



A Review of Fabrication Method of Casting Metal Matrix Composite Materials in Liquid State

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Abstract. This paper provides an overview of liquid-state fabrication techniques for metal matrix composites (MMCs). Aluminium-based MMCs (AMMCs), in particular, are extensively utilized in the automotive, aerospace, and medical sectors due to their advantageous characteristics, including low density, high wear resistance, and favorable specific strength. The liquid-phase processing methods discussed include infiltration, stir casting, centrifugal casting, squeeze casting, vacuum die-casting, compocasting, and rheocasting. Each method offers specific advantages in reinforcement distribution, cost efficiency, and complex shape manufacturability. Infiltration is effective in achieving good interfacial bonding; stir casting is popular because it is simple and economical for mass production; centrifugal casting excels in forming high-density and wear-resistant composites; squeeze casting and vacuum die casting increase the strength and density of composites; while compocasting and rheocasting offer more homogeneous microstructure and grain refinement. This review shows that the selection of method should be based on the specific application requirements and material characteristics to achieve optimum mechanical properties. With improvements in technology and control of process parameters, liquid casting methods offer significant potential for the manufacture of high-performance structural and functional components.

Keywords: casting; Metal Matrix Composites; manufacturing process

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1. Introduction

Composite materials represent a class of advanced and adaptable engineering materials characterized by higher specific strength compared to conventional monolithic alloys. This superior performance has facilitated their growing use across various sectors, including automotive and aerospace manufacturing, medical applications, infrastructure development, and defence. The choice of matrix alloy and reinforcement particles is typically guided by the intended application (1,2,3,4,5). Aluminium Metal Matrix Composites (AMMCs), in particular, have garnered significant interest due to their exceptional mechanical strength, low density, and enhanced wear resistance, making them highly suitable for use in defence, automotive, and aerospace industries (6).

The transformative impact of advanced manufacturing technologies, particularly additive manufacturing (AM), has significantly influenced modern materials science by enhancing both design flexibility and production efficiency. In contrast to traditional fabrication methods, AM offers notable advantages such as reduced material waste, greater freedom in design, and the capability to produce intricate geometries. Incorporating these techniques into research has elevated the relevance of materials studies and demonstrated substantial utility across sectors like aerospace and healthcare. The integration of additive manufacturing into materials development enables researchers to address contemporary challenges and explore innovative solutions (7).

The high strength, low density, high stiffness, low cost, and superior fatigue characteristic of aluminium matrix composites (AMCs) have led to their widespread use in research (8). This is because AMCs have all these characteristics. Magnesium has been used in a variety of applications,

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including the aviation industry, automotive sector, and military departments, due to its lightweight nature (with a density of about 1.74 grams per cubic centimetre) (9). There is a significant increase in heat resistance, adequate strength, high damping capacity, and low wear rate when magnesium matrix composites are reinforced with ceramic particles (10). Copper matrix composites are employed across a broad spectrum of applications, including the production of radiators, electronic components, and jet engine housings. The incorporation of ceramic reinforcements, particularly aluminium and silicon carbide, plays a critical role in enhancing the performance of these composites (11). Due to their high thermal conductivity and low wear rate, copper-based composites are especially suitable for use in electronic devices (12). One notable variant is the Carbon Fiber Reinforced Copper Matrix Composite, which offers promising properties for advanced engineering applications.

2. Methodology

This study is a literature review of previously published research result related to fabrication method of casting metal matrix composites materials in liquid state. Research with this kind analysis method focused to take conclusion from methodology or approach used by studies. This review literature is the result of research related fabrication method of casting metal matrix composites materials in liquid state, both traditional and modern. Through a descriptive study of related literature, it is hope that this article can be developed and become a reference for the future need.

3. Results and Discussions

Liquid-state fabrication methods for metal matrix composites have garnered significant industrial interest due to their relative simplicity and cost-effectiveness. This approach involves incorporating the reinforcing phase into molten metal, followed by cooling and solidification. Achieving strong interfacial bonding between the reinforcement and the metal matrix is essential for enhancing the composite's mechanical properties. Various liquid-state processing techniques are outlined below.

