ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (2299-2944)

10.24425/afe.2026.158013

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

The Influence of Manufacturing Technology on the Structure and Properties of a Composite Based on EN AB-43000 Alloy Reinforced with SiC Particles

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Received 27.04.2026; accepted in revised form 15.06.2026; available online 31.08.2026

Abstrakt

This paper presents an innovative and comprehensive comparison of the influence of various casting technologies and mould materials on the structure and mechanical properties of composites based on EN AB-43000 alloy reinforced with silicon carbide particles. The composite castings and castings of the matrix alloy were produced by gravity casting into conventional sand moulds, into shell moulds made using the Croning process, and into metal moulds. Particular attention was paid to composite castings produced using die-casting technology, the application of which in the case of metal composites reinforced with SiC particles poses a significant technological challenge due to the difficulties associated with achieving a homogeneous structure and the appropriate quality of the castings. The composite castings were produced with 10% and 15% SiC particle content. The cast strength specimens were tested for tensile strength, yield strength and elongation on a Zwick 1488 testing machine. In order to determine the influence of casting technology and mould material on the structure of the tested materials, microstructural photographs were taken of the samples remaining after the strength tests. The results of the tests show that the addition of silicon carbide to the matrix alloy causes a slight decrease in tensile strength (Rm), a significant decrease in elongation, but a slight increase in the yield strength (R02). The composites cast by gravity into moulds made from conventional moulding sand exhibited the greatest percentage increase in R0.2 and the smallest decrease in Rm compared to the matrix alloy. Die-castings made from both the pure matrix alloy and the composite exhibited the best properties. The structure of these composites was homogeneous, free from defects such as porosity, clusters or non-metallic inclusions. The research conducted demonstrated the relationship between the manufacturing technology, the homogeneity of the composite structure and the mechanical properties, which allowed die-casting to be identified as the most effective method for producing the composite materials under investigation.

Keywords: Silumin, Metal matrix composites, Silicon carbide, Mechanical properties, Die casting

1. Introduction

Metal composites have been a group of materials that have found increasingly widespread use as structural materials for many years. One of the most commonly used materials of this type in industry is aluminum alloy matrix composites reinforced with silicon carbide particles. The addition of silicon carbide (SiC) particles to aluminum alloys primarily increases abrasion resistance and, in some cases, improves mechanical properties. [1–

4]. Aluminum's low density and low cost compared to other light metals, such as titanium or magnesium, make aluminum alloys far more commonly used as the matrix for metal composites. In addition to improved wear resistance and, in some cases, increased strength, composites based on Al alloys reinforced with SiC particles exhibit higher hardness, elevated strength at elevated temperatures, lower thermal conductivity, and a lower coefficient of thermal expansion [5–9].

Metal composites are a group of materials whose properties are influenced by many factors. The choice of materials, including the matrix and the reinforcement, is the main factor determining these properties. The size of the reinforcing particles and the manner in which they are prepared before introduction into the molten metal are also important. The method of producing the composite suspension is also important, but casting such a suspension is even more significant [10, 11].

The choice of manufacturing technology for composite castings largely depends on the physicochemical properties of the matrix and reinforcement materials, as well as the feasibility of bonding them. It is important to note that liquid metal alloys do not wet most composite reinforcements. Various casting technologies for metal composites are described in the literature, ranging from gravity casting to pressure casting and liquid-state pressing [12–14].

Gravity casting is the most commonly used technology for producing composite castings. However, the method employed – casting into molds made of molding sand or casting into a metal mould – is of significant importance. Casting into sand molds can result in an uneven distribution of particles within the casting due to the slow cooling process. On the other hand, casting into metal molds promotes a more uniform distribution of reinforcing particles because of the higher solidification rate. It follows that the casting structure can be controlled by regulating the crystallization and solidification processes of the composite slurry [15, 16].

The production of composite castings using the centrifugal casting method yields excellent results. The only drawback of this method is that it allows castings to be produced only in the form of solids of revolution. The distribution of particles in this type of casting is influenced by many factors, such as the mould material, the pouring temperature, the mould temperature, but above all, the rotational speed. The mechanisms determining whether particles are located in the outer or inner part of a centrifugal casting are extremely complex. The density of the ceramic particles plays the greatest role in this process; however, the literature and the author's own research indicate that the mould's rotational speed has a greater influence on particle distribution. At higher speeds, the particles are usually found in the inner layer of the casting, whereas at lower speeds they are found in the outer layer [17, 18].

Another method for producing composite castings is die casting. This method allows precise control over the casting's solidification. The high pressure and high injection speed during casting allow lower casting and mould temperatures, resulting in faster solidification and, consequently, a more uniform distribution of particles within the casting. When producing composite castings using this technology, there are no limitations associated with the composite slurry's low flowability, unlike in gravity casting. Consequently, pressure-cast composites can contain a higher particle content than gravity castings.

