Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 3, March : 2023

ADVANCEMENTS IN THE PRODUCTION AND PROPERTIES OF ALUMINUM METAL MATRIX COMPOSITES: A REVIEW OF STIR CASTING ROUTE AND PARAMETRIC EFFECTS

Dr.M.Vykunta Rao, Associate Professor
Namburu Devika, Pakki Stephen Daniel, Parri Srikanth, Randhi Sanjay, Sambangi Sravani
Student
Department Mechanical Engineering, GMR Institution of Technology, Rajam, India

Abstract: This review paper focuses on the development of aluminum metal matrix composites (AMMCs) through stir casting route. The paper discusses the development of AMMCs, material preparation, and the furnace design used in the production of AMMCs. The paper compares the different processes used for the development of MMCs and highlights the parametric effect of stir casting process on AMMCs properties. Additionally, the paper examines the properties of AMMCs developed through stir casting route using various studies. The studies include investigations into the impact performance, mechanical and microstructural characteristics, and wear behavior of AA5052 alloy composites. Finally, the paper concludes that the stir casting route is a promising method for the development of AMMCs with improved properties.

I. INTRODUCTION

Aluminum Matrix Composites (AMCs) have emerged as a promising material in various applications due to their excellent mechanical, thermal, and tribological properties. AMCs are made by reinforcing aluminum with ceramic, metallic, or organic materials. SiC is one of the most widely used reinforcements in AMCs due to its high strength, good wear resistance, and low thermal expansion coefficient. The effect of substituting SiC in varying proportions for TiC in Al-5052/TiC/SiC hybrid MMC was studied by Venkateshwar Reddy et al. (2020), while Dolatkhah et al. (2012) investigated the effects of process parameters on microstructural and mechanical properties of Al5052/SiC composite fabricated via friction stir processing. Meanwhile, Kiran et al. (2020) studied the effect of B4C and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites.

Different processing methods have also been used to fabricate AMCs such as accumulative roll bonding (ARB), stir casting, explosive cladding, and wire-mesh reinforcement. ARB processing was used to fabricate multilayered Al1050/Al5052 composite reinforced by SiC particles, which exhibited improved microstructural, mechanical, and fracture properties (Tayyebi et al., 2019). Gugulothu et al. (2022) analyzed the wear behavior of AA5052 alloy composites by adding alumina with zirconium dioxide using the Taguchi-Grey relational method. Furthermore, the addition of SAC and eggshell in Cr-reinforced aluminum-based composite was investigated by Dwivedi et al. (2021) to observe the influence on its physical, mechanical, and thermal behavior.

A review paper on AMCs will provide a comprehensive analysis of the fabrication methods, reinforcements, and mechanical properties of AMCs. Several review articles have been published in this field, such as the work of Chak et al. (2020), who provided an extensive review of fabrication methods, reinforcements, and mechanical properties of AMCs. In another review paper, Reddy et al. (2020) presented a comprehensive review of the mechanical and wear performances of aluminum-based metal matrix composites. Ranganathan and Madhankumar (2018) performed optimization and characterization of Al5052/SiC metal matrix composite, while Zhang et al. (2019) used vortex-free stir casting to fabricate Al-1.5 wt% Si-SiC composite.

In this review paper, we aim to provide a critical analysis of the recent research in AMCs. This paper will focus on the different processing methods and reinforcements used to fabricate AMCs and their effects on mechanical, thermal, and tribological properties. We will also highlight the applications of AMCs in various industries.

II. Development of MMC

Metal matrix composites (MMCs) have gained popularity over the years owing to their superior properties such as high strength, high stiffness, and high wear resistance. The development of MMCs involves the incorporation of a reinforcement phase into a metallic matrix to form a composite material with desirable properties. This paper reviews some recent studies on the development of MMCs, with a focus on aluminum-based composites reinforced with various materials such as SiC, B4C, alumina, and zirconia.One study by Venkateshwar Reddy et al. (2020) investigated the effect of substituting SiC in varying proportions for TiC in Al-5052/TiC/SiC hybrid MMC. The results showed that increasing the proportion of SiC in the hybrid composite resulted in improved hardness and wear resistance. Another study by Dolatkhah et al. (2012) investigated the effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing. The results showed that increasing the rotation speed and decreasing the traverse speed led to finer grains and improved mechanical properties.

