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Impact of Stir Casting Parameter and Stirrer Blade Design on Mechanical Properties of Aluminium MMC: A Review

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Abstract

Among many other qualities, aluminium matrix composites provide reduced weight, increased strength, and increased resistance to wear. Comparing the stir casting technique to other manufacturing methods, it is simple to use, inexpensive, and appropriate for large quantities. Because it significantly affects the material's characteristics, distributing reinforcement evenly throughout the matrix is one of the main issues in producing aluminium MMCs. Review the many studies on the effects of stir casting parameters and stirrer blade design on the mechanical characteristics of aluminium MMC in order to fill this gap. The review highlights that both stir casting parameters and stirrer blade design significantly influence the mechanical properties and microstructure of Aluminium MMCs. Optimal stirring speed, time, and temperature promote uniform particle distribution, minimizing porosity and enhancing tensile strength and hardness. Stirrer blade design particularly blade shape, number, and angle affects vortex formation and reinforcement dispersion. Multi-blade and mixed blade designs yield more homogeneous composites with improved Brinell hardness and reduced clustering. Increased blade count and melting temperature enhance microstructural refinement and mechanical performance. Thus, the integration of optimized stir casting parameters and blade designs is crucial for superior AMMC properties.

Keywords; Stir Casting Parameter, Stirrer Blade Design (Geometry), Aluminium Metal Matrix Composite (MMCs), Tensile Strength, Hardness. Stirring Speed, Time.

INTRODUCTION

Recent technological developments and the ongoing need to enhance product quality necessitate a focus on the creation of innovative materials. Materials may be thought of as the foundation of industries in the modern period. A variety of functional qualities may be obtained by combining various materials, including metal and its alloys, polymers, and ceramics (Fig. 1). The objective of a composite material is to derive the advantageous properties of distinct materials by combining them. These materials possess distinct chemical and physical properties (Sahu & Sahu, 2018). Therefore, in order to choose appropriate materials for composite production, a thorough understanding of the materials is needed. Both plants and animals may form natural composites. Abalone shells, wood, teeth, and bone are a few examples. Because they may combine qualities that are normally impossible to achieve, composite materials are becoming more and more popular in the market (Senapati et al., 2020). The qualities that are essential for every operating situation are not always present in metal. One potential method for achieving the necessary properties for a specific condition is to reinforce the alloys with a specific quantity of ceramic particles. Metal matrix composites are materials made by using base alloy to reinforce ceramic particles (MMCs) (Khare & Gupta, 2021). A malleable metallic material with specific mechanical and physical characteristics is known as the matrix material. Reinforcement is the substance that is applied to the matrix material to improve bonding and fortify the matrix material. The selection of matrix and reinforcement materials is contingent upon the necessary mechanical properties, including hardness, tensile strength, corrosion resistance, cost competitiveness, and market availability (MA & MH, 2022).

Due to their light weight, increased strength to weight ratio, resistance to corrosion and wear, improved high temperature performance, resistance to creep and fatigue, and numerous other combination of qualities, MMCs are now utilised in the fields of aerospace, automotive, defence, marine, and general engineering applications (Coyal et al., 2020).

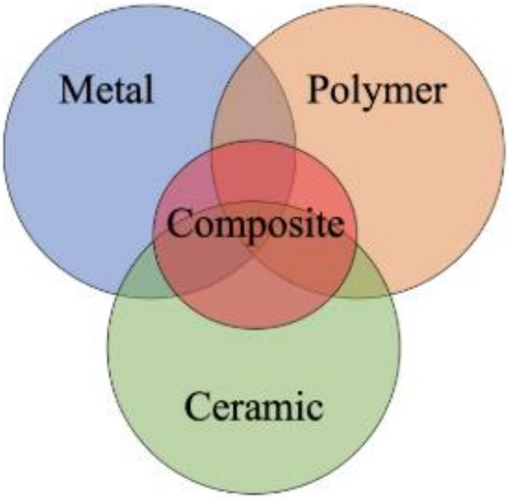

Figure 1 Family of composite materials (Morsiya & Pandya, 2023)

