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Properties of AlSi9Mg Alloy Matrix Composite Reinforced with Short Carbon Fibre after Remelting

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Abstract

The presented work describes the results of examination of the mechanical properties of castings made either of AlSi9Mg alloy matrix composite reinforced with short carbon fibre or of the pure AlSi9Mg alloy. The tensile strength, the yield strength, Young's modulus, and the unit elongation were examined both for initial castings and for castings made of the remelted composite or AlSi9Mg alloy. After preparing metallographic specimens, the structure of the remelted materials was assessed. A few non-metallic inclusions were observed in the structure of the remelted composite, not occurring in the initial castings. Mechanical testing revealed that all the examined properties of the initial composite material exceed those of the non-reinforced matrix. A decrease in mechanical properties was stated both for the metal matrix and for the composite after the remelting process, but this decrease was so slight that it either does not preclude them from further use or does not restrict the range of their application.

Keywords: Metal matrix composites, Short carbon fibre, Silumins, Mechanical properties, Recycling of composites

1. Introduction

The term 'recycling' denotes the recovery of the material consisting in the processing of substances or materials contained in the production wastes in order to obtain a substance or material which can be used again for its original purpose or find another application [1, 2]. The recycling of materials should be carried out as close as possible to the place where the waste material is generated, so that the reuse of wastes would be the most efficient. Foundries can be regarded as examples of such highly efficient reuse of metal scrap. The types of wastes generated by the foundry industry demand for various recycling methods: the material recycling can include the use of metal scrap as a valuable charge material or the reclamation of the spent moulding sands, the product recycling can be realised by repairing of the defected castings, and the energetic recycling concerns the use of combustible gases emitted in the production process [3]. The scrap consisting of composite waste is even a greater problem. In general, this material can only be remelted. There is a multiplicity of factors which influence the quality of composites after being remelted, e.g. the duration and the temperature of melting, the duration and the velocity of mixing, melting losses of individual elements, reactions proceeding at the metal/ceramics interfaces, changes in surface tension and interfacial tension in adhesive bonds, the sedimentation or the flowing up of the particles. Depending on the type of bonding between the reinforcement and the metal matrix, the transition layer often grows or fades out during the remelting. The reported scientific data state that the composite properties after remelting are lower than those before the process [4, 5]. The recycling process includes not only the remelting of composite scrap, but also the recovery of materials.

However, the separation of composite components and recovery of the matrix alloy is very difficult for metal matrix composites [6-9]. The process is relatively easy only for the so-called infiltrated composites. The increasing production of metal matrix composites demands for the development of a technology which would allow for reusing the industrial waste consisting of such materials. Composite scrap should be applied as charge material for production of new castings. Also a method which would enable the separation of the reinforcement from the metal matrix in order to reuse the matrix alloy is worth searching for.

A broad range of metal matrix composites (MMCs) reinforced with ceramic particles or chopped fibre arranged randomly in the volume of matrix exhibits relatively low mechanical properties mainly due to the irregular arrangement of these reinforcing phases within metal matrix [10, 11]. This irregularity is caused primarily by their production technology, and is usually related to the poor wettability of non-metallic phases with molten metal, the non-optimised mixing process, and sometimes it results from the specific solidification course of such complex systems [12, 13]. Therefore the assessment of the arrangement of reinforcing phases becomes the necessary part of the structural examination.

Mechanical properties of MMCs reinforced with short carbon fibre depend essentially on the properties of the fibre itself, but to the large extent they are also influenced by the quality of bonding between fibre and matrix, which is responsible for the proper transfer of load from one phase to the other [13-15]. Therefore retaining such a good bonding between fibre and matrix is a matter of great importance for the remelted composites.

2. Methods of investigation

The work presents the results of investigations concerning the mechanical properties of the remelted AlSi9Mg alloy matrix composite reinforced with short carbon fibre. The fibre applied for composite production was the chopped carbon fibre of 5 mm length and the diameter of 7 μm. Composite containing 10 vol% of short carbon fibre was selected for examination.

Originally the composite was produced by mechanical mixing of the liquid alloy with simultaneous introduction of the reinforcement to the stirred alloy. The mixing process was carried out under argon protection. The prepared composite suspension was gravity cast in a die. Then the achieved composite castings were remelted and again gravity cast in a die, the pouring temperature being 923 K. After the solidification of castings, metallurgical microsections were prepared in order to observe the resulting structure, taking particularly into account the uniformity of the reinfocement arrangement in the matrix, as well as the degree of contamination of composite after the remelting process. For the purpose of comparison, castings made of pure AlSi9Mg alloy were also prepared in the following manner: the alloy ingot was melted and gravity die cast; specimens for metallographic examination and strength tests were cut out of the castings; the rest of the material was again melted and gravity cast to produce castings for further examinations. The pure AlSi9Mg alloy was also melted under the protective argon atmosphere, as it was in the case of composite under examination.

