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Use of Used Graphite Electrodes as Metal Matrix Composites Reinforcement

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Abstract

The work presents the effect of the addition of graphite from recycled graphite electrodes on the mechanical properties of metal matrix composites (MMC) based on the AlMg10 alloy. A composite based on the AlMg10 alloy reinforced with natural graphite particles was also tested. Further, tests of the mechanical properties of the AlMg10 alloy were performed for comparative purposes. Composites with a particle content of 5, 10 and 15 percent by volume were produced by adding introduction of particles into the liquid matrix while mechanically mixing molten alloy. The composite suspensions were gravitationally cast into metal molds. Samples for the R_m, $R_{0.2}$, A and E tests were made from the prepared castings. Photos of the microstructures of the materials were also taken. The research shows that the addition of graphite to the matrix alloy causes minor changes in tensile strength (R_m) and yield strength (R_{02}), regardless of the type of graphite used. The results of the relative elongation tests showed that the introduction of graphite particles into the matrix alloy had an adverse effect on the elongation values in the case of each of the tested composites. The introduction of graphite particles into the AlMg10 alloy significantly increased the Young's modulus value, both in the case of composites with flake graphite (natural) and graphite from ground graphite electrodes.

Keywords: Recycling, Graphite electrode, Natural graphite, Metal composite materials, Mechanical properties

1. Introduction

Recycling (recirculation) is defined as the processing of both industrial and household waste from products that have been withdrawn from use. These materials are processed in order to put them back into circulation and use them to make new materials or products [1-3].

Electrode consumption depends mainly on the type of material being melted, temperature and process duration [4,5]. The graphite electrode market was estimated at US$ 5.5 billion last year (IMARC: Graphite Electrodes Market – Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2021-2026) and is becoming very important due to the ongoing decarbonization of the steel and metallurgical industry. Therefore, not only the repair process is important, but also the reuse of graphite electrodes or the materials from which the electrodes are made [6,7]. It should be remembered that graphite electrodes are widely used not only in industries such as steel production, but also in many other industries such as the production of batteries, fuel cells and many others [8-10].

There are many benefits of recycling graphite electrodes. First of all, the advantage of this process is the saving of raw materials. Graphite is a very sought-after and valuable raw material, and recycling graphite electrodes allows to recover them from waste, instead of using new graphite. Nowadays, recycling of graphite electrodes is very important for sustainable resource management and environmental protection [11-13].

Ground graphite electrodes can be used in many ways, depending on their purpose and type. Most often, ground graphite electrodes are used to produce new electrodes. Another use of ground electrodes is to use them as a raw material in other applications, such as the production of activated carbon, composite materials, lubricating materials or as an additive in for ceramic products. Ground graphite electrodes can also be used as a raw material in the cement industry as an alternative raw material. They can also serve as an alternative fuel in combustion processes for the production of electricity in thermal power plants or in thermal waste utilization processes [12].

It is important to use appropriate methods of managing ground graphite electrodes – in accordance with applicable environmental protection laws and regulations to minimize potential environmental impacts and promote sustainable resource management [13].

Metal matrix composite materials reinforced with graphite particles are constantly gaining popularity among designers of machine parts in most industry sectors. High abrasion resistance, low friction coefficient and many other advantages mean that the demand for these materials is constantly growing [14,15].

Many publications draw attention to the importance of selecting the appropriate material for the composite matrix and reinforcing material, among other things, due to the lack of wetting of ceramic particles by liquid metal. Researchers pay much attention to such aspects as, for example, the effect of the particle size and the content of graphite particles on the abrasive wear of these materials [16-19]. Less attention is paid to what type of graphite in terms of chemical composition and purity is introduced into the matrix alloy. There are also few publications on the effect of ceramic particles on properties other than tribological ones [20]. The topic of this work is the effect of the type of graphite on the mechanical properties of composites based on the AlMg10 alloy.