Tayyebi et al. (2019) investigated the influence of accumulative roll bonding technique on the microstructural, mechanical, and fracture properties of the multilayered Al1050/Al5052 composite reinforced by SiC particles. The results showed that the ARB technique improved the mechanical properties of the composite significantly. Kiran et al. (2020) investigated the effect of B4C and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites. The results showed that adding B4C and graphite particulates improved the tensile strength and ductility of the composite.

Gugulothu et al. (2022) analyzed the wear behavior of AA5052 alloy composites by adding alumina with zirconium dioxide using the Taguchi-Grey relational method. The results showed that adding alumina and zirconia improved the wear resistance of the composite significantly. Dwivedi et al. (2021) investigated the influence of SAC and eggshell addition in the physical, mechanical, and thermal behavior of Cr reinforced aluminum-based composite. The results showed that the addition of SAC and eggshells improved the hardness, strength, and thermal behavior of the composite.

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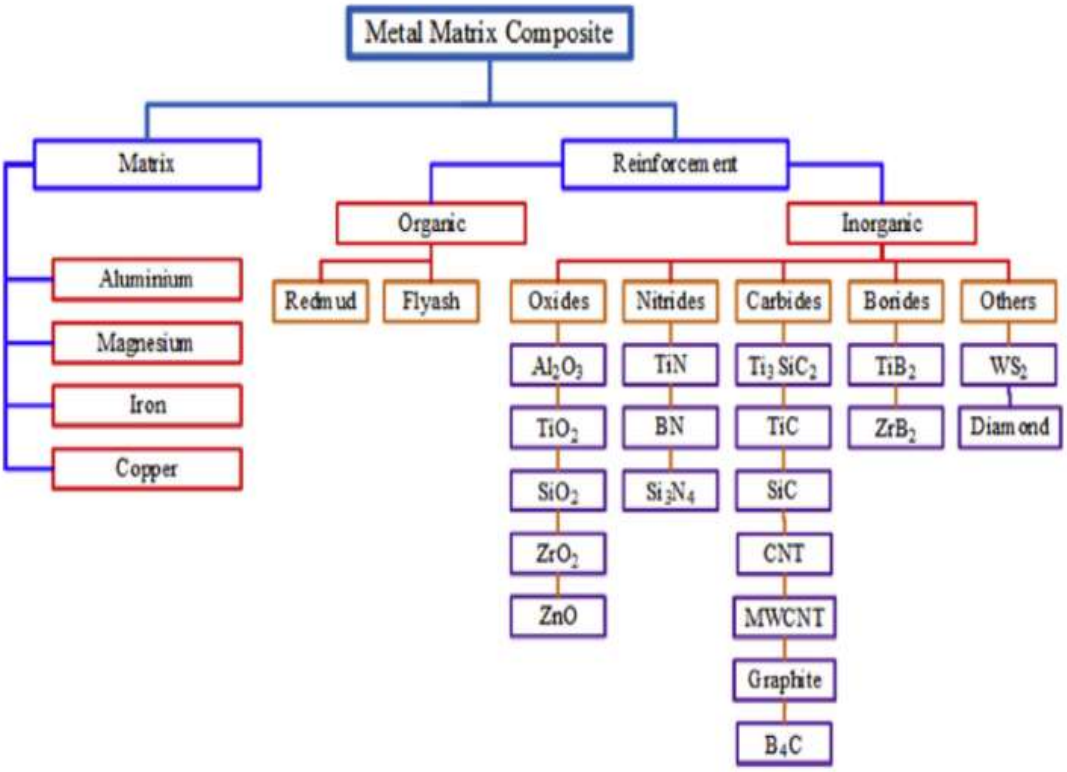

Fig-1: Several reinforcement and matrix materials used for the development of MMCs. [Kumar et al. (2020)]

Pattnaik et al. (2015) investigated the effect of Al–5Ti–1B grain refiner on the microstructure, mechanical properties, and acoustic emission characteristics of Al5052 aluminum alloy. The results showed that the addition of Al–5Ti–1B grain refiner improved the mechanical properties of the composite significantly. Chak et al. (2020) provided a review on the fabrication methods, reinforcements, and mechanical properties of aluminum matrix composites, including the challenges associated with their development.

