Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2024, Volume 15, Issue 11, Page 1526-1548

http://www.jmaterenvironsci.com

Fabrication and Mechanical Strengthening of Aluminium Composite Material-A Review

Gaurav [1] *, Saurabh Kafaltiya [1], V. K. Singh [1], Sakshi Chauhan [1]**

[1]*Department of Mechanical Engineering, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand 263145, India*

**Corresponding author, Email address: playprofessionallife@gmail.com*
***Corresponding author, Email address: skafaltiya@gmail.com*

Received *03 Oct 2024,*
Revised *30 Oct 2024,*
Accepted *01 Nov 2024*

Keywords:
- ✓ *Aluminium;*
- ✓ *Metal matrix composites;*
- ✓ *Mechanical properties;*
- ✓ *Reinforcements;*
- ✓ *Ceramic particles*

Citation*: Gaurav, Saurabh Kafaltiya, V. K. Singh, Sakshi Chauhan (2024) Fabrication and Mechanical Strengthening of Aluminium Composite Material-A Review, J. Mater. Environ. Sci., 15(11), 1526-1548*

Abstract: The transportation, military defence, aerospace, construction, and manufacturing sectors have a high demand for composite materials. Aluminium-based composites are also supplying substantial resources to these industries. Aluminium Metal Matrix Composites (AMMCs) are increasingly favoured for their superior mechanical properties and cost-effective performance. Even so, ongoing research continues to focus on enhancing the properties of AMMCs. This research paper focuses on various aluminium and aluminium alloys due to their extensive applications in the industry. This research explores the application of reinforcement particles, including micro/nano particles (both organic and inorganic) and particles from agricultural or industrial waste. The study also examines different techniques for enhancing the mechanical strength of aluminium composites, such as alloying the aluminium matrix, applying heat treatments, incorporating nano-reinforcements, improving interfacial bonding etc. The study discusses various commonly used reinforcements, including silicon carbide, boron carbide, alumina, titanium carbide, titanium diboride, and zirconium diboride, highlighting the latest research in these areas. This literature seeks to provide a comprehensive overview of the fabrication techniques and strengthening methods used for aluminium metal matrix composites (AMMCs). The current literature identifies knowledge gaps and suggests relevant research activities to address these shortcomings.

1. Introduction

In recent years, Aluminium alloys have a broad spectrum of uses due to their enhanced material properties. In nonferrous metal category, Aluminium can be considered as one of the most popular metals. Multiple aluminium alloy series have been developed in order to achieve certain material characteristics (Vaudreuil *et al.*, 2022). Metal Matrix composites (MMCs) composed of matrix and reinforcement material in order to meet the engineering requirement (Kareem *et al.*, 2021). Composite materials are created by mixing two or more different components in specified ratios to create a material with special properties (Ravindran *et al.*, 2019; Elmagri *et al.*, 2021; Akartasse *et al.*, 2023). When a composite has at least three distinct materials in it, it is referred to be a hybrid composite (Sambathkumar *et al.*, 2023). Aluminium metal matrix composites are in high demand in the automotive, aerospace, and aviation industries, and many researchers are working to improve the combination of features in these materials (Surappa, 2003). The tensile strength of pure aluminium is around 90 MPa, and this strength can be augmented by approximately twofold through techniques like rolling or alternative cold working processes. Through the incorporation of other metals via alloying or the application of heat treatment processes, it is possible to raise the tensile strength to levels within the range seen in structural steel (Verma *et al.*, 2012).

The incorporation of reinforcements into Aluminium Metal Matrix Composites (AMMCs) results in elevated mechanical properties, including enhanced values for compressive strength, tensile strength, hardness etc. of the composite materials (Ravindran *et al.*, 2019). Due to Aluminium characteristics, such as being lightweight, possessing a high strength-to-weight ratio, exhibiting corrosion resistance, wear resistance, and having high thermal conductivity, it is highly valued in various applications (Gill *et al.*, 2022). A variety of materials, including SiC, Al_2O_3, B_4C, TiC, fly ash, graphite, and others, can be utilized as reinforcements in the fabrication of Aluminium MMCs (Panwar & Chauhan, 2018). The key issues encountered in the production of aluminium metal matrix composites, leading to their intricacy and higher costs, involve challenges like wettability, scattering, agglomeration of particles, and interface debonding within the matrix (Moona *et al.*, 2018).

The aim of composite development is to attain superior material performances, and this objective hinges on various factors such as fabrication methods, process parameters, constituents, and compositions (Ward-Close *et al.*, 1999). Many researchers have utilized a range of methods to explore cost-effective and reliable processes for the production of metal matrix composites (Sandeep *et al.*, 2014). Enhancing mechanical properties by increasing the number of reinforcements comes with both positive and negative aspects. However, the broader utilization of hybrid composites has been constrained, mainly due to a limited understanding in the field of development and application (Dhanesh *et al.*, 2021). **Figure 1** presents the aluminium alloy series along with their main alloying elements and heat treatability characteristics. After reviewing numerous research papers, it was observed that aluminium and its alloys, particularly AA 2024, 6061, and 7075, are commonly utilized in industrial applications. The details regarding these matrix elements, along with their key properties and applications, are provided in **Table 1**. The author's aim is to investigate the influence of various reinforcements in Aluminium MMCs and evaluate the feasibility of implementing the different fabrication process.

Table 1. Commonly used Al alloy as matrix material

Matrix material	Properties	Application	References
Pure Al	Soft and Ductile; corrosion resistance; High Electrical conductivity; High thermal conductivity	Electrical wiring, aerospace engineering, automobile manufacturing and consumer goods (kitchen utensils, foil and cans)	(Georgantzia *et al.*, 2021)
AA 2024	High tensile strength and yield strength; good machinability	aircraft industry, automotive panels, and mechanical parts	(Kumaraswamy *et al.*, 2018)
AA 6061	High tensile strength and yield strength; good toughness and fatigue strength; excellent resistance to corrosion; easy to machine, form and weld	Aerospace, automobile, marine and consumer products (camera lenses, bicycles and scuba tanks)	(Samuel *et al.*, 2021)
AA 7075	High strength, ductility, toughness and fatigue resistance; good corrosion resistance	Aircraft structural parts and highly stressed structural applications	(Khalid *et al.*, 2023)

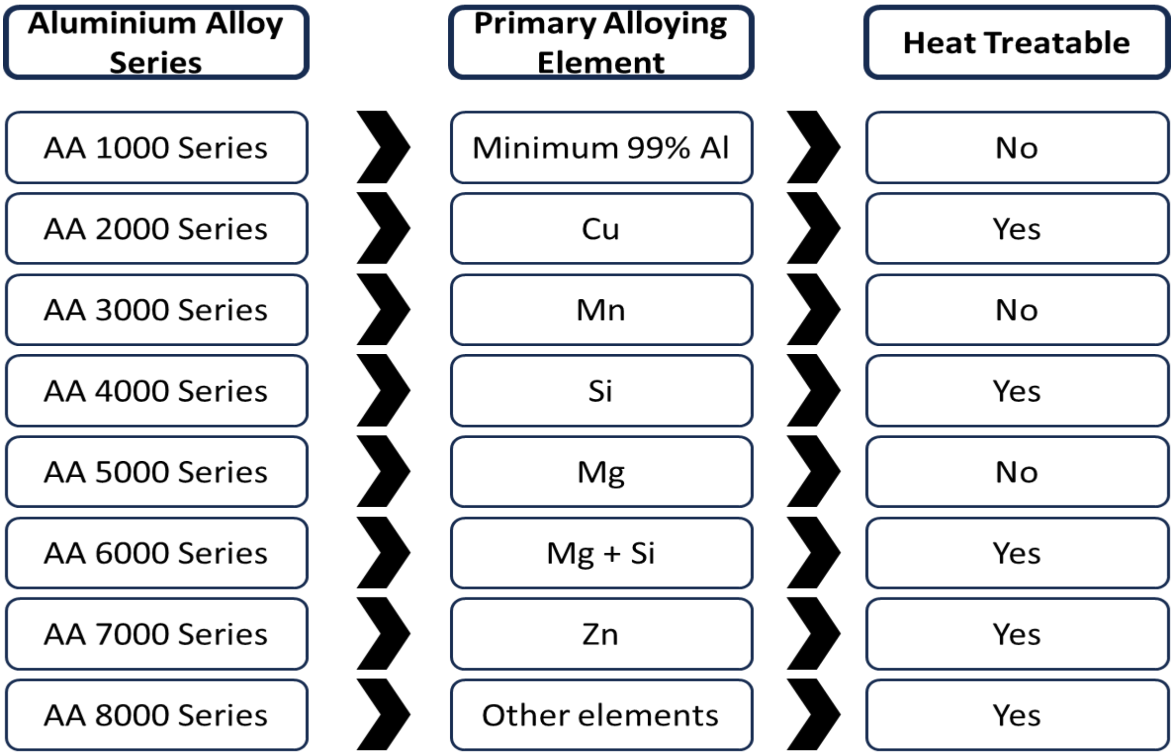

Figure 1. List of aluminium alloys series

2. Methods of fabrication

Different fabrication processes are available for the production of composites with an aluminium matrix. The fabrication processes significantly impact mechanical performance parameters like tensile strength, compressive strength, impact strength, hardness, fatigue. Every approach has its specific advantages, limitations, and drawbacks. An overview of various manufacturing processes for MMCs, emphasizing their benefits, limitations, and common applications are provided in **Table 2**. The categorization of aluminium composite fabrication methods is illustrated in **Figure 2**. This section presents a summary of the methods accessible for producing MMCs.