3.1. Infiltration Methods

Infiltration techniques are generally categorized into two types: melt infiltration and pressure less infiltration. In the melt infiltration process, the reinforcing particles are initially positioned within a mold, after which molten metal is introduced and allowed to solidify without the application of external pressure. Previous research has been conducted on the character of aluminium matrix composites Al6061/Ti₃SiC₂ made using the melt infiltration method at low temperatures with result the chemical reaction between the particles and the matrix occurs at a temperature of 950°C (13). The tribological behavior of A356 alloy reinforced with 304 stainless steel flakes was investigated using the melt infiltration technique at a processing temperature of 730°C. A schematic representation of the melt infiltration process was also provided (14). In the pressure infiltration method, external pressure is directly applied during fabrication, and its performance was compared with other techniques. The findings indicate that pressure infiltration offers notable advantages in terms of composite quality and mechanical performance (15).

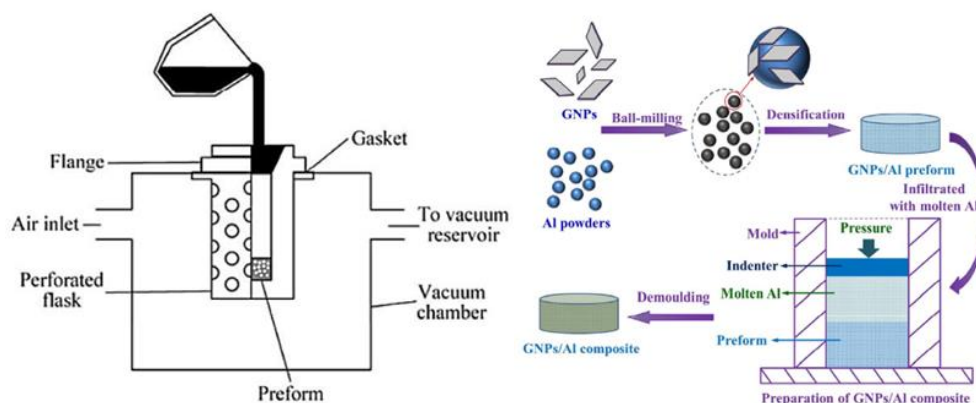


Figure 1. Fabrication of GNP/Al Composite by melt infiltration and pressure infiltration process

The figure illustrates the significance of both melt infiltration and pressure infiltration techniques in enhancing composite material properties. These methods depend on the retention and solidification of reinforcement particles, with minimal or no external pressure, to improve mechanical characteristics. The results demonstrate that such infiltration techniques effectively enhance the mechanical strength and wear resistance of various composite systems.

3.2 Stir Casting

Stir casting is a commonly used technology for producing metal matrix composites. This process involves mechanical mixing or conventional approaches to mix the matrix material and the reinforcing particles in a liquid state. Stir casting is a cost-effective and economical method for producing aluminium matrix composites. This technique is favoured due to its simplicity, ease of use, and its ability to be applied in large-scale production. Several crucial process factors affect the stirring results, including stirring speed, stirring temperature, and stirring duration. These parameters have a direct influence on the microstructural changes and mechanical characteristics of the resulting composites. A schematic layout of the stir casting process setup is shown in [Figure 2](#).

Stir casting is a widely adopted technique for the fabrication of metal matrix composites. This method involves the mechanical mixing of the molten matrix material with reinforcing particles, utilizing either conventional or specialized stirring mechanisms. It is recognized for its cost-effectiveness and suitability for large-scale production, particularly in the manufacturing of aluminium matrix composites. The simplicity and operational ease of stir casting contribute to its popularity. Key process parameters—such as stirring speed, temperature, and duration—play a critical role in determining the microstructure and mechanical properties of the final composite. A schematic representation of the stir casting setup is presented in [Figure 2](#).