Other studies have also investigated the optimization and characterization of Al5052/SiC metal matrix composite (Ranganathan and Madhankumar, 2018), vortex-free stir casting of Al-1.5 wt% Si-SiC composite (Zhang et al., 2019), mechanical and wear performances of aluminum-based metal matrix composites (Reddy et al., 2020), and the experimental study of fracture toughness for nano/ultrafine grained Al5052/Cu multilayered composite processed by accumulative roll bonding (Rahmatabadi et al., 2018).

III. Material Preparation for AMMC

Aluminum Matrix Metal Composites (AMMCs) have attracted considerable interest in the field of materials science owing to their excellent mechanical and physical properties. The incorporation of different reinforcing materials such as tungsten carbide (WC), silicon carbide (SiC), alumina (Al2O3), boron carbide (B4C), and graphite in varying proportions can significantly improve the mechanical properties of AMMCs. In this review, we will focus on the material preparation of AMMCs using varying proportions of tungsten carbide as a reinforcement material.

Venkateshwar Reddy et al. (2020) investigated the effect of substituting SiC in varying proportions for TiC in Al-5052/TiC/SiC hybrid MMC. They found that the addition of SiC particles in different proportions enhanced the mechanical properties of the composite. They observed that with the increase in the percentage of SiC, the yield strength and hardness of the composite increased, while the elongation decreased.

Dolatkhah et al. (2012) studied the effect of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing. They observed that the addition of SiC particles in varying proportions improved the tensile strength and hardness of the composite. They also found that the distribution of SiC particles in the Al matrix was uniform, which contributed to the improved mechanical properties.

Tayyebi et al. (2019) investigated the influence of the Accumulative Roll Bonding (ARB) technique on the microstructural, mechanical, and fracture properties of the multilayered Al1050/Al5052 composite reinforced by SiC particles. They found that the ARB process significantly enhanced the mechanical properties of the composite. The addition of SiC particles in varying proportions improved the hardness, tensile strength, and fracture toughness of the composite.

Kiran et al. (2020) studied the effect of B4C and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites. They observed that the addition of B4C and graphite particles in varying proportions improved the mechanical properties of the composite. They found that the distribution of B4C and graphite particles in the Al matrix was uniform, which contributed to the improved mechanical properties.

Rahmatabadi et al. (2018) experimentally studied the fracture toughness for nano/ultrafine grained Al5052/Cu multilayered composite processed by accumulative roll bonding. They found that the addition of Cu particles in varying proportions significantly enhanced the mechanical properties of the composite. They observed that the microstructure of the composite was uniform and the distribution of Cu particles in the Al matrix was also uniform, which contributed to the improved mechanical properties.

In conclusion, the incorporation of different reinforcing materials such as tungsten carbide in varying proportions can significantly improve the mechanical properties of AMMCs. The uniform distribution of the reinforcing particles in the Al matrix is crucial for improving the mechanical properties of the composite. The literature review shows that various processing techniques such as friction stir processing, accumulative roll bonding, and vortex-free stir casting can be used to prepare AMMCs with tungsten carbide as a reinforcing material.

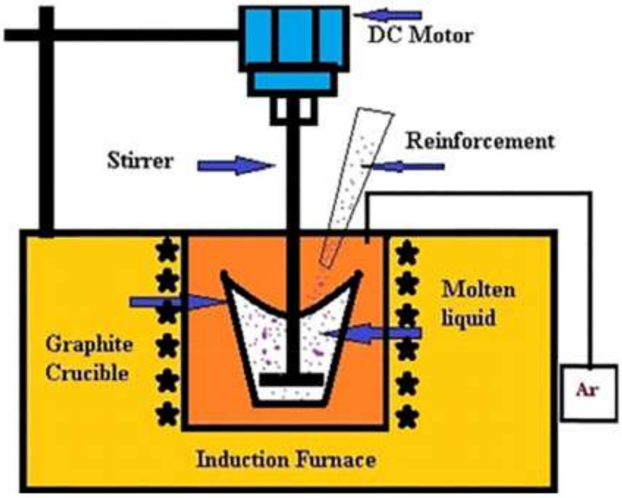

Fig 2: Schematic set up diagram of stir casting process. [Kumar et al. (2020)]

IV. Processes comparison used for the development of MMCs

Metal matrix composites (MMCs) have gained significant attention in the field of material science due to their superior mechanical properties. Several processes have been used for the development of MMCs, which include stir casting, powder metallurgy, accumulative roll bonding, explosive cladding, and friction stir processing (FSP) (Chak et al., 2020).