2. Methodology and research results

The type of graphite particles used as the reinforcing phase in metal composite materials has a very large impact on the properties of the composite. This work presents the effect of the type of graphite on the mechanical properties of a composite based on the AlMg10 alloy. An alloy containing about 10% magnesium was used as the metal matrix of the composite because magnesium facilitates the wetting of particles by the liquid metal and, therefore, the introduction of particles without the need to treat their surface.

Two types of graphite were used to produce the composites: chemically refined flake (natural) graphite and recycled graphite obtained from ground graphite electrodes. In both cases these were particles with a fraction size ranging from 100 to160 µm. In order to remove moisture, flake graphite particles and graphite obtained from ground graphite electrodes were annealed at a temperature of 250°C. The tested composites contained 5, 10 and 15 percent by volume of reinforcing particles.

The technology of producing composites based on aluminum alloys into which low-density particles such as graphite are introduced causes many problems, despite the high magnesium content in the alloy. Therefore, in this case, the particles were introduced into the alloy in a liquid-solid state, then heated to the pouring temperature and cast into prepared metal molds. The entire process took place under the argon shroud. Ready-made samples were cast for strength tests. After carrying out the tests, metallographic sections were polished on these samples in order to observe the microstructure of the tested materials. Some other samples were also cast from the AlMg10 alloy alone, in the same way as the composites, for comparative purposes.

Figures 1 and 2 show photos of graphites used to produce the composites. Figure 1 shows flake graphite (natural) and Figure 2 shows graphite obtained from ground graphite electrodes.

Fig. 1. Flake graphite

Fig. 2. Graphite from ground graphite electrodes

The following figures show the microstructures of the matrix alloy and the produced composites. Figure 3 shows the microstructure of the AlMg10 matrix alloy, Figure 4 shows the microstructure of the composite containing 10% of flake graphite particles (natural), and Figure 5 shows the microstructure of the composite containing 10% of graphite from ground electrodes.

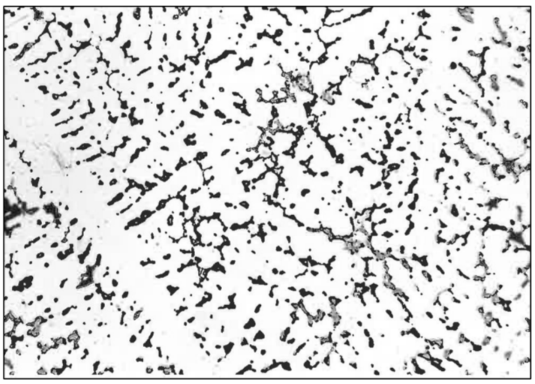

Fig. 3. Microstructure of the AlMg10 matrix alloy, magnification 200x

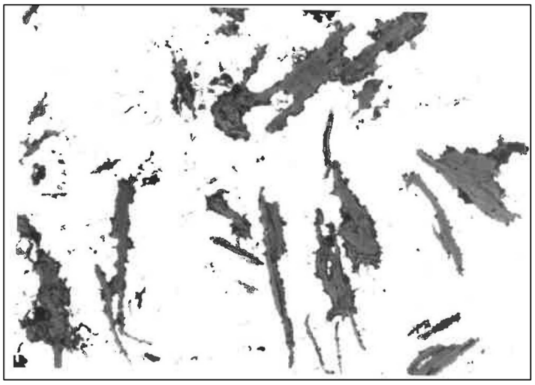

Fig. 4. Microstructure of the AlMg10 composite + 10% flake graphite, magnification 200x

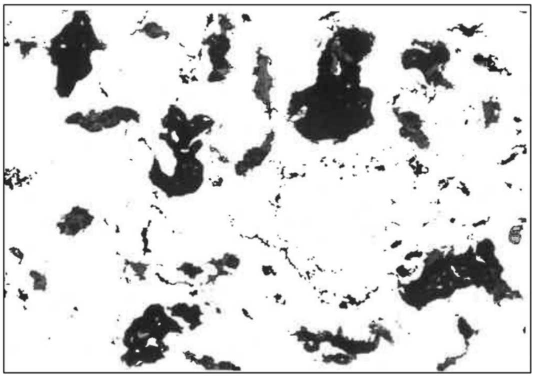

Fig. 5. Microstructure of the AlMg10 composite + 10% graphite from ground electrodes, magnification 200x