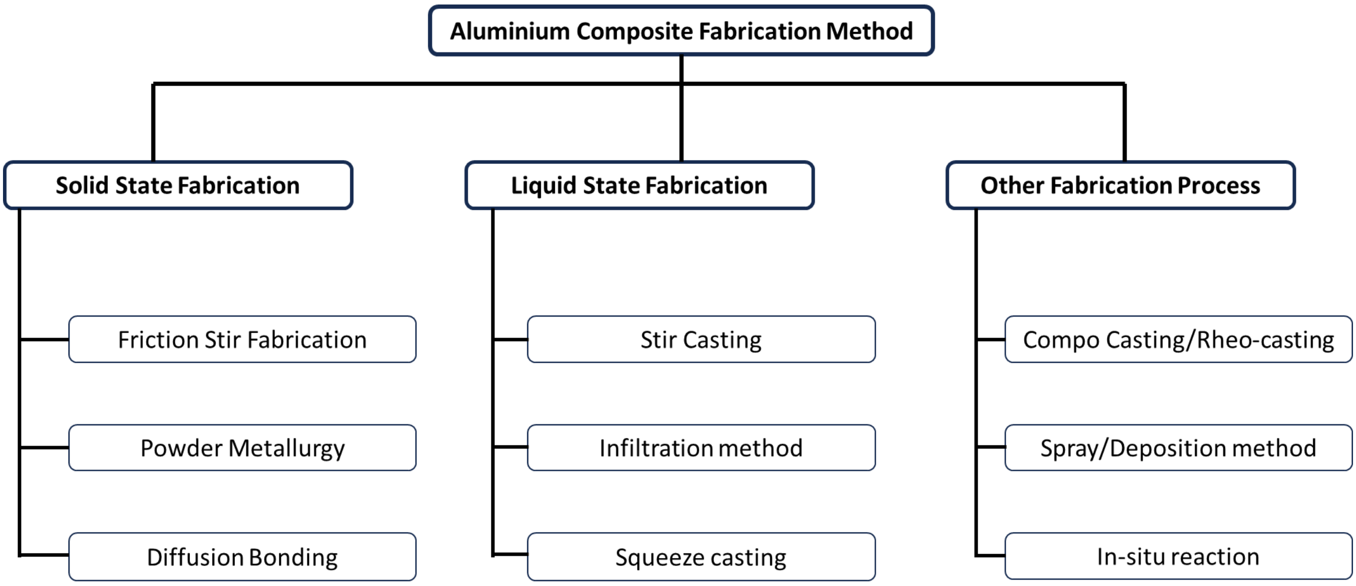

Figure 2. The categorization of fabrication processes for aluminium MMCs

2.1 Solid state fabrication

Solid-state processing involves the fabrication of Metal Matrix Composites (MMCs) through the bonding of matrix and reinforcement materials. This bonding occurs due to mutual diffusion under pressure at elevated temperatures. Various solid-state fabrication methods used in the production of Aluminium MMCs are discussed below.

2.1.1 Friction stir fabrication

It relies on the principles of friction stir welding. It does not involve the joining of two metal plates; rather, it induces a modification in microstructure, leading to enhanced properties (Sharma *et al.*, 2014). The process involves using a non-consumable tool with a pin and shoulder that is stirred and plunged into the workpiece. This action creates substantial friction, leading to the generation of heat, which, in turn, softens the metals through plastic flow. Due to intense plastic deformation, the grain size transforms into a very fine structure (Dinaharan *et al.*, 2019). **Figure 3** illustrates the schematic diagram of the friction stir fabrication process. Composites processed through friction stir exhibit higher tensile strength compared to those produced by stir casting, while still maintaining ductility (Bajakke *et al.*, 2019a). The production of Aluminium-Alumina composites using Friction Stir Processing (FSP) was focused on enhancing mechanical properties such as hardness, strength, and wear resistance. The process resulted in notable improvements, including a 23.56% rise in tensile strength, a 37.9% boost in hardness, a 25.5% increase in fatigue strength, and a 30.12% enhancement in wear resistance (Mohammad *et al.*, 2024).

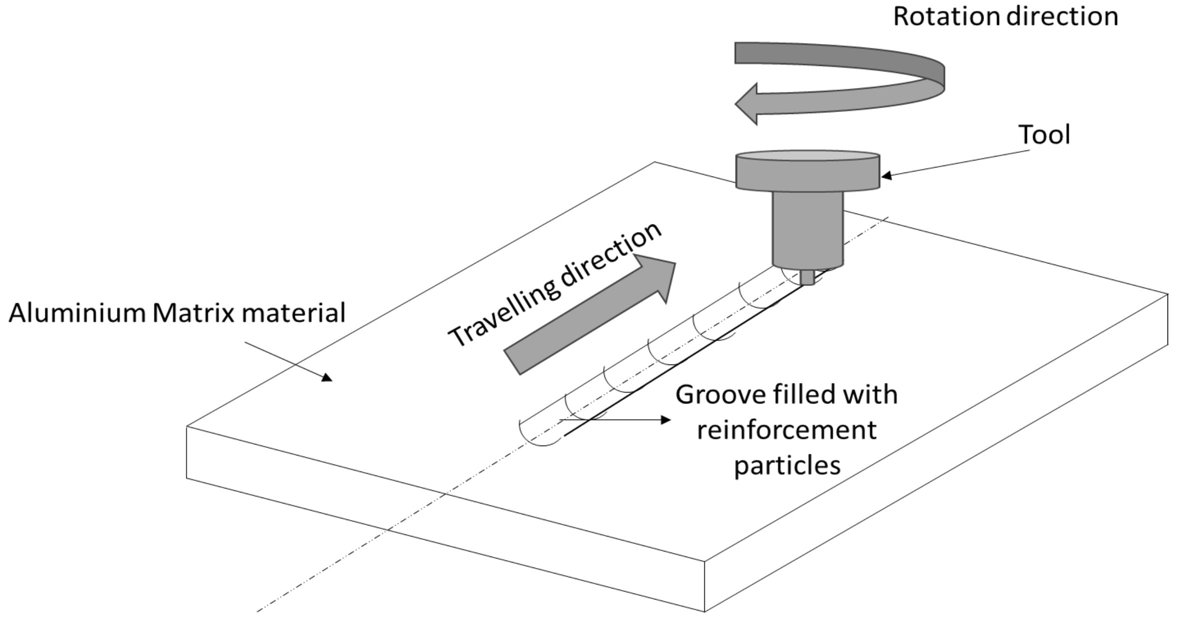

Figure 3. Schematic diagram of the friction stir fabrication process

2.1.2 Powder metallurgy

Powder metallurgy includes the mixing of fine powdered materials, compression into a desired shape, and subsequent heating to bond the surfaces of particles (Woo & Zhang, 2004). **Figure 4** presents a schematic diagram of the spark plasma sintering process. The powder metallurgy method helps mitigate various flaws in composites, including porosity and inadequate wetting (Sharma *et al.*, 2022). Powder metallurgy has the capability to produce precisely net-shaped components with complex geometry (Sharma *et al.*, 2014). The development of aluminium alloy (AA 2024) composites reinforced with boron fibers was carried out using powder metallurgy, which allows for a uniform distribution of the reinforcement and minimal porosity. Different weight fractions and particle sizes of boron fibers were applied, with the results showing a decrease in the composite's density as the weight percentage of boron fiber reinforcement increased(Ramanjaneyulu *et al.*, 2023).