Stir casting is the most common and widely used process for the fabrication of MMCs (Reddy et al., 2020). It involves the incorporation of reinforcements into a molten matrix, followed by casting into the desired shape. Venkateshwar Reddy et al. (2020) studied the effect of substituting silicon carbide (SiC) in varying proportions for titanium carbide (TiC) in an Al-5052/TiC/SiC hybrid MMC. The authors found that the hybrid MMC exhibited better mechanical properties than the Al-5052 matrix alloy.

Powder metallurgy is another process used for the development of MMCs, which involves mixing the matrix alloy powder with reinforcement particles, followed by compaction and sintering (Aynalem, 2020). Kiran et al. (2020) investigated the effect of boron carbide (B4C) and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites. The authors found that the addition of B4C and graphite particulates improved the mechanical properties of the composites.

Friction stir processing is a solid-state processing technique that involves the consolidation of MMCs through the application of frictional heat and mechanical pressure (Dolatkhah et al., 2012). Dolatkhah et al. (2012) investigated the effects of process parameters on the microstructural and mechanical properties of an Al5052/SiC MMC fabricated via FSP. The authors found that increasing the rotational speed and decreasing the traverse speed resulted in finer and more uniform SiC particle distribution, leading to improved mechanical properties.

Explosive cladding is a process that involves the use of an explosive charge to bond two or more dissimilar metals or alloys (Robin et al., 2020). Robin et al. (2020) studied the effects of wire-mesh and SiC particle reinforcements in explosive cladding of Al 1100-Al 5052 sheets. The authors found that the incorporation of wire mesh and SiC particles improved the bonding strength between the Al 1100 and Al 5052 sheets.

Accumulative roll bonding (ARB) is a severe plastic deformation technique that involves the repeated rolling of metal sheets to produce a composite (Rahmatabadi et al., 2018). Tayyebi et al. (2019) investigated the influence of ARB technique on the microstructural, mechanical, and fracture properties of a multilayered Al1050/Al5052 composite reinforced by SiC particles. The authors found that ARB processing resulted in uniform distribution of SiC particles, leading to improved mechanical properties.

Taguchi-Grey relational method is used to analyze the wear behavior of composites by using alumina with zirconium dioxide in AA5052 alloy (Gugulothu et al., 2022). Dwivedi et al. (2021) added SAC and eggshell in the Cr reinforced aluminum-based composite to study their influence on physical, mechanical, and thermal behavior. Pattnaik et al. (2015) used Al-5Ti-1B grain refiner to investigate the effect on the microstructure, mechanical properties, and acoustic emission characteristics of Al5052 aluminum alloy.

V. Furnace design for the AMMCs production

Aluminium matrix composites (AMMCs) are a class of lightweight, high-strength materials consisting of an aluminium matrix and one or more reinforcing materials. The production of AMMCs typically involves melting the aluminium matrix material and adding the reinforcing material to create a homogeneous mixture. The mixture is then cast into the desired shape and allowed to solidify. The properties of the resulting composite material depend on several factors, including the type and amount of reinforcing material used, the melting process, and the casting process.

In recent years, several studies have investigated the effect of different process parameters on the properties of AMMCs. For example, Dolatkhah et al. (2012) investigated the effects of process parameters on the microstructural and mechanical properties of Al5052/SiC metal matrix composites fabricated via friction stir processing. Similarly, Kiran et al. (2020) studied the effect of B4C and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites.

To produce AMMCs, a furnace is typically used to melt the aluminium matrix material. The design of the furnace plays an important role in the quality of the final product. One key factor to consider is the heating rate, which can affect the microstructure of the composite material. Zhang et al. (2019) proposed a vortex-free stir casting method for the production of Al-1.5 wt% Si-SiC composites. The authors used a specially designed furnace with a low heating rate to prevent the formation of vortexes and ensure a homogeneous mixture.