Figure 4 illustrating the microstructure of the composite containing flake graphite particles shows a uniform distribution of particles in the matrix volume. No particle clusters or porosity were observed. Figure 5 shows the microstructure of the composite with particles from ground graphite electrodes. Particle clusters were observed on the structures of these composites and their distribution was not as uniform as in the case of composites with flake graphite. Already when screening particles from ground electrodes and dosing these particles into the metal, it was observed that these particles agglomerated into larger fractions. Mixing the alloy while dosing these particles did break up these agglomerates but not sufficiently.

The tests of the mechanical properties included the determination of yield strength R_{02}, tensile strength R_m, modulus of elasticity E and relative elongation A. All the measurements were performed in a tensile test on a Zwick 1488 tensile tester. Three parallel measurements were made for each type of composite and, for comparison, for the matrix alloy. The results of the research are presented in Figures 6-9.

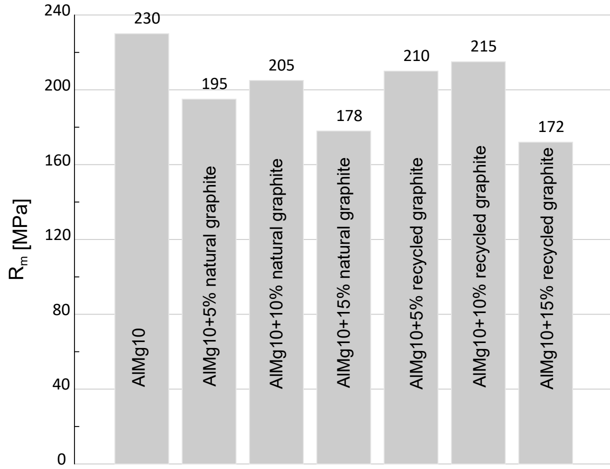

Fig. 6. Tensile strength of the tested materials

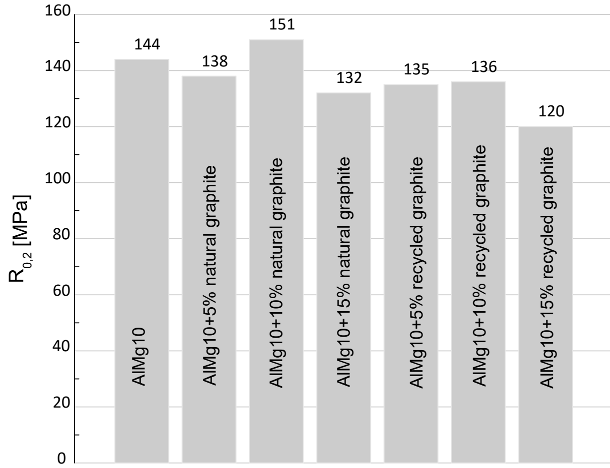

Fig. 7. Yield strength of the tested materials

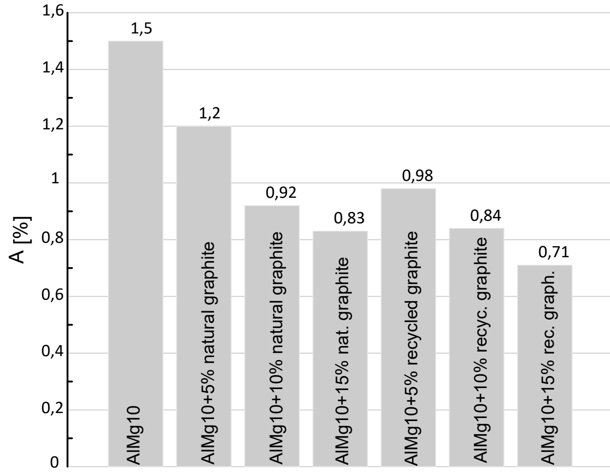

Fig. 8. Elongation of the tested materials

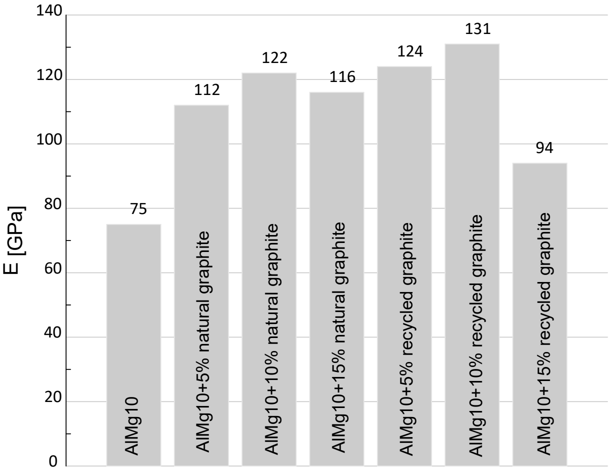

Fig. 9. Young's modulus of the tested materials

The research shows that the addition of graphite to the matrix alloy causes minor changes in tensile strength (R_m) and yield strength (R_{02}), regardless of the type of graphite used. In the case of composites, the most advantageous seems to be the use of a volume fraction of particles of 10%. When this amount of flake graphite particles was used, the yield strength increased slightly compared to the yield strength of the AlMg10 alloy. The results of the relative elongation tests showed that the introduction of graphite particles into the matrix alloy had an adverse effect on the elongation values in the case of each of the tested composites. In the case of the composite containing 15% of particles from ground graphite electrodes, the elongation was halved. The introduction of graphite particles into the AlMg10 alloy significantly increased the Young's modulus value, both in the case of composites with flake graphite (natural) and graphite from ground graphite electrodes. With the increase in the number of particles, the Young's modulus reached higher values. Moreover, composites containing 5 and 10 percent of recycled graphite showed higher Young's modulus values than composites reinforced with flake graphite. The higher values of the elastic modulus in the case of composites indicate the possibility of development of a relatively strong bond between the particles and the metal matrix.