Metal matrix composite

Metal matrix composites (MMCs) are composite materials that include fibres or particles scattered across a metallic matrix, including steel, copper, or aluminium, according to materials science. A ceramic (like silicon carbide or alumina) or another metal (like steel) usually makes up the secondary phase. Their classification usually depends on the kind of reinforcement: particles, continuous fibres, or short discontinuous fibres (whiskers) (Zulfia et al., 2019). MMCs and cermets have several similarities; the latter usually contain less than 20% metal by volume. A hybrid composite is made up of at least three different components. MMCs are frequently employed in demanding applications due to their significantly higher strength-to-weight ratios, rigidity, and ductility (Upadhyay & Saxena, 2021). MMCs can't be used in the most extreme conditions because of their weak radiation resistance and generally inferior electrical and thermal conductivity. Fig. 2 lists the most often reported matrix and reinforcing materials utilised in the manufacturing of MMCs.

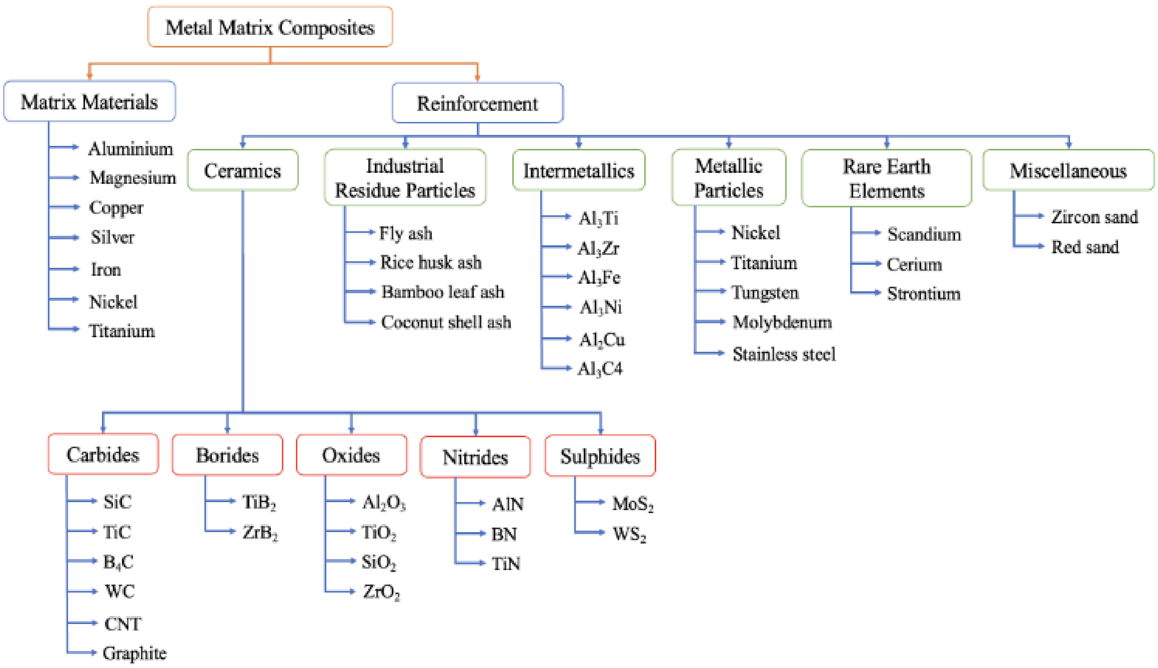

Figure 2 Matrix and reinforcement materials used for production of MMCs (Morsiya & Pandya, 2023)