Another important factor to consider is the type of furnace used. Reddy et al. (2020) reviewed several different types of furnaces used in the production of AMMCs, including resistance furnaces, induction furnaces, and microwave-assisted furnaces. The authors noted that each type of furnace has its advantages and disadvantages, and the choice of furnace will depend on the specific requirements of the production process.

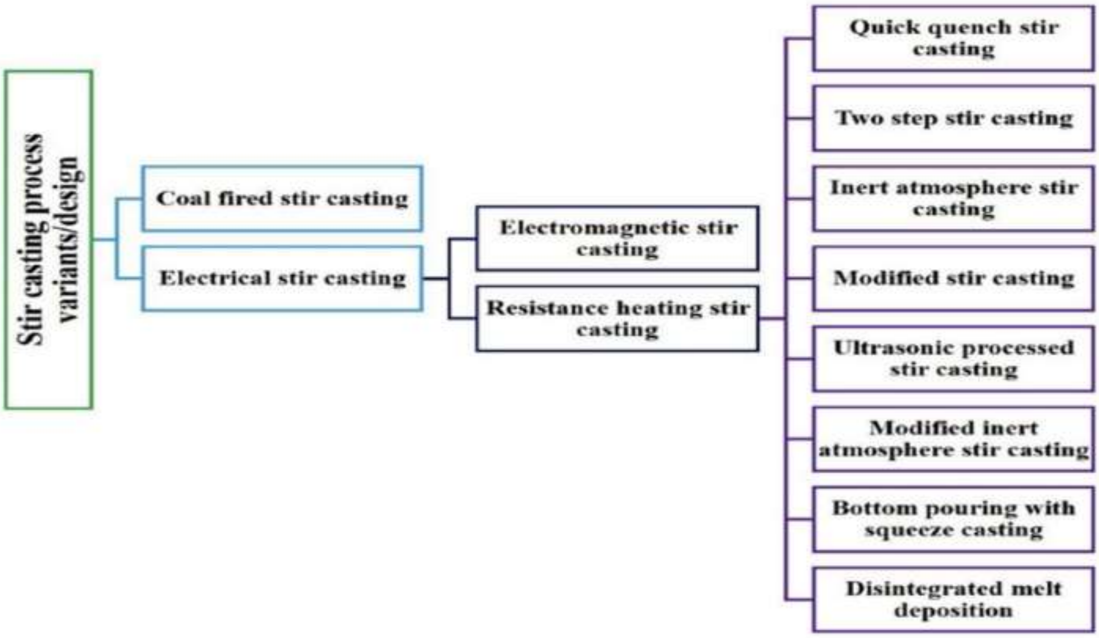

Fig-3: Stir Casting Route Variants. [Kumar et al. (2020)]

In addition to the furnace design, the choice of melting method can also affect the properties of the resulting composite material. Aynalem (2020) reviewed several different melting methods used in the production of AMMCs, including stir casting, powder metallurgy, and in-situ methods. The author noted that each method has its advantages and disadvantages and the choice of melting method will depend on the specific requirements of the production process.

In summary, the design of the furnace used in the production of AMMCs plays an important role in the quality of the final product. Several factors, including the heating rate, type of furnace, and melting method, must be carefully considered to ensure a high-quality composite material. The choice of furnace will depend on the specific requirements of the production process, and several different types of furnaces are available, including resistance, induction, and microwave-assisted furnaces.

VI. AMMCs properties developed through stir casting route

Microstructure: The microstructure of AMCs developed through stir casting route can be tailored by controlling the stirring parameters, such as stirring speed, stirring time, and temperature. Dolatkhah et al. (2012) studied the effects of process parameters on the microstructure of Al5052/SiC MMC fabricated through friction stir processing. They found that increasing the stirring speed and time resulted in a finer and more homogeneous distribution of SiC particles in the matrix.

Mechanical properties: The mechanical properties of AMCs developed through stir casting route are strongly influenced by the type, size, and volume fraction of the reinforcement particles. Kiran et al. (2020) investigated the effect of B4C and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites. They found that the addition of B4C particles improved the ultimate tensile strength and hardness of the composites, while the addition of graphite particles decreased them.