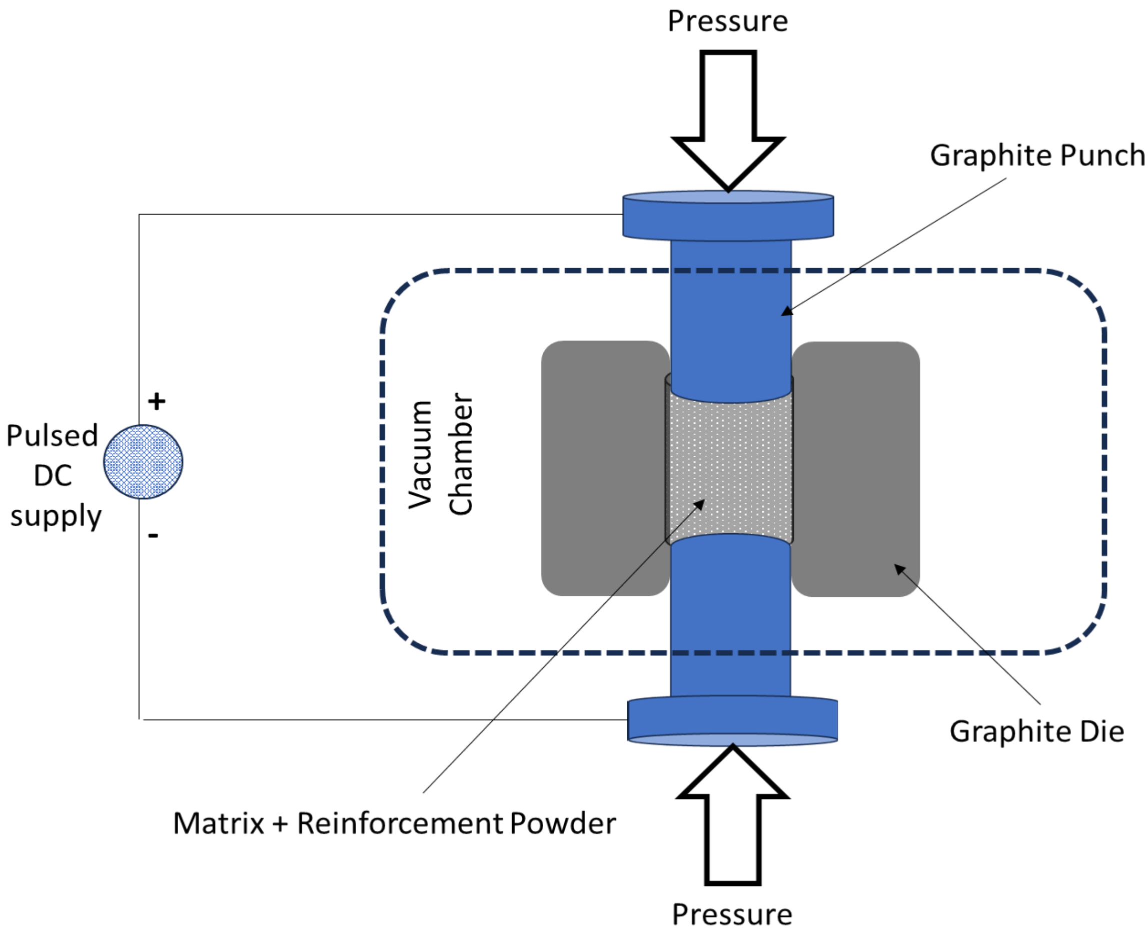

Figure 4. Schematic diagram of the spark plasma sintering process

2.1.3 Diffusion bonding

Stacked layers undergo hot pressing through hot isostatic pressing, facilitating diffusion bonding between the materials. Fiber orientation and percentage can be controlled precisely. Conversely, it demands elevated processing temperatures and pressures. This process is costly, and the range of shapes that can be fabricated is limited (Chawla & Chawla, 2006; Surappa, 2003b). **Figure 5** illustrates the schematic diagram of the diffusion bonding process. The study investigates the effect of process parameters, including bonding temperature, holding time, and bonding pressure, on the bonding strength of AA5083 diffusion-bonded joints. The maximum bonding strength achieved is 36.94 MPa, with a peak shear strength of 119.46 MPa, under optimized conditions of 520°C bonding temperature, 5 MPa bonding pressure, and a 45-minute holding time (Venugopal *et al.*, 2022).

2.2 Liquid state fabrication

Several industries opt for the liquid state process in the manufacturing of Metal Matrix Composites (MMCs) due to its simplicity and cost-effectiveness. It involves dispersing the reinforcement phase into the molten metal matrix, followed by the subsequent solidification process (Sharma *et al.*, 2020). The critical aspect is the selection ratio of ceramic reinforcement, determined by the matrix alloy. In instances where wetting particles are introduced into the melt, some ceramic reinforcing materials may not experience sufficient wetting by the molten metal (Ervina Efzan *et al.*, 2016). Some of the technique used for Liquid state fabrication are discussed below.

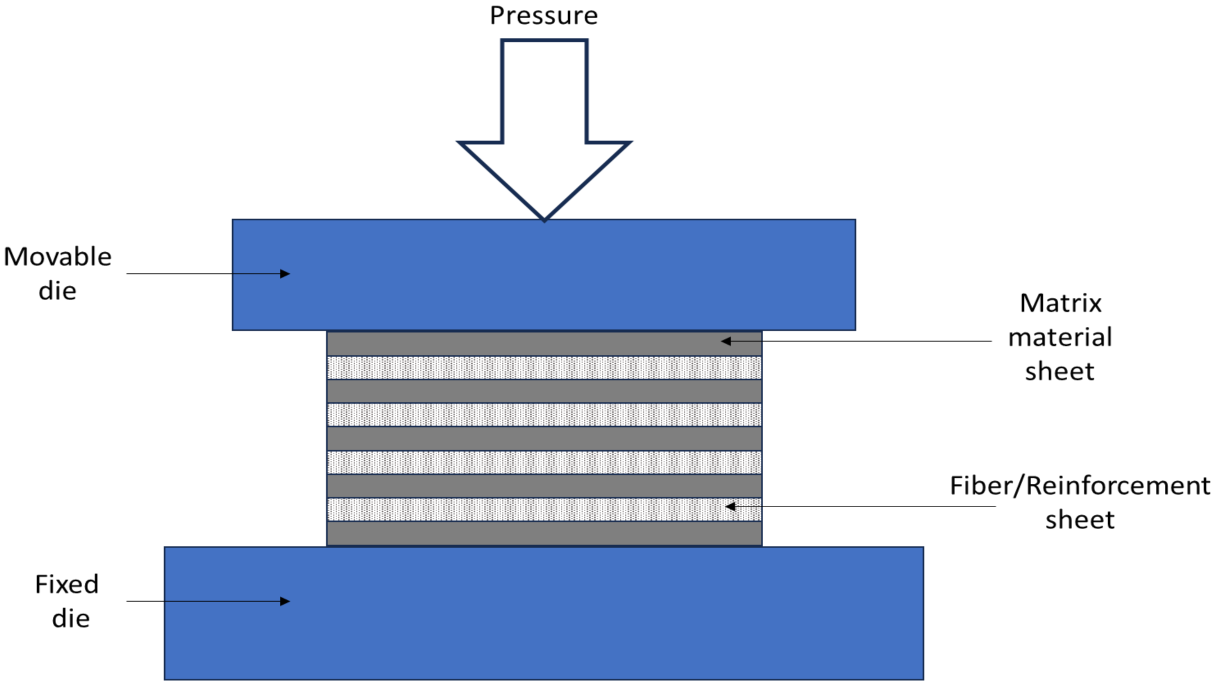

Figure 5. Schematic diagram of the spark plasma sintering process

2.2.1 Stir casting

This method is frequently employed for the mass production of Aluminium MMCs and their alloys, offering a cost-effective and flexible manufacturing approach. The suitable reinforcement is introduced into the molten metal at the melting temperature. Subsequently, an external device is employed to implement a stirring procedure, ensuring the uniform distribution of the reinforcement throughout the molten metal. This helps prevent heterogeneous spreading and reduce porosity (Tekale & Dolas, 2022). The schematic diagram of the stir casting process is presented in **Figure 6**. The impact of Friction Stir Processing (FSP) on the mechanical properties and microstructural enhancement of aluminium alloy AA6082, along with its composite reinforced with Titanium Aluminium Carbide (Ti_3AlC_2), was examined. The study recorded a 26% microstructural refinement in the composite material after multiple FSP treatments. Additionally, the compression strength of the FSP-processed materials demonstrated a significant improvement of 16.3% (Algizani & Moustafa, 2024).

2.2.2 Infiltration method

In this approach, a porous reinforcement phase is retained, and molten aluminium is passed through it, effectively filling all the pores and forming a composite material. The schematic diagram of the pressure infiltration process is shown in **Figure 7**. The vital process parameters in this method involve the initial composition, temperature of the reinforcement phase and infiltrating material, the nature and magnitude of the external force applied to the matrix metal, and the volume fraction of reinforcement (Lade *et al.*, 2023a; Narciso *et al.*, 2016). The fabrication of aluminium composites reinforced with graphite using the squeeze infiltration method was studied and analysed. To enhance wetting and prevent interfacial reactions, graphite particles were coated with copper. Porous graphite preforms were created and infiltrated with A356 aluminium alloy under high pressure. Natural graphite flakes were employed as carbon-based reinforcements due to their self-lubricating properties, excellent thermal conductivity, and ease of machinability. The composites demonstrated improved thermal conductivity, reaching up to 52 W/m·K at a 60% graphite volume fraction (Akhil *et al.*, 2021).