3. Conclusion

The tests of the mechanical properties of the composites have confirmed the known effect of ceramic particles. Composites with graphite particles show a significant decrease in elongation relative to the matrix alloy and a slight decrease in the tensile strength. These composites are characterized by an increase in the elastic modulus and by a yield strength comparable to that of the matrix alloy. In general, the properties of the composites are satisfactory, especially since a negative impact of particles on the mechanical properties was to be expected. According to the theory of strengthening of this type of composites, stresses are transferred by both the matrix and the reinforcement, which inhibits plastic deformations. This mechanism has been confirmed by the presented research results. The yield strength of the composites had values comparable to those of the matrix. The elongation systematically decreases with the increase in the volume fraction of particles and is lower than the elongation of the matrix alloy. The tests of the elastic modulus of the composites show higher values than for the matrix alloy, which suggests the possibility of development a relatively strong bond between the particles and the matrix. The mechanical properties of the produced composites are satisfactory. These materials are expected, above all, to be highly resistant to abrasive wear while maintaining mechanical properties comparable to those of the matrix.

Quality of the prepared composite suspension was assessed based on observations of the structure of the tested composites. The even distribution of reinforcing phases is important in shaping the properties of composites. More favorable particle distribution results were achieved when flake graphite was used, but that affected the mechanical properties of the tested materials only slightly. The high magnesium content in the composite matrix alloy facilitated the wetting of particles of each of the graphite types without additional particle coating procedures.

Based on the research, it was found that even a small addition of graphite, both from recycled electrodes and flake graphite (natural), caused a slight deterioration of the mechanical properties of the AlMg10 alloy. The mechanical properties were similar in both cases, so the use of recycled graphite compared to the much more expensive natural graphite seems to be more advantageous. Recycling graphite electrodes is important for sustainable resource management and environmental protection because it allows the use of secondary raw materials instead of new ones, which can help reduce the negative impact of industry on the environment.

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