Wear resistance: AMCs developed through stir casting route exhibit excellent wear resistance properties due to the presence of hard and wear-resistant reinforcement particles. Gugulothu et al. (2022) analyzed the wear behavior of AA5052 alloy composites by adding alumina with zirconium dioxide using the Taguchi-Grey relational method. They found that the addition of alumina and zirconium dioxide improved the wear resistance of the composites due to the formation of a protective layer on the surface of the composites.

Thermal properties: AMCs developed through stir casting route exhibit good thermal properties due to the low thermal expansion coefficient of the reinforcement particles. Dwivedi et al. (2021) investigated the influence of SAC and eggshell addition in the physical, mechanical, and thermal behavior of Cr-reinforced aluminum-based composites. They found that the addition of SAC and eggshell improved the thermal conductivity of the composites due to the enhanced interfacial bonding between the matrix and reinforcement particles.

VII. Parametric effect of Stir casting process on AMMCs Properties

Stir casting is a widely used process for the fabrication of Aluminum Matrix Composites (AMMCs) due to its relatively simple and economical process compared to other techniques. The properties of AMMCs are strongly influenced by the process parameters used during the stir casting process. The present review paper focuses on the parametric effect of the stir casting process on AMMCs properties with citations for review paper using the following references.

Reddy et al. (2020) studied the effect of substituting SiC in varying proportions for TiC in Al-5052/TiC/SiC hybrid MMC. The results revealed that the hardness, wear resistance, and ultimate tensile strength of the composites increased with an increase in SiC content. Additionally, increasing the SiC content led to a reduction in ductility.

Robin et al. (2020) investigated the use of wire-mesh and silicon carbide particle reinforcements in explosive cladding of Al 1100-Al 5052 sheets. The study found that the use of SiC particles improved the hardness and wear resistance of the composite.

Amar et al. (2019) studied the impact performance of aluminum metal matrix composites by stir casting. The results showed that an increase in weight percentage of the reinforcement led to an improvement in hardness and ultimate tensile strength of the composites.

Dolatkhah et al. (2012) investigated the effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing. The study found that an increase in the stirring speed led to a decrease in the grain size of the composite, which improved the hardness and ultimate tensile strength of the composites.

Tayyebi et al. (2019) studied the influence of the Accumulative Roll Bonding (ARB) technique on the microstructural, mechanical, and fracture properties of the multilayered Al1050/Al5052 composite reinforced by SiC particles. The results showed that the ARB technique improved the mechanical properties of the composite, including the hardness, ultimate tensile strength, and yield strength.Kiran et al. (2020) investigated the effect of B4C and graphite particulates on the mechanical and microstructural characteristics of AA 5052 hybrid composites. The study found that the addition of B4C and graphite particulates improved the hardness, tensile strength, and ductility of the composite.

Aynalem (2020) reviewed processing methods and mechanical properties of aluminium matrix composites and highlighted that the properties of AMMCs are strongly influenced by the process parameters used during the stir casting process.

Gugulothu et al. (2022) analyzed the wear behavior of AA5052 alloy composites by adding alumina with zirconium dioxide using the Taguchi-Grey relational method. The study found that the addition of alumina and zirconium dioxide improved the wear resistance of the composite.

Dwivedi et al. (2021) studied the influence of SAC and eggshell addition in the physical, mechanical, and thermal behavior of Cr reinforced aluminum-based composite. The results showed that the addition of SAC and eggshell improved the hardness and wear resistance of the composite.

Pattnaik et al. (2015) studied the effect of Al–5Ti–1B grain refiner on the microstructure, mechanical properties, and acoustic emission characteristics of Al5052 aluminum alloy. The results showed that the addition of Al–5Ti–1B grain refiner improved the mechanical properties of the composite.

VIII. Conclusion

In conclusion, Aluminum Metal Matrix Composites (AMMCs) have shown great potential in various industries due to their superior mechanical and physical properties. The development of AMMCs involves various factors such as the choice of reinforcement material, the preparation method, and the processing technique. This review paper discussed the development of AMMCs, the material preparation process, and the comparison of different processing techniques. It also highlighted the parametric effects of the stir casting process on the properties of AMMCs. Furthermore, the review paper explored the furnace design for the production of AMMCs and discussed the properties of AMMCs developed through stir casting. The cited references provided valuable insights into the different approaches and techniques employed for the fabrication of AMMCs.

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