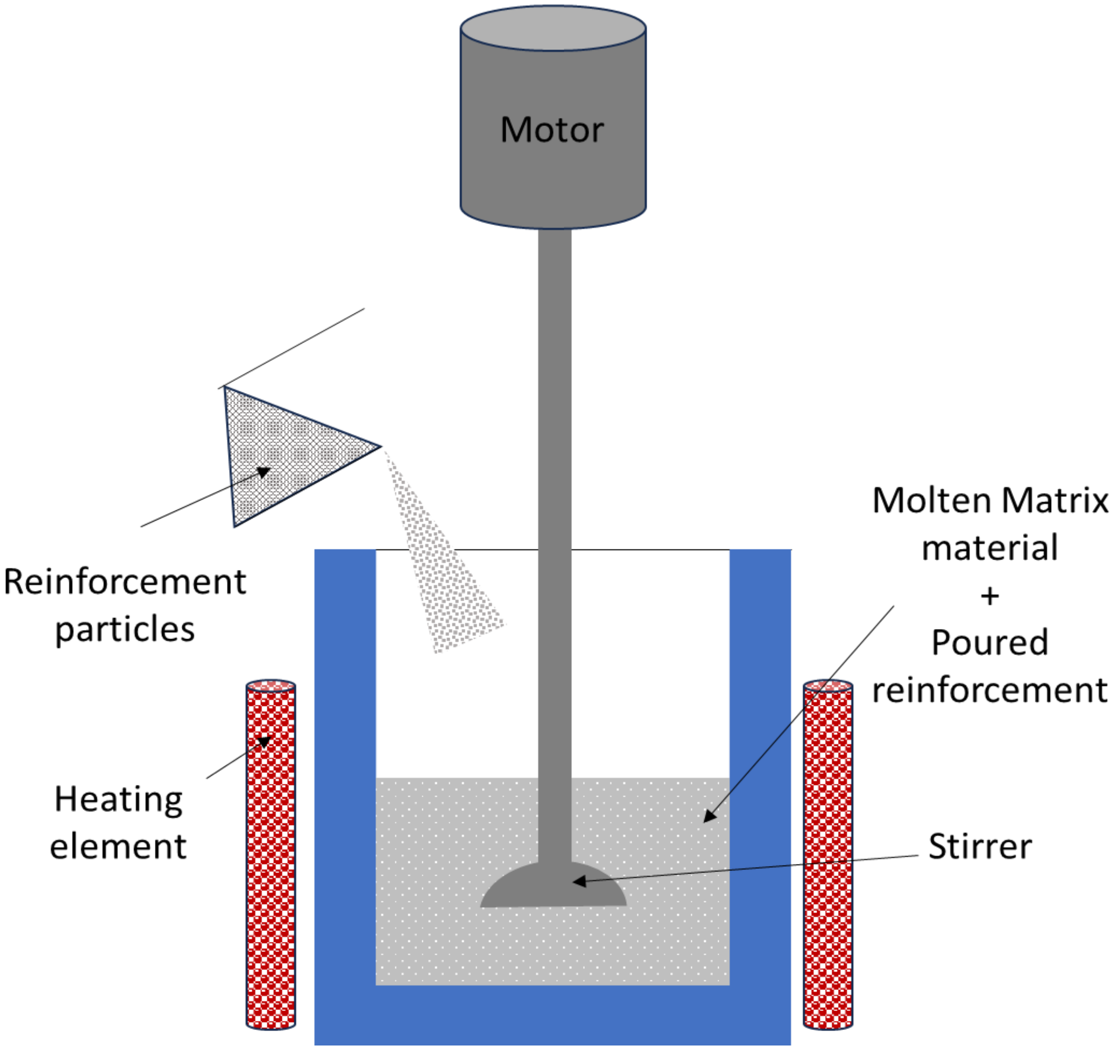

Figure 6. Schematic diagram of the stir casting process

2.2.3 Squeeze casting

Squeeze casting is a rapid method known for achieving the finest surface finish when employed in the creation of metal matrix composites (Lade *et al.*, 2023b). In this method, molten metals are introduced into the bottom die, and the solidification process of the melt undergoes maximum pressure force. **Figure 8** presents the schematic diagram of the squeeze casting process for metallic alloys. The application of pressure is essential for solidification and attaining the desired size (Moona *et al.*, 2018). This type of technique is employed for the production of simple, small parts such as engine pistons (Bhaskar *et al.*, 2014). The squeeze casting parameters, including squeeze pressure, pressure duration, pouring temperature, and initial die temperature, were optimized to enhance the yield strength and ultimate tensile strength of the aluminium alloy (Al-12%Si). Using the Taguchi method for experimental design, 27 trials were conducted to identify the optimal casting conditions. The best results were achieved with 150 MPa squeeze pressure, a 15-second pressure duration, a pouring temperature of 700°C, and an initial die temperature of 150°C. These settings led to significant improvements in the alloy's mechanical properties(Ojarigho *et al.*, 2024).