Tests of mechanical properties of the examined composite included the following measurements: yield strength $R_{0.2}$, tensile strength R_m, longitudinal elastic modulus E, and unit elongation A_5. All mechanical ratings were determined during tensile tests carried out according to the PN-91/H-04310 Standard. The measurements have been performed by means of Zwick 1488 tester at the parameters as follows: the initial stress – 1 MPa, the strain rate – 7 mm/min, maximum breaking force – 10 kN. All measurements were taken for five composite specimens and five AlSi9Mg alloy, both prior to and after the remelting.

3. Results of investigation

Figure 1 presents the microstructure of the remelted AlSi9Mg alloy. The structure is free from the non-metallic impurities, despite the fact that the alloy was not refined.

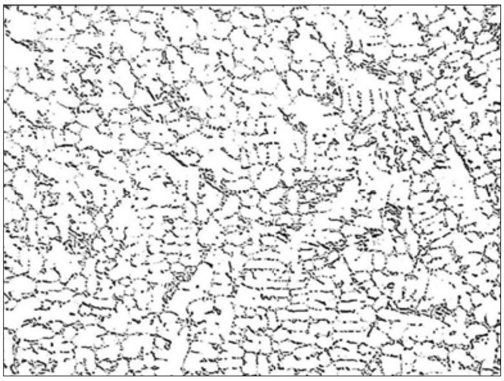

Fig. 1. Microstructure of the remelted AlSi9Mg alloy, magn. 100×

Figure 2 shows the exemplary microstructure of composite produced by mixing of the liquid alloy with simultaneous introduction of short carbon fibre (CF).

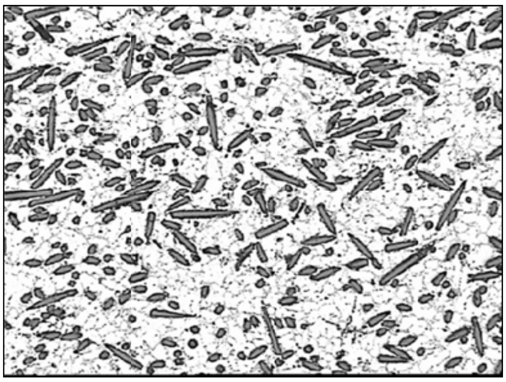

Fig. 2. Microstructure of the AlSi9Mg/10% CF composite, magn. 100×

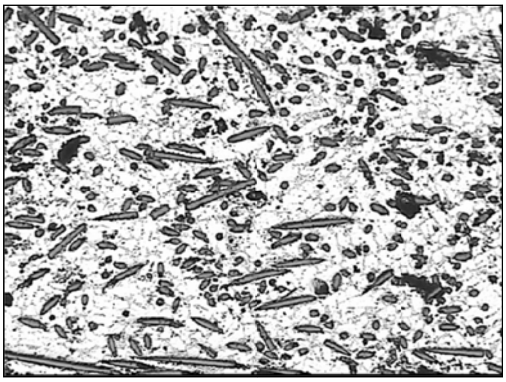

Fig. 3. Microstructure of the AlSi9Mg/10% CF composite after remelting, magn. 100×

Figure 3 depicts the microstructure of the composite produced by the remelting of the previously made composite castings.

The observation of microstructures allows to state that the composite reinforced with short carbon fibre is characterised by the uniform arrangement of the reinforcement within the metal matrix, and its microstructure, presented in Fig. 2, is free of contaminating inclusions or pores. The structure of the remelted composite is also characterised by the uniform arrangement of the reinforcement in the matrix, but it is contaminated by the occasional non-metallic inclusions.

Figures 4 and 5 present the results of measurements concerning mechanical properties of AlSi9Mg alloy and the composite containing 10% of carbon fibre (CF), respectively, both prior to and after the remelting. The presented results are actually the averages taken from five measurements.

