix alloy to such a change. As far as pure matrix alloy is concerned, the increase of load from 5 to 15 N led to the mass loss increased by 70%, both for gravity cast and for semi-solid squeeze cast alloy, but in the case of composite material the mass loss under the enlarged load was greater by about 85%.

Additionally, observation of microstructures of castings produced according to either gravity casting or semi-solid squeeze casting technology confirms that the latter, at least for the pressure value of 100 MPa applied during the experiment, allows for achieving sound castings without structural discontinuities like gas or shrinkage porosity, which are characteristic for gravity castings.

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Received: 10 January 2014.