Stir casting

MMCs are primarily and most frequently manufactured through the process of casting. While stirring entails rotating a stirrer into the melt to distribute reinforcing particles, casting entails melting and pouring the material (Upadhyay & Saxena, 2021). Fig. 3 shows the setup for stir casting. In order to achieve the necessary temperature, the matrix material is melted in a furnace. Resistance heating furnaces and muffle furnaces are the most often utilised types of furnaces. The feeder is used to provide the melt reinforcement particles. The crucible's particle feed rate is a critical criterion. Before combining, reinforcement particles are heated to a certain temperature to increase their wettability (Wazeer et al., 2022). To ensure that the particles are evenly distributed throughout the melt, a stirrer is then utilised. The control panel, which allows for the adjustment of the necessary temperature and RPM, may be linked to the furnace and motor. This configuration also includes a gas supply arrangement. For the production of reactive alloy MMCs, like magnesium, an inert gas supply is necessary. After choosing an appropriate stirring time, the melt is placed into the die or mould. Another option is to keep the mould vacuumed before pouring in order to prevent flaws like porosity. The flow diagram for stir casting procedures is shown in Figure 4 (Muhammad & Jalal, 2023).

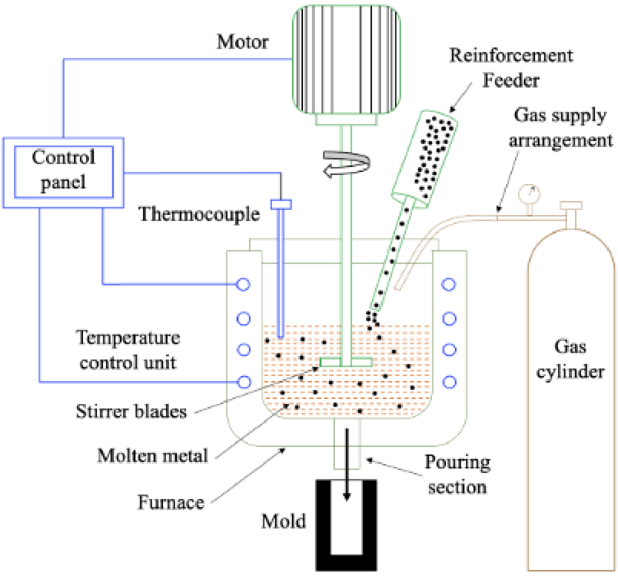

Figure 3 Stir casting setup in-situ (Morsiya & Pandya, 2023)

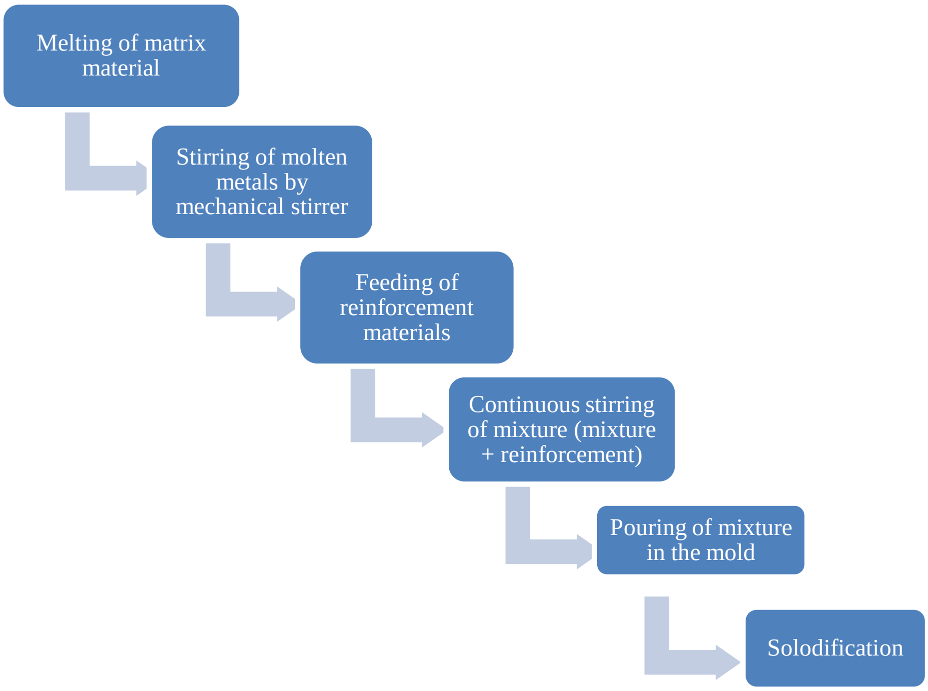

Figure 4 Flow diagram of stir casting techniques (Sahu & Sahu, 2018)

Stir casting process parameter

The following factors must be taken into account while utilising stir casting to create Metal Matrix Composite (MMC) components.