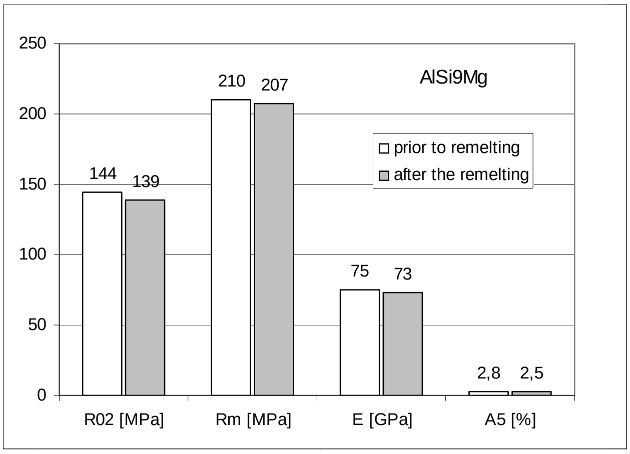

Fig. 4. Mechanical properties of AlSi9Mg alloy prior to and after the remelting

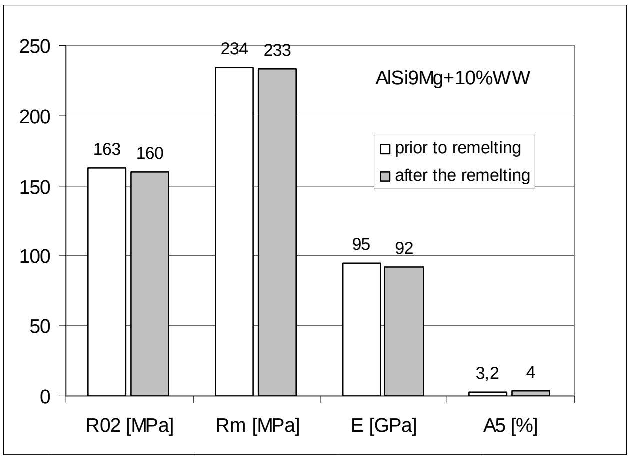

Fig. 5. Mechanical properties of AlSi9Mg alloy/10% CF prior to and after the remelting

The employed technology of composite casting production brought the satisfactory results as far as mechanical properties of the composite are concerned. Admittedly, there are reports pointing to the possible reduction of composite strength as compared with the strength of the matrix itself, but the above presented results of investigations do not confirm such a phenomenon. The difference should be possibly attributed to the different technology of MMCs production. The presented here results of investigations indicate a slight increase in both tensile strength and yield strength for the composite reinforced with carbon fibre as compared with the matrix alloy itself. Also the distinct increase in the elastic modulus E and the unit elongation A_5 was found for the composite material as compared with the values of E and A_5 measured for the matrix alloy.

It is well known that mechanical properties of fibrous composites depend strongly on the indexes of uniformity of fibre arrangement and the strength of bonding between the fibre and the matrix. The presented results of examination indicate that there is a possibility of strengthening the relatively brittle aluminium casting alloys with chopped carbon fibre. The achieved level of strength properties of aluminium matrix composite reinforced with short carbon fibre is satisfactory, and the introduction of fibre into the metal matrix allowed to rise distinctly the plastic properties of the investigated material. It is well known that short carbon fibre arranged randomly in the volume of aluminium alloy increase definitely the energy required to break the material by increasing the fracture area while the cracking starts, therefore even better results can be expected as far as the crack resistance of the examined materials is concerned.

Comparing the mechanical properties of the examined materials before and after remelting one can find that the satisfactory level of this properties is retained, provided that the conditions under which the remelting process is held are properly selected, and first of all the time of holding the alloy or composite suspension in the furnace is not too long. Even the slight increase in the unit elongation was observed for the remelted fibrous composite. It was concluded that the presence of a few fibre clusters observed in the initially produced composite can be considered as a possible reason of this phenomenon. Those regions could exhibit the weakened bonding between the fibre and the matrix, however this influence should also affect other mechanical properties of the composite. Such clusters were not found after remelting, so that they were probably scattered during the repeated mixing of the suspension.

4. Conclusion

The performed investigations showed that the remelted AlSi9Mg alloy matrix composite reinforced with carbon fibre exhibits the reinforcement arrangement similar to that observed in the initial composite. Although a few non-metallic inclusions were found in the microstructure of the remelted composite, they did not preclude further application of the material. The structure of the remelted pure matrix alloy also remained free of such defects as inclusions or porosity.

The results of examinations indicate that both the castings produced of the remelted AlSi9Mg alloy and the ones made of AlSi9Mg alloy matrix composite containing 10% of carbon fibre in general retain the strength and the plastic properties similar to the initial castings. The decrease in properties, though observed, is so slight that it either does not preclude them from further use or does not restrict the range of their application.

The performed investigations prove also that the reuse of the waste composite materials as charge material for the further production of composite castings is quite reasonable. The castings produced of the remelted composite waste exhibit the regular structure, not diverging from the structure of initial composite. The quantity of impurities in the alloy did not rise to the large extent.

The results of examination did not confirm the fact of the decrease in properties of composite after its remelting. They prove that the properly chosen technology of the initial composite production, as well as the carefully carried out remelting and casting processes, allow to retain the satisfactory level of composite properties.

It can therefore be considered that the remelting of composite waste opens the encouraging perspective for the difficult problem of recycling of composite materials, the more that the attempts of their recycling consisting in the separation of composite components and the recovery of the matrix alloy so far have not been very effective.

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