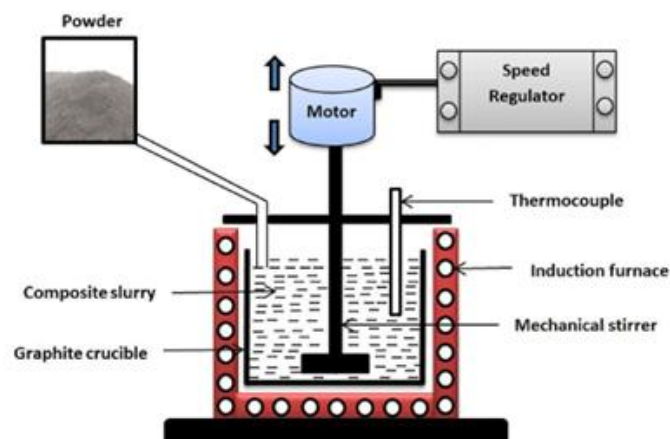


Figure 2. Schematic of stir casting set up

Enhancing the machinability of metal matrix composites (MMCs) is a key advantage of the stir casting technique. This process yields a more uniform microstructure, characterized by the even distribution of reinforcing particles—such as ceramics—within the molten metal. Such uniformity contributes to reduced tool wear, fewer machining defects, and improved surface finish. Additionally, stir casting allows for better control over the interaction between the matrix and reinforcement, thereby optimizing the composite's hardness and strength. These improvements directly influence cutting forces and extend tool life. Overall, the increased machinability achieved through stir casting makes MMCs highly suitable for precision manufacturing and long-term industrial applications ([16](#)).

3.3 Centrifugal Casting

Centrifugal casting is a composite manufacturing procedure that involves pouring molten metal into a rapidly rotating mold. This method is relatively cost-effective, where the molten metal is pushed to the mold surface by centrifugal force with considerable pressure. This technique is generally classified into two types, namely based on the horizontal and vertical axes. [Figure 3](#) shows a schematic design of a vertical centrifugal casting system.

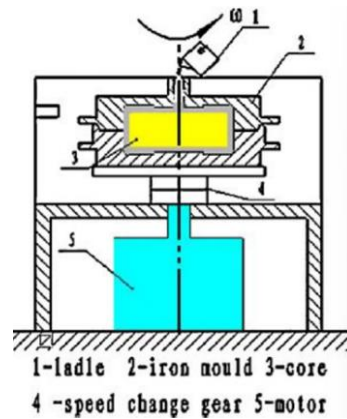


Figure 3. Schematic diagram of vertical centrifugal casting setup

The processing characteristics of Al-B-Mg composites fabricated via centrifugal casting have been examined. In this method, a heated dipper is rotated around the vertical axis of a centrifugal casting apparatus using an electric motor, enabling the formation of a high-quality mold fill with improved microstructure and enhanced mechanical strength (17). Investigations into the transfer behavior of Al/SiC aluminium matrix composites produced by centrifugal casting revealed that SiC particles tend to migrate toward the mold periphery due to centrifugal forces, resulting in non-uniform particle distribution. Nevertheless, pistons manufactured through centrifugal casting under optimized conditions exhibit excellent wear resistance (18). Centrifugal casting is recognized as an efficient and cost-effective technique for composite production, offering substantial control over material properties through high rotational forces. Although it significantly improves microstructural integrity and mechanical strength, challenges such as uneven reinforcement distribution persist. Further refinement of process parameters may enhance its applicability for complex, high-performance components.

3.4 Squeeze Casting

Squeeze casting integrates aspects of traditional casting and hydraulic forging. Figure 4 shows a schematic diagram of the squeeze casting process. This process involves the rapid release of molten material into a mold, which is then immediately forged using a hydraulic press with great force. A connecting line between the molten material reservoir and the mold allows the flow of molten material from the furnace to the mold.