- **Rotational speed:** Controlling speed is very important for making casting work. The structure is also affected by rotational speed; a higher speed promotes refinement, while a very low speed causes the fluid mass to become unstable. To prevent ripping, it is preferable to use the fastest speed possible (Zulfia et al., 2019).
- **Stirring speed:** Wettability, or how well the matrix and reinforcement stick together, is the most crucial thing to think about while making composites. The stirring speed usually affects this. The stirring

speed directly regulates the molten metal's flow pattern (Zulfia et al., 2019).

- **Stirring temperature:** One of the crucial parameters is the processing temperature, which has an impact on the matrix material's viscosity. The distribution of particles in the matrix changes in tandem with any change in viscosity. As the processing temperature rises and the stirring duration increases, the liquid's viscosity decreases and the chemical interaction between the matrix and reinforcement speeds up (Ibrahim et al., 2023).
- **Pre-heat temperature:** The reinforcement and matrix may better moisten and bind if the mould and reinforcement particles are heated beforehand. During casting, it may also aid in avoiding thermal shock (Mathur & Barnawal, 2013).
- **Stirring time:** Stirring helps to ensure that the particles are distributed evenly throughout the liquid and that the reinforcement and matrix are well bonded. One important consideration in the production of composites is the amount of time that is spent swirling the matrix and reinforcement (Kumar & Kumar, 2017).
- **Pouring temperature:** The pouring temperature has a major impact on the method of solidification and determines the relative importance of the desired structural type. Greater equiaxed structure and grain refinement are associated with low temperatures, while many substances form columnarly at higher temperatures. However, in real-world situations, the range is constrained. A sufficiently high pouring temperature is necessary to provide optimum metal flow (Mathur & Barnawal, 2013).
- **Mould temperature:** Its principal significance is associated with the degree of die development that occurs during preheating. In non-ferrous casting, the mould temperature shouldn't be too high or too low. The mold's thickness should increase with the casting's size and weight, starting at a minimum of 25 mm (Singh et al., 2013).

Stirrer blade geometry parameter

The design of the stirrer blade has a major effect on the dispersion of reinforcing particles and the overall quality of the composite material during the stir casting process (Muhammad & Jalal, 2021). The impeller diameter, blade angle, and blade breadth are important variables. These variables impact the molten metal's axial vs radial flow patterns and mixing intensity, which in turn affects the porosity creation and particle distribution uniformity (Tamilanban et al., 2020a). Here is a closer examination of the parameters:

- **Blade Angle:** Angle of blade inclination in relation to impeller shaft. The angle affects the flow patterns of the molten metal.
- **Blade Width:** Within the combining vessel, the flow characteristics are significantly influenced by the blade's breadth.
- **Impeller Diameter:** Additionally, the crucible diameter and the impeller diameter are connected; for semi-spherical and flat bases, respectively, a ratio of 0.5-0.55 is typical. Particle concentration in the crucible's centre is prevented by this ratio.
- **Stirrer Position:** In order to guarantee even mixing, the stirrer's depth inside the crucible is also important.
- **Number of Blades:** The flow patterns and mixing efficiency may also be impacted by the impeller's blade count.

LITERATURE REVIEW

(Annapoorna et al., 2025) (Annapoorna et al., 2025) The purpose of this study is to enhance the performance of the Al-Mg-Si (Al6061) alloy by optimising the stir casting parameters for its production. The alloy is reinforced with hybrid nano Al_2O_3 and nano ZrO_2. A hybrid metal matrix composite's ultimate tensile strength was examined in relation to the significant impacts of stir casting parameters using the Taguchi optimisation approach. According to the results, the output response (UTS) was most significantly influenced by filler content (ZrO_2 and Al_2O_3) and temperature, while stirring speed and stirring duration were of comparatively diminished significance among the parameters examined. The best conditions (750 degrees Celsius, 500 rpm, and 10 minutes of stirring) were identified by stir casting to provide higher ultimate tensile strength: 1 weight percent ZrO_2 and 1 weight percent Al_2O_3.