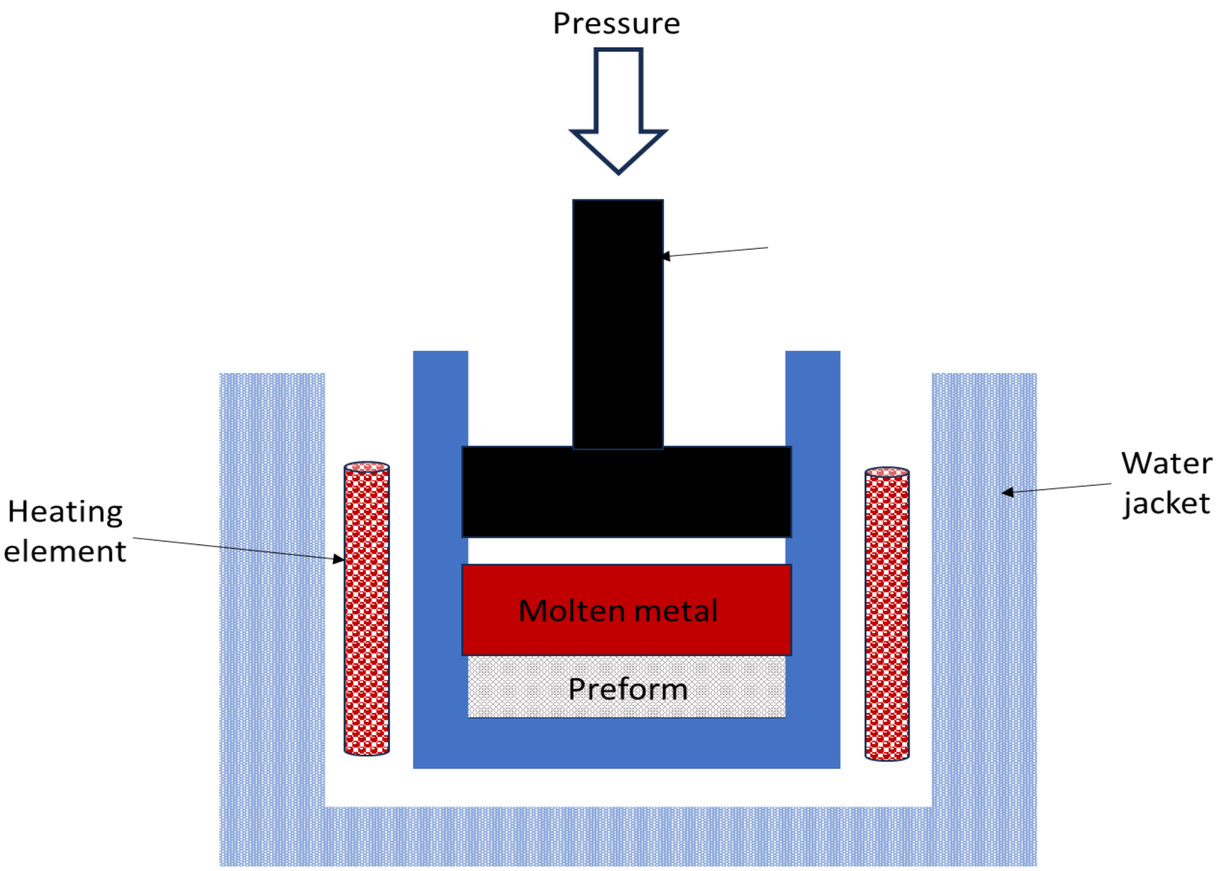

Figure 7. Schematic diagram of the pressure infiltration process

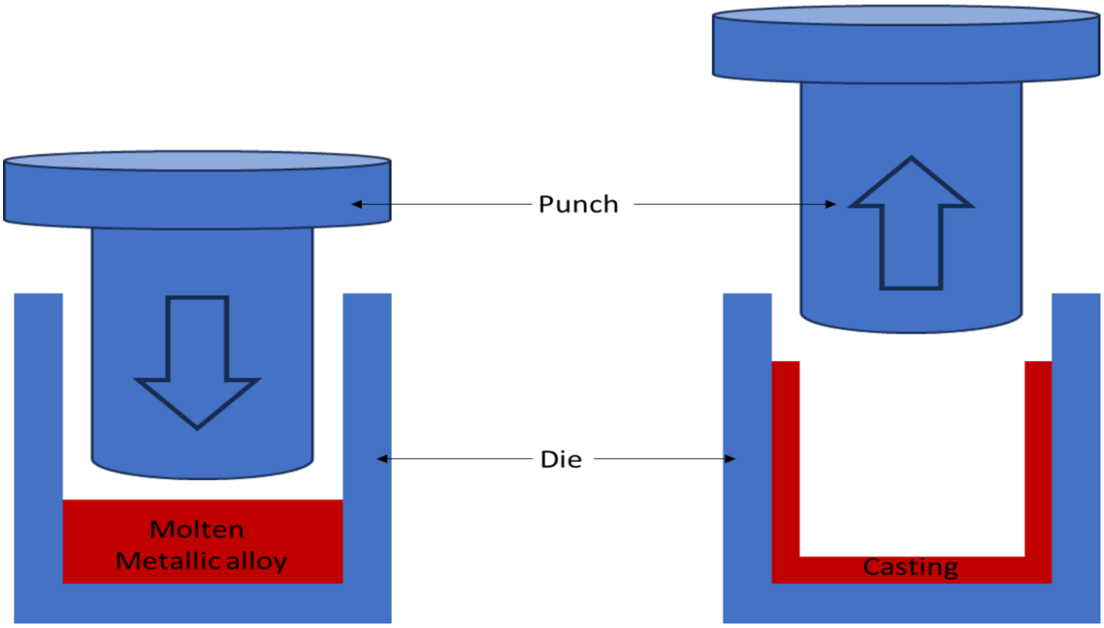

Figure 8. Schematic diagram of the squeeze casting process

2.3 Some other processes

These processes are generally based on the liquid or solid based fabrication technique but provide some important modification to them. These modification helps to overcome drawback of conventional fabrication technique. Some of these popular fabrication techniques are discussed below.

2.3.1 Compo casting or Rheo-casting

In this process, short fibers or heated reinforced particles are introduced into partially solidified and highly viscous molten metal slurries by intense stirring (Devender & Praveena, 2019). Hence, the reinforcement is captured between the proeutectic phase within the alloy slurry, preventing segregation. As continuous stirring occurs, the slurry's viscosity decreases, promoting mutual interaction between the metal matrix and reinforcement. Consequently, enhanced wetting and bonding between the two are achieved (Ramanathan *et al.*, 2019). An effort was made to improve the strength-ductility balance of a rheo-diecast semi-solid Al–Si–Mg–Cu–Fe–Sr alloy by optimizing the pouring temperature and heat treatment process. Reducing the pouring temperature from 700°C to 670°C produced finer, more spherical primary α-Al grains, decreased porosity, and increased the solid phase fraction, all contributing to enhanced mechanical properties. The T6 heat treatment promoted the spheroidization of eutectic Si phases, fragmentation of Al_3Fe phases, and formation of Mg_2Si precipitates, further boosting the alloy's strength and ductility (Liu *et al.*, 2021).

2.3.2 Spray / Deposition method

Spray casting involves propelling fine droplets of atomized molten material at high speed onto a preheated substrate. During this process, reinforcement particulates are impacted in the melted spray, resulting in the integration of reinforcement within fine molten metal droplets to form a composite (Sharma *et al.*, 2022; Trinh & Sastry, 2016). **Figure 9** depicts a basic functional diagram of the spray deposition method. To enhance the wear resistance of the Al–12.5Si alloy, zirconium oxide reinforcement particles were incorporated into metal matrix composites using the spray deposition method. An experimental investigation into spray forming parameters, including flight distance, gas pressure, melt temperature, and ZrO_2 reinforcements, revealed that ZrO_2 reinforcements and gas pressure significantly influenced mechanical properties such as hardness and ultimate tensile strength. The optimal spray forming conditions for achieving maximum hardness and ultimate tensile strength were determined, yielding an ideal set of parameters: melt temperature of 798°C, flight distance of 0.35 m, gas pressure of 0.97 MPa, and ZrO_2 reinforcements at 11.6%. These conditions resulted in the highest hardness and ultimate tensile strength values of 80.4 HV and 173.2 MPa, respectively (Patil *et al.*, 2022).

2.3.3 In-situ reaction

In this production procedure, the metal and reinforcement undergo a controlled chemical reaction to generate composites. The chemical reaction between them resulted in strong interfacial bonding with a homogeneous microstructure. SiC, AlN, and TiC stand out as the ceramics most frequently employed for in-situ reaction (Samal *et al.*, 2020; Senthil *et al.*, 2021). The microstructural and mechanical properties of Al6061/TiB_2 metal matrix composites (MMCs) fabricated through in-situ synthesis were analysed. The TiB_2 particles were uniformly distributed throughout the aluminium matrix, leading to significant grain refinement and a reduction in grain size (**Table 3**). This uniform dispersion contributed to enhanced mechanical properties of the composite. (Ramesh *et al.*, 2011). The reactions involved in the formation of this in-situ composite are outlined in **Eqn. 1**.

$$2B + Ti + Al \rightarrow TiB_2 + Al \qquad \textbf{Eqn. 1}$$

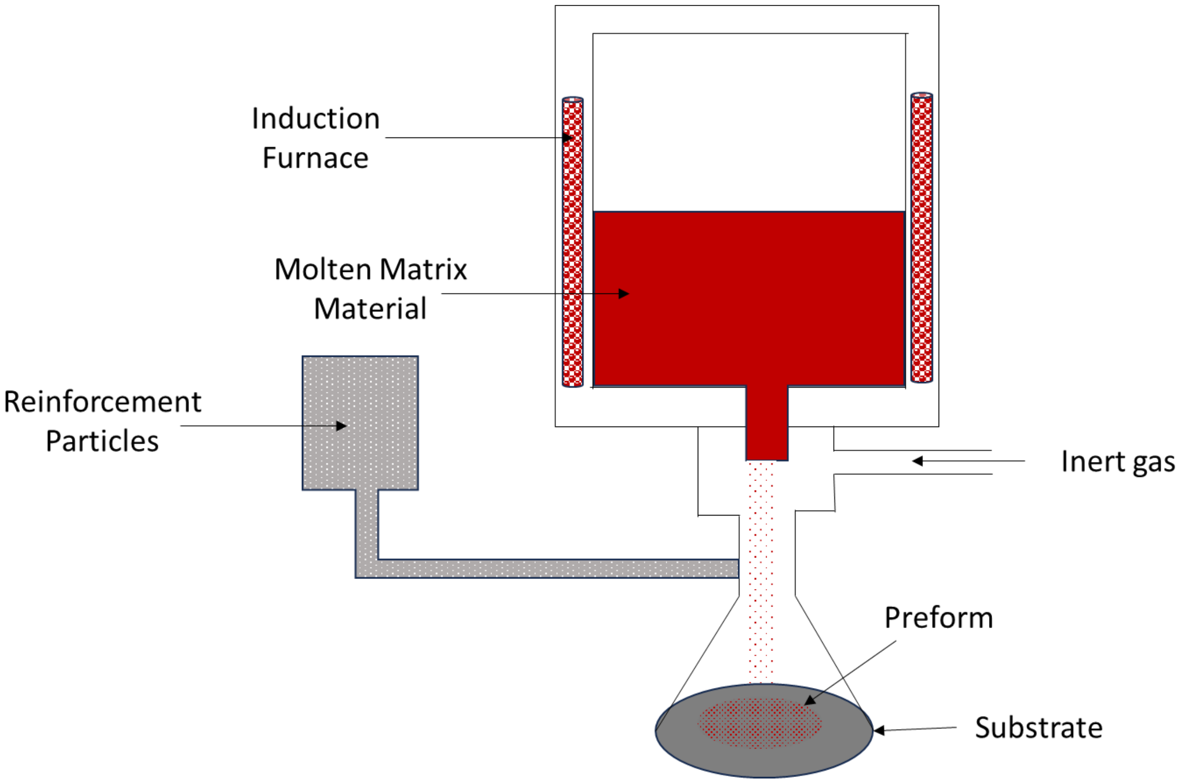

Figure 9. Schematic diagram of the spray deposition method

Table 2. Fabrication process for MMCs with their advantages, limitation and application.

Process	Advantages	Limitations	Applications	References
Friction stir fabrication	It offers grain refinement, strengthening, and Structural homogeneity	Tools used in Friction stir processing can wear out quickly, generally effective for materials with limited thickness	Aerospace and Railways	(Zykova *et al.*, 2020);(Bajakke *et al.*, 2019)
Powder metallurgy	Homogeneous microstructure, Maximum utilization of material	Size constraints, Costly	Biomedical and Aerospace	(Fang *et al.*, 2018); (Ujah et al., 2019)
Diffusion bonding	No filler material, Minimal plastic deformation	High cost, limited to material that can withstand high temperature	Biomedical, Aerospace and Refractory material	(Gietzelt *et al.*, 2018); (Lathashankar *et al.*, 2022)
Stir casting	Cost-effective, Customization, Ease to use	Limited material usability, Limited structural integrity, Proper control of stir parameter for optimum requirement	Automotive, cylinder heads and Pump housing	(Kumar *et al.*, 2020); (Soltani *et al.*, 2017)

Infiltration method	Enhanced properties, versatility, cost-effective	Complexity, Material Compatibility, Porosity control	Aerospace, Automotive and Electronics	(Etemadi *et al.*, 2018); (Sun *et al.*, 2018)
Squeeze casting	Low porosity, High strength, less wastage of material, good surface finish	High tooling cost, Limited to metals	Agricultural machinery, Piston and Engine block	(Venkatesan & Anthony Xavior, 2018); (Hajjari *et al.*, 2011)
Compo casting or Rheo-casting	Improved wettability, cost effective, complex shapes	Potential of porosity and shrinkage defects, High initial cost of molds and dies	Manufacturing of gears, Transmission cases, Turbine blades and Structural components	(Ramanathan et al., 2019); (Mazahery & Shabani, 2014)
Spray/Deposition method	Enhanced strength, low residual stress	High porosity, Slow process rate, High production cost	Heat exchangers	(Prashar & Vasudev, 2021); (Tao & Wang, 2019)
In-situ reaction	Excellent interfacial bonding, Strong and durable composite fabrication	Time consuming, Weather dependent, Labor-intensive, Ductility reduction	Automobile and Construction	(Mohan *et al.*, 2018); (Wang *et al.*, 2004.)