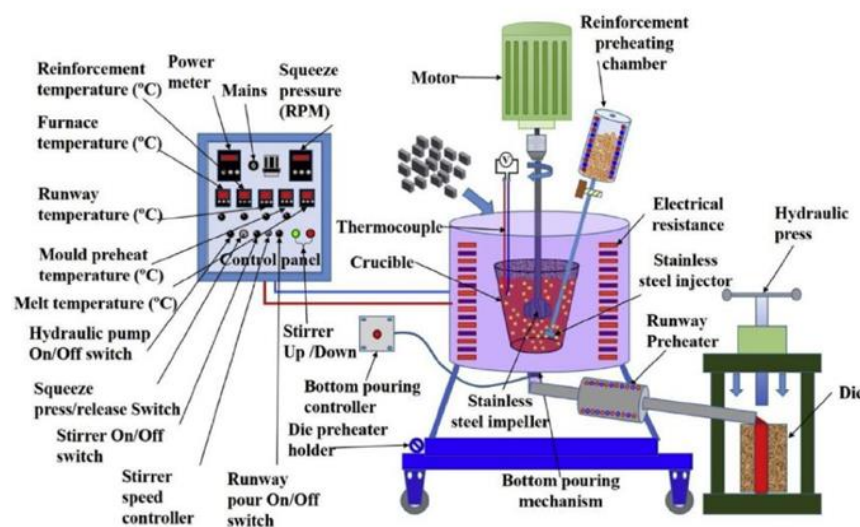


Figure 4. Schematic diagram of Squeeze Casting

Research on the microstructure and mechanical properties of composite materials consisting of AA7075 aluminum matrix reinforced with graphene nanoparticles has been conducted. The composite was made using a combination of stir casting and squeeze casting techniques. The AA7075

composite with 0.3% graphene showed an even distribution of reinforcing particles throughout the matrix. The results showed that the highest maximum tensile strength (Ultimate Tensile Strength/UTS) of 255 MPa was achieved at a graphene concentration of 0.3% (19). Likewise, research to examine the mechanical properties and wear resistance of aluminium matrix composite Al/Al₂O₃ made by a combination of stir and squeeze casting techniques. The squeeze casting process was carried out at a temperature of 750°C and a pressure of 600 MPa has also been carried out (20).

Squeeze casting, which integrates principles of both casting and hydraulic forging, enhances the mechanical properties of composites by facilitating uniform dispersion of reinforcement particles. Experimental studies on AA7075/graphene and Al/Al₂O₃ composites have demonstrated notable improvements in tensile strength and wear resistance, thereby validating the effectiveness of stir casting and squeeze casting techniques in composite fabrication.

3.5 Vacuum Die Casting

Vacuum die casting in the mold cavity aims to reduce gas trapping during metal injection and minimize porosity in the casting results. As a result, castings with better characteristic quality are obtained. Figure 5 shows a schematic of the stir vacuum die casting process.

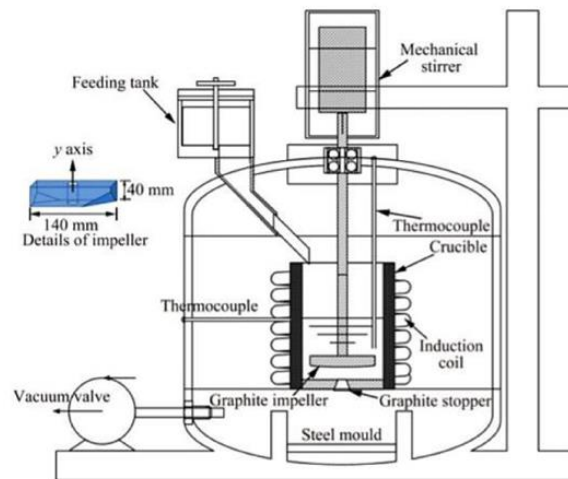


Figure 5. Schematic diagram of stir vacuum casting setup

The main advantage of this technique is the reduction of void content in the composite due to the reduction of the amount of gas dissolved in the liquid metal. Thus, the mechanical properties and density of the casting are significantly improved. A study on the microstructural evaluation and mechanical characterization of AA6061 aluminium matrix composite reinforced with 31% B₄C produced using this technique was produced using an advanced stir vacuum casting procedure. Scanning electron micrographs showed that B₄C particles were evenly distributed throughout the aluminium matrix. The cast aluminium matrix composite showed superior tensile strength of 340 MPa, compared to the AA1100/31%B₄C composite (21).

3.6 Compocasting

In the compocasting process, preheated reinforcement is introduced into the semi-solid metal at a temperature of about 690°C with vigorous stirring (22). Figure 6 presents a schematic illustration of the compocasting process, wherein initially solid particles are transformed into a semi-solid slurry. This slurry is subsequently directed into the mold cavity and subjected to pressure during the cooling and solidification stages.