(Morsiya & Pandya, 2023) (Morsiya & Pandya, 2023) Few research have been published on the impact of stirrer blade design and factors including stirrer form, size, and location. Instead, thermal, mechanical, and tribological qualities are often investigated in combination with changes in reinforcement percentage. Researchers utilise computational fluid dynamics to examine how stirrer blade design affects particle dispersal. Reinforcement particle dispersion is influenced by the stirrer design parameters, which also influence the creation of a vortex during mixing. According to reports, a stirrer with four blades and a blade angle of 30°

or 45° demonstrated consistent particle dispersion inside the melt as a result of appropriate lift forces. 40 percent of the base is the recommended stirring position. It is advised to stir at various rates between 300 and 600 rpm

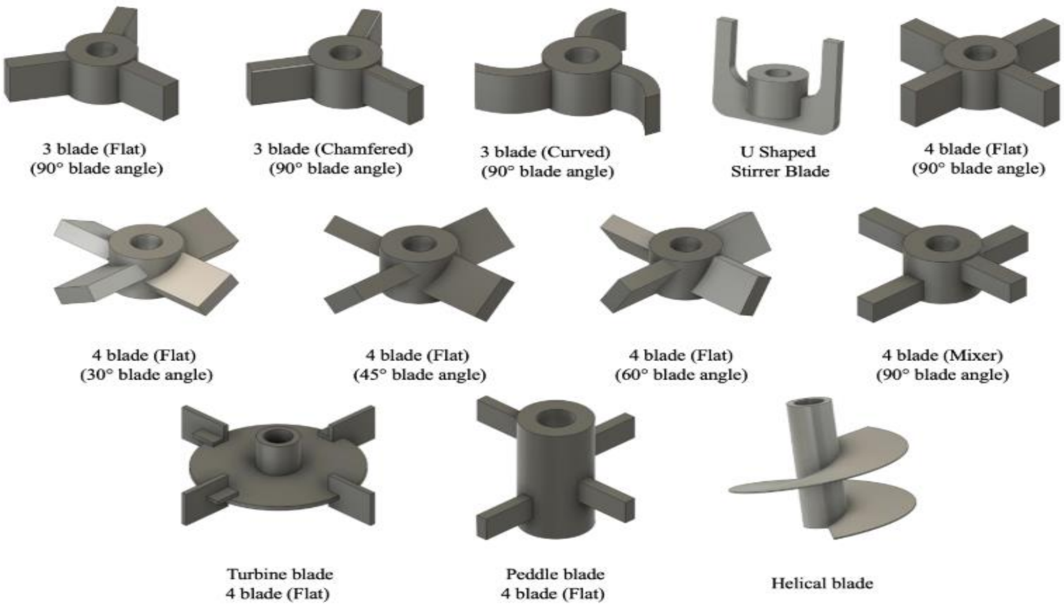

Figure 5 Various stirrer designs reported in publications Quality (Morsiya & Pandya, 2023)

(Karthik et al., 2022) (Karthik et al., 2022) Using stir casting parameters under the impact of various process factors, the current study aims to manufacture aluminium metal matrix composites. This study was conducted using the aluminium alloy AA 5083-H321 as the base material, with the addition of reinforcement particulates such as zirconium oxide ($ZrO2$). The following parameters are selected for stir casting: the percentage of reinforcement (3%, 6%, and 9%), the speed of stirring (300, 350, and 400 rpm), and the duration of stirring (20, 25, and 30 minutes). Using 9% reinforcement, 300 rpm stirring speed, and 30 minutes stirring duration, the highest impact strength measured in the impact strength study is 26.37 Nm. The homogeneous pace with a diverse range was a significant factor in the increase of the composites' impact strength when stirred.