3. Various reinforcement used with Al MMCs

The selection of reinforcement is based on the desired material properties and cost considerations. Among the various forms of reinforcements, particulate reinforcements are widely utilized due to their broad availability and superior dispersive properties. Achieving the desired properties in a composite is challenging without careful consideration during the selection and combination of appropriate reinforcements with aluminium alloys. Hence, it is crucial to gather comprehensive information about different reinforcements and their applications. The commonly used reinforcements in aluminium composites, along with their relevant properties and applications, are listed in **Table 3**.

3.1 Silicon Carbide (SiC)

The predominant choice for reinforcement with an aluminium matrix is silicon carbide, mainly due to its cost-effectiveness compared to other options and its widespread availability in the market (Tekale & Dolas, 2022). Silicon carbide has transformed into ceramic material widely utilized in applications such as abrasives, refractories (Kumar & Singh, 2014). The microstructure, tensile strength, hardness, and resistance to acidic corrosion of aluminium-silicon carbide (Al-SiC) composites produced through liquid metal stir casting were examined. SiC particles were added at concentrations of 0%, 10%, and 20% to the aluminium alloy matrix. The incorporation of 20% SiC particles significantly enhanced the tensile strength by 14.70% and increased hardness by 26.88%. However, the corrosion rate was highest with the 20% SiC particles due to the formation of an interfacial region. The weight percentage of reinforcement had the most significant impact on the corrosion rate.(Singh *et al.*, 2023)

3.2 Boron Carbide (B_4C)

The incorporation of B_4C into the Al matrix results in a composite material with reduced porosity, heightened hardness, and a lightweight composition (Tekale & Dolas, 2022). The homogeneous distribution of aluminium composites is attributed to the larger particle size of B_4C, in contrast to specimens containing smaller particle sizes. This phenomenon occurs because smaller particles tend to promote the formation of agglomerates, whereas the larger B_4C particles contribute to a more even dispersion within the composite material (Kerti & Toptan, 2008). The addition of B_4C particles as reinforcements in an aluminium matrix result in improved ultimate stress, breaking load, maximum movement, and flexural strength. This enhancement in various mechanical properties positively contributes to the overall strength and performance of the composite material (Patidar & Rana, 2017). The corrosion behaviour of an aluminium matrix composite reinforced with micro-sized boron carbide in a 3.5% NaCl solution was investigated. It was found that the corrosion rate of the aluminium matrix composite increased with the addition of boron carbide (B_4C) particles, attributed to the breakdown of the passive layer caused by particle agglomeration. Conversely, the hardness of the composite improved as the B_4C content increased. (Samsu *et al.*, 2023)

3.3 Alumina (Al_2O_3)

Aluminium oxide, commonly known as alumina, is widely utilized as a reinforcing particle, primarily due to its outstanding compatibility with aluminium surfaces and its non-deleterious effects on the material's surface (Tekale & Dolas, 2022). The introduction of Al_2O_3 nanoparticles into AA 7075 composites led to substantial improvements in both wear resistance and essential mechanical properties, including ultimate tensile strength, yield tensile strength, and hardness (Al-Salihi *et al.*, 2019). It is suitable for high thermal conductivity application, matrix material strengthening, polishing, and cutting tools (Gireesh *et al.*, 2018; Ramnath *et al.*, 2014). After silicon carbide (SiC), Alumina (Al_2O_3) is the second most commonly used reinforcement, primarily owing to its exceptional interfacial compatibility (Pilania *et al.*, 2014). The mechanical properties of aluminium were improved by reinforcing it with graphite and alumina using the stir casting technique. The incorporation of graphite and alumina led to significant increases in tensile strength and hardness; however, there was a reduction in toughness.(Dwivedi & Kumar, 2019).

3.4 Titanium carbide (TiC)

The incorporation of aluminium-containing TiC particles leads to a reduction in both the coefficient of friction and the specific wear rate (Tekale & Dolas, 2022). TiC particles are also acknowledged as a dependable reinforcement for enhancing the corrosion resistance of Aluminium MMCs (Pandey *et al.*, 2017). The addition of 7.5% TiC creates optimal conditions for minimizing both the coefficient of friction and the specific wear rate.(Agrawal & Tungikar, 2020).

3.5 Titanium diboride (TiB_2)

Titanium diboride (TiB_2) reinforced aluminium composites were fabricated via the in-situ salt reaction synthesis method(Lakshmi *et al.*, 1998). The study focused on aluminium matrix composites (AMCs) reinforced with titanium diboride (TiB_2). Composites were fabricated with different weight fractions of TiB_2 particles, revealing that the A713 alloy with 6 wt.% TiB_2 showed a 35.86% increase in hardness and a 21.81% enhancement in tensile strength compared to the A713 alloy alone. These property improvements are attributed to grain refinement and dispersion strengthening due to the increased weight proportion of TiB_2 particulates. (Rangrej *et al.*, 2023).

3.6 Zirconium diboride (ZrB_2)

ZrB_2 has a high melting point (3245ºC), hardness (23 GPa), and modulus of elasticity (489 GPa). It also exhibits high electrical resistivity and thermal conductivity. Adding ZrB_2 to aluminium alloys enhances mechanical properties such as hardness, tensile strength, and compressive strength. It also improves wear and corrosion resistance (Kumar *et al.*, 2018). The study focused on analysing the properties of the Al 7175 alloy reinforced with zirconium diboride (ZrB_2) nanoparticles to improve wear resistance. It examined the relationships among material composition, load, speed, sliding distance, and their effects on friction force, wear rate, and friction coefficient. The findings reveal that increasing the ZrB_2 percentage while reducing speed and load can effectively decrease both the wear rate and friction coefficients in the Al 7175 alloy. The study was conducted to enhance the wear resistance properties of the Al 7175 alloy reinforced with zirconium diboride (ZrB_2) nanoparticles. It examined the relationships between material composition, load, speed, sliding distance, and their effects on friction force, wear rate, and friction coefficient. The results indicate that increasing the percentage of ZrB_2 while decreasing speed and load can effectively reduce both the wear rate and friction coefficients in the Al 7175 alloy.(Raj *et al.*, 2024).

3.7 Agro-industrial waste-based reinforcement

Incorporating agro-industrial waste materials into aluminium composites not only improves their mechanical properties but also helps address environmental concerns related to waste disposal(Vinod *et al.*, 2019). Aluminium composite materials utilizing agricultural and industrial waste have gained significant attention for their potential to enhance mechanical properties while addressing environmental concerns. The integration of waste materials such as Rice Husk Ash (RHA) and fly ash into aluminium alloys not only improves performance but also promotes sustainability(Senapati *et al.*, 2016).

The addition of Rice Husk Ash (RHA) and Silicon Carbide (SiC) to AA6061 alloy has demonstrated notable enhancements in mechanical properties, such as tensile strength and hardness, especially following heat treatment(Dwivedi *et al.*, 2020). The addition of agro-waste such as Lemon Grass Ash to metal matrix composites (MMCs) has resulted in steady improvements in tensile properties, providing a low-cost reinforcement option(Jose *et al.*, 2018). A novel hybrid aluminium metal matrix composite (AMC) was developed by incorporating waste materials such as eggshells, cow dung ash, snail shell ash, and boron carbide as reinforcements. The composites were fabricated using a stir casting method, with varying weight percentages of the reinforcements. Researchers suggested that carburized eggshells can enhance mechanical properties and reduce corrosion sensitivity. In contrast, cow dung ash is more effective at lower weight percentages, while an increase in boron carbide content tends to increase the brittleness of the composite.(Bose *et al.*, 2019).