Furthermore, forced flow reduces production costs for composite castings, as there is no need to activate particle surfaces, apply coatings to the particles, or modify the metal matrix due to the reinforcing phase's poor wetting of the matrix material. However, this method is not without its drawbacks. The main disadvantages of this method are the inability to feed the castings, the occurrence of gas and shrinkage porosity, and the potential for non-metallic inclusions. Die casting also has limited application due to the high cost of tooling, restrictions on casting size, and the fact that not all alloys can be cast using this method [19, 20].

2. Research methodology

The purpose of the research presented in this publication is to assess the impact of manufacturing technologies for metal composite castings on the structure and properties of such castings. To this end, composite castings were produced using gravity and die casting. The castings were produced using an EN AB-43000 (EN AB-AlSi10Mg) alloy matrix, whilst the reinforcing phase consisted of silicon carbide particles measuring 71–100 µm. The particle volume fractions were 10% and 15%. The silicon carbide particles were annealed at 2000°C to remove moisture. Gravity casting was performed using both a mould made from conventional molding sand and a permanent mould, as well as a shell mould. The pressure mould, the permanent mould, and the mould made from conventional molding sand all allowed four strength test specimens to be produced simultaneously with a single mould filling. The shell mould allowed two specimens to be produced with a single pour, which is why two shell molds were prepared. The shell mould was manufactured using Croning technology. The molding sand consisted of sand coated with phenol-formaldehyde resin and hardened with urotropine. The composite slurry had to be prepared before casting could begin. To this end, the matrix alloy was melted in an induction furnace to a temperature of 900 K, after which the metal's temperature was reduced to 850 K. The metal was maintained at a constant temperature, allowing the appropriate amount of SiC particles to be introduced. The slurry temperature was then raised, and the castings were produced. The die-castings were produced on a cold-chamber machine with a clamping force of 2 MN. Many years of research into the correct selection of die-casting parameters for composites have allowed these to be established at a fixed level: die-casting piston diameter dk = 40 mm, piston speed in the first injection phase vk1 = 0.3 m/s, clamping force NZ = 1.6 MN, suspension temperature (900 K), mould temperature (573 K), piston speed in the second injection phase (vII) 3.6 m/s, injection pressure (pIII) 40 MPa, and gate width (dw) 3 mm. The mechanical property testing of the composites included measurements of yield strength R02, tensile strength Rm, and relative elongation A. All mechanical properties were determined from a tensile test conducted in accordance with PN-EN ISO 6892-1, using a Zwick 1488 machine.

3. Research results

Figures 1–3 show the average results from 12 test runs measuring tensile strength, yield strength and relative elongation for castings produced using conventional moulding sand, castings produced using shell moulds, gravity castings and die-castings.

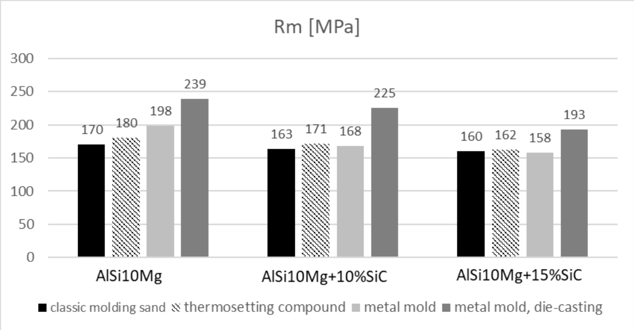

Fig. 1. Tensile strength of the tested materials.

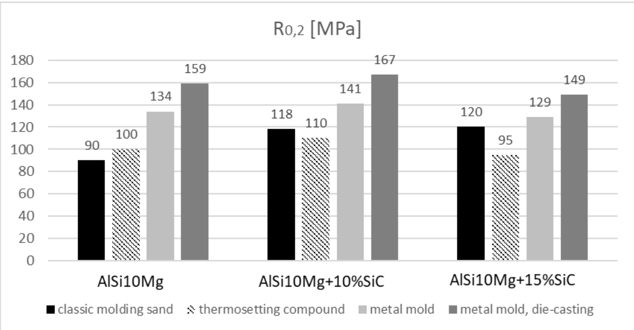

Fig. 2. The yield strength of the tested materials.