(Muhammad & Jalal, 2022) (Muhammad & Jalal, 2022) The uniform distribution of reinforcing particles is the procedure's main obstacle. Optimising the design of the stirrer is crucial, as it can enhance its effectiveness. In the context of composite production, this paper investigates the experimental contributions of stirrer design. This page compiles, arranges, contrasts, and presents earlier research and contributions. It is challenging to generalise any suggested stirring parameter without knowing the stirrer design since the impeller blade's profile and number have an impact on both stirring duration and speed as separate factors.

(Krishnan et al., 2021) (Krishnan et al., 2021) The current study used both tests and the computational fluid dynamics (CFD) approach to predict the effects of stirrer blade design on the dispersion of reinforcement particles in the aluminium metal matrix. The generated metal matrix composites' (MMCs') mechanical characteristics and microstructure were examined. The manufactured samples were tested for tensile strength, compression, and hardness. The four-blade flat stirrer (B4) design was the best one, according to the CFD advice, which was based on the structure, power number, and number of blades. With the four-blade flat stirrer design obtaining the best compressive strength (642 MPa), highest hardness (45 HRB), and highest tensile strength (206 MPa) among the five distinct blade designs examined, the testing findings further supported the CFD suggestion.

(Gaurav Patil & Patil, 2020) (Gaurav Patil & Patil, 2020) In order to investigate the relationship between hardness and tensile strength, the Taguchi approach is used in this study to optimise the stir casting process parameter. To conduct the tests utilising the L9 orthogonal array, three distinct process parameters—melt temperature, die temperature, and stir pressure—were chosen. Better tensile strength and hardness were shown by the composites produced at ideal casting circumstances, which included a melting temperature of 750 oC, a stirring speed of 500 RPM, and a stirring time of 7 minutes. Process parameters that have been identified offer an advantageous environment for the direct processing of alloys on the crucible until they have reached complete solidification. The findings suggest that tensile strength and hardness are strongly correlated.

(Tamilanban et al., 2020) (Tamilanban et al., 2020a) Stirrer blade impact on aluminium composite stir casting with 12 weight percent SiC, 4 weight percent magnesium, and 2 weight percent copper was noted. Therefore, altering the stirrer's design to vary the vortex method may have an impact on the composites' mechanical and microstructure behaviour. The test results for hardness and tensile strength vary depending on the blade stirrer. SEM images and optical microstructure were analysed to determine the distribution of reinforcement and the cast structure of the composites. Along the composite's grain boundaries, the SiC particles seemed to disperse, and cast flaws were also visible. The finest mechanical qualities were obtained from a composite made with an alternative peddle blade.

(Paul & MT, 2015) (Paul & MT, 2015) This study examines the impact of stir casting's stirrer parameter. Testing the samples also reveals the relevance of each stirrer blade. One of the most cost-effective ways to process MMC on carbide composite is to use stir casting to create casting composites based on aluminium alloys. When measuring tensile strength and hardness, adjustments to the blade stirrer provide the best results. The stir casting method of producing and reinforcing SiC may be the cause of the composites' superior mechanical qualities when compared to matrix alloys. While the percentage of elongation falls, the tensile strength rises. The four-blade stirrer has the greatest brinell hardness number, making it suitable for stir casting furnaces for optimal outcomes. The results of the mechanical properties testing indicate that the four-blade stirrer possesses a higher level of strength and hardness than the two-blade and five-blade stirrers.

Table 1 Effect of stirrer blade geometry on mechanical properties of Aluminium MMC