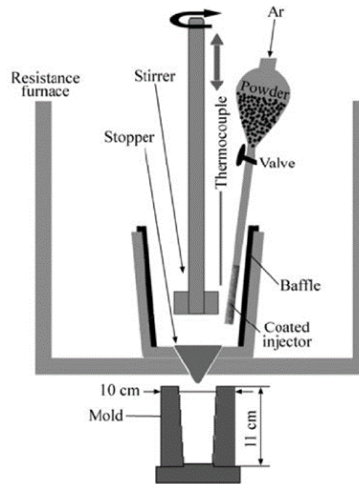


Figure 6. Schematic diagram of compocasting method

Slurry movement is usually accomplished by powered vibration, motorized stirring, or tilting cooling methods to distribute the reinforcement evenly. The primary solid particles dispersed in these semi-solid slurries reduce agglomeration, resulting in good reinforcement dispersion, grain modification of the matrix, and much lower void content compared to stir casting methods (23).

Compocasting offers several key advantages, including reduced production cycles and lower casting temperatures, which contribute to extended mold longevity. When mixing occurs at lower temperatures within the aluminium processing range, the wettability of the reinforcement is notably enhanced. Although still in the early stages of industrial adoption, with limited applications such as brake cylinders and pistons, compocasting demonstrates considerable potential (24). Compared to stir casting, it provides improved reinforcement dispersion, refined grain structure, and minimized porosity. The lower casting temperatures not only preserve mold integrity but also enhance material bonding, making compocasting a promising technique for high-performance composite manufacturing.

3.7 Rheocasting

Rheocasting involves generating a semi-solid slurry from molten metal through the application of shear forces, during which reinforcing particles are mechanically introduced as solidification progresses. The resulting mixture is then directly poured into a mold shaped according to the desired component design. Due to its cost efficiency and high production rate, this method is now one of the popular manufacturing methods (25). The particle distribution in the composite is greatly enhanced by the intensive shear action, and there is a very good improvement in the microstructure as a result of the application of pressure (26). The rheocasting process prevents particle agglomeration because the reinforcement is introduced into the partially solidified (semi-solid) melt. The reinforcement particles must be stable at a certain working temperature and also non-reactive during the rheocasting process.

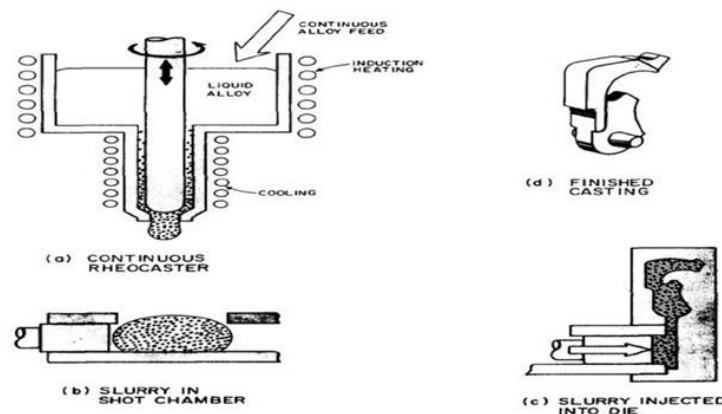


Figure 7. Schematic diagram of rheocasting process

Figure 7 shows a complete schematic diagram of the rheocasting process. This process enables the manufacture of excellent composite casting components, such as complex parts, high mechanical strength, perfect metal filling, and better wear resistance performance. The main drawback of the rheocasting method is the need for advanced technology and labor with special knowledge and preparation. Research has been conducted using the rheocasting method to manufacture and determine the characteristics of Al359/SiC aluminium matrix composites reinforced with SiC powder. It was found that the hardness increased from 73 to 93 HRB with increasing SiC content (27).

4. Conclusions

Liquid-state casting represents a versatile and effective approach for producing high-performance metal matrix composites (MMCs). Each technique—ranging from infiltration to rheocasting—offers distinct benefits and limitations with respect to microstructural integrity, reinforcement distribution, and production cost. When process parameters are carefully controlled, these methods can significantly enhance the mechanical properties and reliability of MMCs, making them suitable for a wide range of strategic industrial applications. Ongoing advancements in technology and process optimization are expected to further broaden the scope of MMC applications in the future.

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