Table 3. Commonly used reinforcements in Al MMCs with properties and applications

Reinforcement	Properties	Applications	References
SiC	Extremely hard and strong; Excellent thermal conductivity; Chemical resistance	Aeroengine field, nuclear energy field, Sandpapers, grinding wheels, Cutting tools, Power modules, Car brakes, Clutches, Water pump seals	(Gerhardt, 2011); (P. Wang *et al.*, 2019)

B_4C	High hardness; Neutron absorption capabilities, Resistance to solvents, Corrosive resistance, Lightweight	Structural, automotive and Aerospace application	(Bhatia *et al.*, 2021)
Al_2O_3	Low production cost, High hardness, Chemical inertness, Biocompatibility, Wear resistance	High temperature application, Absorbent in analytical chemistry, Dental application	(Lazouzi *et al.*, 2018).; (Krishnan et al., 2021)
TiC	Easy availability, High hardness, High melting point, Good thermodynamic stability, Chemical stability, Exceptionally good wear properties	Industrial & manufacturing, Aerospace, Medical, Defence	(Mao *et al.*, 2022).; (Parashivamurthy et al., 2001)
TiB_2	Considerable hardness, elastic modulus, Wear and corrosion resistance; Exceptional electrical and thermal conductivity	High-speed machining tools, Wear-resistant coatings, High-temperature nuclear reactors, Atmospheric reentry vehicles, and Electrode materials	(Cao *et al.*, 2024)
ZrB_2	High melting point, Low fracture toughness, Poor thermal shock resistance	Aerospace, Grinding and cutting tools, Nuclear reactors, Refractory crucibles, Microelectronics, and Solar absorbers	(Oguntuyi *et al.*, 2021)

4. Method of improving strength of aluminium composite

Different method of for improving strength of aluminium composite are discussed below

4.1 Alloying the Aluminium Matrix

Incorporating alloying elements such as Copper (Cu), Magnesium (Mg), and Zinc (Zn) can enhance the strength of the matrix through solid-solution strengthening or precipitation hardening (Callister Jr & Rethwisch, 2020). The effects of alloying atoms on the stability and micromechanical properties of aluminium alloys were explored using a machine learning-accelerated first-principles approach. Researchers concluded that alloying elements such as Sc, Cu, B, Zr, Ni, Ti, Nb, V, Cr, Mn, Mo, and W enhance the strength of the aluminium matrix, while elements like K, Na, Y, and Tl are challenging to dissolve(Huang *et al.*, 2023). The inclusion of copper in aluminium alloys like AA2024 induces lattice distortions, which lead to significant strengthening (Callister Jr & Rethwisch, 2020). Copper (Cu) atoms in aluminium alloys play a significant role in effective solid-solution strengthening due to their strong pinning effects(Kong *et al.*, 2023).

4.2 Heat treatment

Different types of heat treatment can be applied on aluminium composites such as quenching, annealing etc. Quenching is the rapid cooling of aluminium following solution heat treatment, which "locks" the dissolved alloying elements in place and prevents them from precipitating out during the cooling process. While this technique can significantly increase the strength of aluminium alloys, it may also induce residual stresses that could necessitate further treatment (Polmear, 2005). Annealing is a softening process that relieves internal stresses, improves ductility, and refines the grain structure of aluminium alloys. During annealing, the aluminium alloy is heated to a temperature just below its melting point and held there for a period of time before cooling slowly. This allows recrystallization to occur, which refines the grain size and improves mechanical properties like ductility and toughness (Rooy & Kaufman, 2004).

The impact of heat treatment on the tensile strength of directly recycled aluminium alloy (AA 6065) was investigated. The experiments included preheating aluminium samples at various temperatures and durations, followed by tensile testing and microstructural analysis. The researchers found that higher preheating temperatures significantly improved tensile strength, with optimal results obtained at 550°C for a duration of three hours(Suryakant & Yadav, 2023).

4.3 Hybrid composites

A composite material is formed by combining two or more distinct materials with different physical or chemical properties. These materials retain their individuality within the final structure, resulting in a composite with properties that differ from those of the individual components(Bodunrin *et al.*, 2015). Combining various reinforcements can deliver enhanced performance compared to using a single type of reinforcement in composites(Chung, 2010). For instance, incorporating titanium carbide and graphite into aluminium matrices led to an increase in tensile strength from 170 MPa to 239.11 MPa(Velavan *et al.*, 2023). These composites are commonly employed in structural applications due to their light weight, high strength, and superior wear resistance, making them well-suited for parts like drive shafts and housings(Kumar *et al.*, 2024).

The incorporation of boron carbide (B_4C) and graphite in LM6 aluminium alloy composites significantly enhanced tensile strength and hardness while maintaining ductility(Somegowda et al., 2023). The mechanical properties of Aluminium 8011 hybrid metal matrix composites reinforced with boron carbide (B_4C) and fly ash particles were investigated. The composite containing 8% B_4C and 2% fly ash exhibited the most favourable overall mechanical properties, demonstrating a 17.72% improvement in hardness, a 44.7% increase in compressive strength, a 44.29% enhancement in flexural strength, a 26.09% boost in impact strength, and a 26.34% rise in tensile strength compared to the base material(Sambatkumar *et al.*, 2024).

4.4 Nano-reinforcement inclusion

Aluminium composite reinforced with nanoparticles are highly advantageous in aerospace applications owing to their superior strength-to-weight ratio and increased thermal stability(Qadir *et al.*, 2023). However, ensuring uniform distribution of nanoparticles and preventing agglomeration are significant challenges that still require further investigation(Pandit *et al.*, 2023). The stir casting process is frequently utilized for producing aluminium matrix composites (AMCs) because it enables uniform distribution of nanoparticles, which is essential for achieving optimal mechanical properties(Qadir *et* *al.*, 2023). Techniques like gas ultrasound sensor double-stir casting have been used to improve the even distribution of nanoparticles within the matrix(Seshappa & Prasad, 2021).

The incorporation of nanoparticles such as TiO_2 and Al_2O_3 into aluminium alloys has led to notable enhancements in mechanical properties. For example, one study reported a 14.71% increase in the fatigue life of AA 7071 alloy with the addition of 5 wt.% TiO_2 following heat treatment(Sabari, 2024). The application of waste-derived Al_2O_3/SiC nanoparticles in aluminium composites has been investigated to improve micro-hardness and tensile strength while also reducing costs(Seshappa & Prasad, 2021).

4.5 Improving Interface Bonding

Using various additives during fabrication can improve interfacial bonding between matrix and reinforcement particles. Surface treatments, including nickel coating and the use of wetting agents, improve the wettability and bonding of reinforcements with the aluminium matrix, leading to better load transfer efficiency and enhanced composite strength(Zeng *et al.*, 2023). Surface treatments like pulsed laser surface treatment (PLST) have been applied to enhance the bonding between aluminium alloys and reinforcements. This results in the creation of intermetallic compounds that increase both hardness and strength(Esmaily *et al.*, 2019). Traditional surface treatments, such as anodizing and metallic coatings, are extensively used to protect aluminium substrates from corrosion and wear, which enhances their durability (Zeng *et al.*, 2023).

5. Future scope of research for Aluminium MMCs

Processing aluminium MMCs poses several challenges due to the significant variability in their properties, resulting in a broad range of performance deviations. Hence, selecting an appropriate processing method is crucial to ensure the material meets specific application requirements. No single process can be universally applied to all applications, as each requires a tailored approach based on the specific material properties and performance criteria needed. Various factors such as cost-effectiveness, feasibility, and desired material properties play a crucial role in determining the appropriate composite fabrication method.

There is limited literature available on the treatment of reinforcement particles with flux, acid, or wetting agents prior to fabrication, highlighting a gap in research on these pre-processing methods. The use of nanoparticles in composites is also limited due to challenges like agglomeration, which hinders achieving uniform distribution and reduces the overall effectiveness of the reinforcement. Some studies, such as oxidative acid treatment on reinforcements, have primarily focused on polymer composites, while limited research has been conducted on applying these techniques to aluminium composite materials.

6. Summary/Conclusion

The review presents a detailed overview of the fabrication processes, emphasizing the mechanical properties of aluminium metal matrix composites (MMCs) reinforced with various reinforcement. The choice of fabrication process is largely influenced by factors like the required quality, cost-effectiveness, and overall process efficiency. This review paper also discusses various studies where fabrication parameters have been optimized. Moreover, issues such as wettability, porosity, and the shape, size, and distribution of reinforcements remain challenging and require further exploration. The review provides an in-depth discussion of different methods for improving the strength of aluminium composites. Research has shown that grain refinement, which impedes dislocation movement, plays a significant role in enhancing tensile strength. Lastly, this review will provide insight into the latest research and processing challenges associated with aluminium composites, while showcasing their outstanding performance in contemporary applications.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

References

Agrawal, E., & Tungikar, V. (2020). Study on tribological properties of Al-TiC composites by Taguchi method. *Materials Today: Proceedings, 26*, 2242–2247.