Blade design	No. of blade count	Angle	Effect on mechanical properties	References
D4-Helical stirrer with a cylindrical shaft	1	90°	Tensile strength - sic (167), Silica (127) Hardness (N/mm2)- sic (50.7), Silica (34.32) Elongation(%) - sic (14), Silica (11) Impact strength (J) - sic (9.4), Silica (6.3)	(Muhammad & Jalal, 2023)
D5-Helical stirrer with a helical shaft	1	90°	Tensile strength - sic (172), Silica (132) Hardness (N/mm2)- sic (56.4), Silica (37.32) Elongation(%) - sic (16), Silica (13) Impact strength (J) - sic (10.2), Silica (7.2)	
B1- 3 Blades (radial, flat) B2- 3 Blades (radial, curved) B3-3 Blades (radial, chamfered) B4-4 Blades (mixer, flat) B5-3 Blades (axial, chamfered) Sample	1	90°	B4 - highest porosity of 2.9%, which is 3.8% higher than the B1 condition. B4 - highest ultimate tensile strength of 206 MPa, which is 111% higher than the B1 condition. B4 - yield a better result, which is 14.1% higher than the (B1) B4 - the highest compressive strength of 642 MPa, which is 51.9% higher than the B1	(Krishnan et al., 2021)
Four side peddle blade	1	90°	Ultimate Tensile strength – 147.6 MPa Average hardness – 81.3	(Tamilanban et al., 2020b)
alternate peddle blade			Ultimate Tensile strength – 173.3 MPa Average hardness – 80.7	
helical blade			Ultimate Tensile strength – 119.7 MPa Average hardness – 69.9	
2 blade stirrer,	1`	90°	Ultimate Tensile strength – 97.92 MPa Hardness - 58	(Paul & MT, 2015)
4 blade stirrer			Ultimate Tensile strength – 126.21 MPa Hardness - 90	
5 Blade stirrer			Ultimate Tensile strength – 117.72 MPa Hardness - 77	

RESEARCH GAP

Despite extensive research on aluminium metal matrix composites (AMMCs) produced via stir casting, a significant research gap exists in understanding the combined influence of stir casting parameters and stirrer blade design on the mechanical properties of AMMCs. Most existing studies focus either on process parameters (such as stirring speed, time, and temperature) or on blade geometry in isolation. However, the interaction between these two factors remains underexplored. Moreover, standardized guidelines for optimizing stirrer blade configuration specific to different reinforcements and matrix compositions are lacking. This gap limits the reproducibility and performance enhancement of AMMCs in industrial applications.

RESEARCH OBJECTIVE

- This article study the stir casting process, parameter of stir casting and stirrer blade geometry.
- Study the various literature's perspective on impact of stir casting parameter and stirrer blade design on mechanical properties of Aluminium MMC.

RESEARCH METHODOLOGY

This review paper adopts a qualitative research methodology based on secondary data to evaluate the impact of stir casting parameters and stirrer blade design on the mechanical properties of Aluminium Metal Matrix Composites (AMMCs). The study involves a comprehensive and systematic literature review of peer-reviewed journals, scholarly articles, technical papers, government reports, and case studies published between 2016 and 2025. Relevant publications were identified using scientific databases such as Scopus, ScienceDirect, and Google Scholar. The selected literature was critically analyzed to extract data on key process parameters, stirrer blade configurations, and their effects on tensile strength, hardness, and wear resistance.

CONCLUSION

The review reveals that both stir casting parameters and stirrer blade design play a critical role in determining the mechanical properties and microstructure of Aluminium Metal Matrix Composites (AMMCs). Optimal stirring parameters, such as speed, time, and temperature, significantly influence particle distribution and bonding in the matrix. Excessive stirring speed can lead to vortex formation and air entrapment, increasing porosity, whereas moderate speed improves particle dispersion and impact strength. Stirrer design parameters—including blade shape, dimensions, number of blades, and blade angles—directly affect vortex formation and the uniform distribution of reinforcement particles. Designs like alternate paddle blades and four-blade stirrers have demonstrated better particle dispersion and minimized clustering. Increased blade number in stirrers results in improved Brinell hardness and tensile strength. Microstructural analysis confirms smaller grain size and fewer particle clusters at higher melting temperatures and with optimized blade designs. It was also observed that blade variation influences mechanical properties significantly, with higher blade counts enhancing hardness and strength. In conclusion, the combined effect of controlled stirring parameters and optimized stirrer blade design improves the homogeneity, grain refinement, and overall mechanical performance of AMMCs. Future research should explore more advanced stirrer designs and multi-objective optimization of parameters to further enhance composite quality and reproducibility.

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