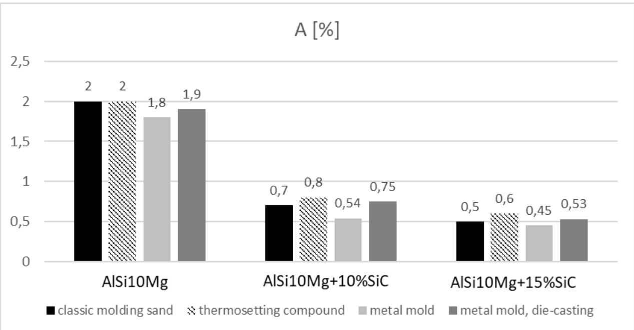

Fig. 3. Elongation of the tested materials.

Composites based on the AlSi10Mg matrix exhibit a decrease in tensile strength as the silicon carbide particle content increases, as well as a marked decrease in elongation compared to the unreinforced matrix. However, the results of the yield strength tests are of particular interest. The addition of 10% SiC particles resulted in an increase in yield strength in every case, whilst the addition of 15% particles caused a slight decrease in yield strength. This suggests the possibility of forming a strong bond between the particles and the metal matrix. In essence, the results of the composite property tests are satisfactory, particularly given the expected negative impact of the particles on the mechanical properties. The test results suggest that the optimal particle volume fraction is 10%. The tensile strength varies depending on the mould material used to cast the castings. The lowest Rm value for the matrix alloy was observed in gravity-cast samples, and the highest in die-cast samples. The decrease in Rm following the introduction of particles into the matrix was not significantly affected by whether the casting was gravity or die-cast. However, the decrease in Rm for the composites compared to the unreinforced matrix was smaller for samples from the conventional sand mould and the shell mould than for samples from the permanent mould or die-cast samples. The greatest increase in yield strength was also observed in composites produced using conventional casting. However, the matrix alloy and composites produced by die-casting undoubtedly exhibited the best properties. The quality of the castings produced and the composite slurry prepared is assessed based on observations of the materials' structures under investigation. Many years of research into the production of metal composites have enabled the selection of parameters that ensure even particle distribution. Die-casting technology is particularly advantageous for casting metal composites, as filling the mould under high pressure preserves the uniform particle distribution achieved during slurry mixing in the furnace crucible. The properties of die-castings of unreinforced matrices and composites are superior to those of gravity castings, as rapid solidification results in strong fragmentation of the primary phase crystals. The highest number of defects, such as particle clusters and non-metallic inclusions, was observed in gravity castings produced with conventional molding sand. Figures 4–7 show the microstructures of castings produced using various technologies from the matrix alloy.

Fig. 4. Microstructure of the AlSi10Mg alloy cast by gravity casting into a mould made from conventional molding sand, mag. x200.

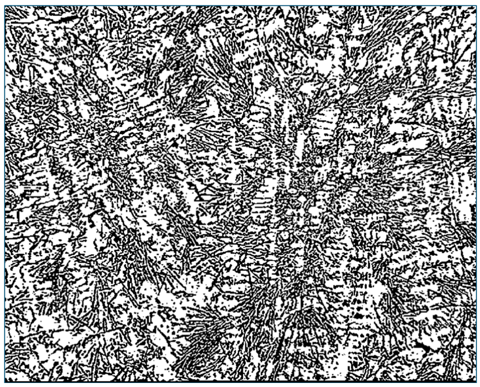

Fig. 5. Microstructure of the AlSi10Mg alloy cast by gravity casting into a mould made of shell mould material, mag. x200.

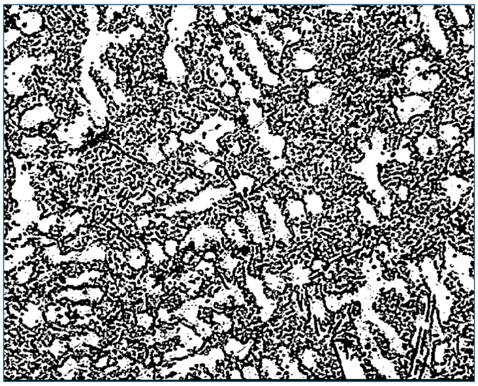

Fig. 6. Microstructure of the AlSi10Mg alloy cast by gravity casting into a permanent mould, mag. x200.

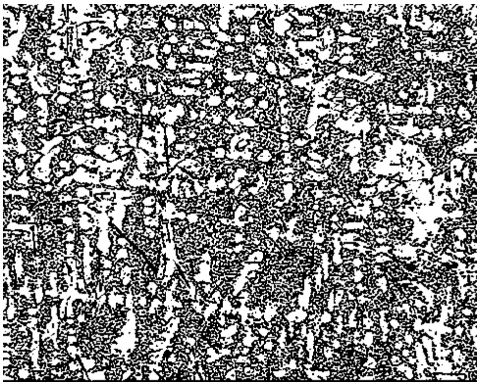

Fig. 7. Microstructure of die-cast AlSi10Mg alloy, mag. x200.

The following figures show the microstructures of the composites under investigation.

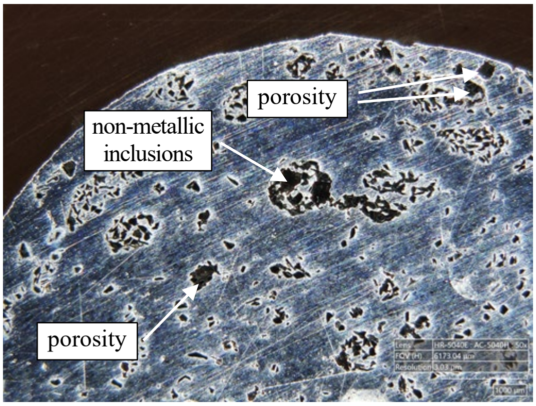

Fig. 8. The microstructure of a composite containing 10% SiC, gravity-cast into a mould using a conventional casting process.

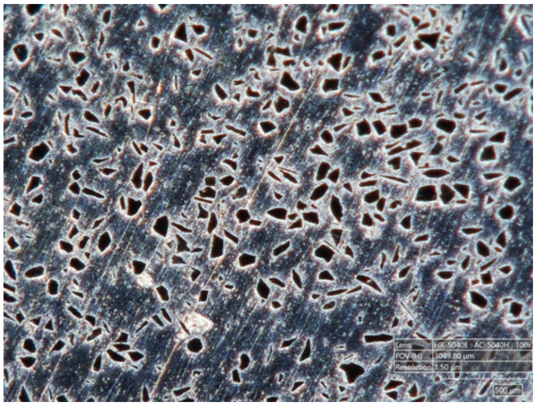

Fig. 9. The microstructure of a composite containing 10% SiC, cast by gravity into a shell mould (thermosetting).

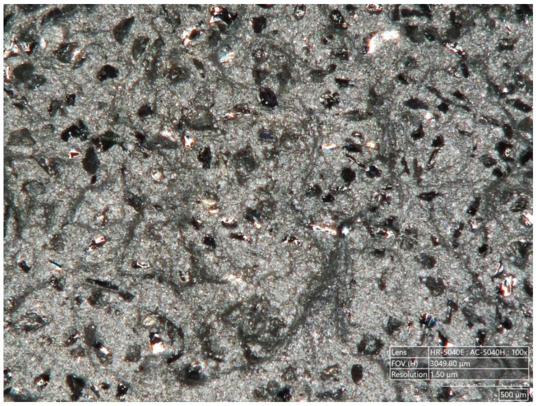

Fig. 10. The microstructure of a composite containing 10% SiC, cast using the gravity casting method into a metal mould.

Fig. 11. The microstructure of a 10% SiC-containing die-cast composite.

Fig. 12. An example of the microstructure of a composite containing 10% SiC – cross-section of a sample, die-cast.

3. Summary

This paper presents an innovative and comprehensive comparison of the relationship between casting technology, the uniformity of the composite structure and changes in mechanical properties, which has demonstrated that modern technologies such as die-casting are the most effective method for producing metal composites.

Studies on the effect of manufacturing technologies on the structure and properties of AlSi10Mg alloy-based metal composites reinforced with silicon carbide particles show that die casting is the most effective production method. This method enables the production of complexly shaped castings and facilitates the optimization of manufacturing parameters. The composite slurry's high solidification rate enables the production of castings with high mechanical properties. The increase in yield strength following the addition of particles to the matrix alloy is due to the inhibition of plastic deformation as stresses are transferred through the metal matrix and particles. It should be noted that these materials are designed primarily for use under friction conditions and are intended to exhibit high wear resistance while maintaining properties comparable to those of the matrix alloy. The results of the above tests showed that the particles have a negligible influence on the mechanical properties. When comparing mechanical test results for the matrix and the composite, the casting method had no significant effect; the mould material had a greater influence. In die casting, adding 10% particles caused a 5% decrease in Rm, and adding 15% SiC caused a 20% decrease. In gravity casting into permanent moulds, the decrease in Rm was similar. In contrast, in casting into shell molds, the decrease in Rm was 5% and 10%, respectively, and in castings made in conventional sand molds, 5% and 6%, respectively. The largest percentage increase in yield strength after particle introduction was observed for castings made in a traditional sand mold. This indicates that the solidification rate significantly affects the metal matrix structure. However, introducing ceramic particles into the metal reduces the metal volume, and the effect of the mold material on mechanical properties is less significant, especially at higher proportions of reinforcing particles. Therefore, selecting the technology for manufacturing metal composite materials, as well as the optimal amount of reinforcement to introduce into the matrix, is crucial.

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