Akartasse N., Azzaoui K., Mejdoubi E., Hammouti B., Elansari L.L., Abou-salama M., Aaddouz M., Sabbahi R., Rhazi L. and Siaj M. (2022), Environmental-Friendly Adsorbent Composite Based on Hydroxyapatite/Hydroxypropyl Methyl-Cellulose for Removal of Cationic Dyes from an Aqueous Solution, *Polymers*, 14(11), 2147; https://doi.org/10.3390/polym14112147

Akhil, M. G., Arsha, A. G., Manoj, V., Vishnu, R. L., Rajan, T. P. D., & Pai, B. C. (2021). Squeeze infiltration processing and structural characteristics of lightweight aluminum-carbon metal matrix composites. *Transactions of the Indian National Academy of Engineering, 6*(1), 41–48. https://doi.org/10.1007/s41403-020-00172-0

Algizani, Z. T., & Moustafa, E. B. (2024). The impact of friction stir process on mechanical properties of AA6082 enhanced by titanium aluminum carbide Ti3AlC2. *Multidisciplinary Materials Chronicles*, 42–48. https://doi.org/10.62184/mmc.jmmc110020244

Al-Salihi, H. A., Mahmood, A. A., & Alalkawi, H. J. (2019). Mechanical and wear behavior of AA7075 aluminum matrix composites reinforced by Al_2O_3 nanoparticles. *Nanocomposites, 5*(3), 67–73.

Bajakke, P. A., Malik, V. R., & Deshpande, A. S. (2019). Particulate metal matrix composites and their fabrication via friction stir processing–a review. *Materials and Manufacturing Processes*, *34*(8), 833–881. https://doi.org/10.1080/10426914.2019.1605181

Bhaskar, C., Kandpal, B. C., Kumar, J., & Singh, H. (2014). Production technologies of metal matrix composite -A Review. *International Journal of Research in Mechanical Engineering & Technology. 4*(2), 27-32

Bhatia, S., Angra, S., & Khan, S. (2021). A review on mechanical and tribological characterization of boron carbide reinforced epoxy composite. *Advanced Composite Materials, 30*(4), 307–337. https://doi.org/10.1080/09243046.2020.1759482

Bodunrin, M. O., Alaneme, K. K., & Chown, L. H. (2015). Aluminium matrix hybrid composites: A review of reinforcement philosophies; Mechanical, corrosion and tribological characteristics. *Journal of Materials Research and Technology*, *4*(4), 434–445. https://doi.org/10.1016/j.jmrt.2015.05.003

Bose, S., Pandey, A., Mondal, A., & Mondal, P. (2019). A novel approach in developing aluminum hybrid green metal matrix composite material using waste eggshells, cow dung ash, snail shell ash, and boron carbide as reinforcements. In *Lecture Notes in Mechanical Engineering* (pp. 551–562). Pleiades journals. https://doi.org/10.1007/978-981-13-6412-9_54

Callister Jr, W. D., & Rethwisch, D. G. (2020). *Materials science and engineering: An introduction.* John Wiley & Sons.

Cao, Z., Sun, J., Zhang, K., Ji, W., Cai, K., Li, B., Liu, B., & Fan, C. (2024). Advances in bulk TiB2-based composites: Densification and toughening. *Composites Part A: Applied Science and Manufacturing*, 108318.

Chung, D. D. L. (2010). *Composite materials: Science and applications*. Springer Science & Business Media.

Dhanesh, S., Kumar, K. S., Fayiz, N. K. M., Yohannan, L., & Sujith, R. (2021). Recent developments in hybrid aluminium metal matrix composites: A review. *Materials Today: Proceedings, 45*, 1376–1381.

Kumar, S. D., Ravichandran, M., & Meignanamoorthy, M. (2018). Aluminium metal matrix composite with zirconium diboride reinforcement: A review. *Materials Today: Proceedings, 5*(9), 19844–19847.

Devender K., & Praveena D. (2019). Influence of Process Parameters on Properties of Aluminium Based Mmc. *International Journal of Recent Technology and Engineering (IJRTE), 8*(1C2), 446–449.

Dwivedi, S. P., & Kumar, A. (2019). Development of graphite and alumina reinforced aluminium-based composite material. *Materials Today: Proceedings, 34*, 825–828. https://doi.org/10.1016/j.matpr.2020.05.461

Dwivedi, S. P., Srivastava, A. K., Maurya, N. K., & Sahu, R. (2020). Microstructure and mechanical behaviour of Al/SiC/agro-waste RHA hybrid metal matrix composite. *Revue Des Composites et Des Materiaux Avances, 30*(1), 43–47. https://doi.org/10.18280/rcma.300107

El Magri A., Vaudreuil S. (2021), Optimizing the mechanical properties of 3D-printed PLA-graphene composite using response surface methodology, *Archives of Materials Science and Engineering* 112/1, 13-22. DOI: https://doi.org/10.5604/01.3001.0015.5928

Ervina Efzan, M. N., Siti Syazwani, N., & Al Bakri, A. M. (2016). Fabrication method of aluminum matrix composite (AMCs): a review. *Key Engineering Materials, 700*, 102-110.

Esmaily, H., Habibolahzadeh, A., & Tajally, M. (2019). Surface modification of Al5456/BNi-2 composite by pulsed laser surface treatment. *Transactions of the Indian Institute of Metals, 72*, 2511–2521.

Etemadi, R., Wang, B., Pillai, K. M., Niroumand, B., Omrani, E., & Rohatgi, P. (2018). Pressure infiltration processes to synthesize metal matrix composites–A review of metal matrix composites, the technology and process simulation. *Materials and Manufacturing Processes, 33*(12), 1261–1290. https://doi.org/10.1080/10426914.2017.1328122

Fang, Z. Z., Paramore, J. D., Sun, P., Chandran, K. S. R., Zhang, Y., Xia, Y., Cao, F., Koopman, M., & Free, M. (2018). Powder metallurgy of titanium–past, present, and future. *International Materials Reviews, 63*(7), 407–459. https://doi.org/10.1080/09506608.2017.1366003

Georgantzia, E., Gkantou, M., & Kamaris, G. S. (2021). Aluminium alloys as structural material: A review of research. *Engineering Structures, 227*, 111372. https://doi.org/10.1016/j.engstruct.2020.111372

Gerhardt, R. (2011). Properties and applications of silicon carbide. BoD–Books on Demand.

Gietzelt, T., Toth, V., & Huell, A. (2018). Challenges of diffusion bonding of different classes of stainless steels. *Advanced Engineering Materials, 20*(2). https://doi.org/10.1002/adem.201700367

Gill, R. S., Samra, P. S., & Kumar, A. (2022). Effect of different types of reinforcement on tribological properties of aluminium metal matrix composites (MMCs)–a review of recent studies. *Materials Today: Proceedings, 56*, 3094–3101.

Gireesh, C. H., Prasad, K. D., & Ramji, K. (2018). Experimental investigation on mechanical properties of an Al6061 hybrid metal matrix composite. *Journal of Composites Science, 2*(3), 49. https://doi.org/10.3390/jcs2030049

Hajjari, E., Divandari, M., & Arabi, H. (2011). Effect of applied pressure and nickel coating on microstructural development in continuous carbon fiber-reinforced aluminum composites fabricated by squeeze casting. *Materials and Manufacturing Processes, 26*(4), 599–603. https://doi.org/10.1080/10426910903447311

Huang, J., Xue, J., Li, M., Cheng, Y., Lai, Z., Hu, J., Zhou, F., Qu, N., Liu, Y., & Zhu, J. (2023). Exploration of solid solutions and the strengthening of aluminum substrates by alloying atoms: Machine learning accelerated density functional theory calculations. *Materials, 16*(20). https://doi.org/10.3390/ma16206757

Jose, J., Christy, T. V., Peter, P. E., Feby, J. A., George, A. J., Joseph, J., Chandra, R. G., & Benjie, N. M. (2018). Manufacture and characterization of a novel agro-waste based low cost metal matrix composite (MMC) by compocasting. *Materials Research Express, 5*(6), 066530.

Kareem, A., Qudeiri, J. A., Abdudeen, A., Ahammed, T., & Ziout, A. (2021). A review on AA 6061 metal matrix composites produced by stir casting. *Materials, 14*(1), 1–22. https://doi.org/10.3390/ma14010175

Kerti, I., & Toptan, F. (2008). Microstructural variations in cast B_4C-reinforced aluminium matrix composites (AMCs). *Materials Letters, 62*(8–9), 1215–1218.

Khalid, M. Y., Umer, R., & Khan, K. A. (2023). Review of recent trends and developments in aluminium 7075 alloy and its metal matrix composites (MMCs) for aircraft applications. *Results in Engineering, 20*. https://doi.org/10.1016/j.rineng.2023.101372

Kong, S., Li, J., & Zhang, Z. (2023). Molecular dynamics simulation of solution strengthening of Si and Cu atoms in aluminum alloy. *Physica Status Solidi (b), 260*(9), 2300108.

Krishnan, S. V., Ambalam, M. M., Venkatesan, R., Mayandi, J., & Venkatachalapathy, V. (2021). Technical review: Improvement of mechanical properties and suitability towards armor applications – Alumina composites. *Ceramics International, 47*(17), 23693–23701. https://doi.org/10.1016/j.ceramint.2021.05.146

Kumar, A., Singh, R. C., & Chaudhary, R. (2020). Recent progress in production of metal matrix composites by stir casting process: An overview. *Materials Today: Proceedings, 21*, 1453–1457. https://doi.org/10.1016/j.matpr.2019.10.079

Kumar, D., & Singh, J. (2014). Comparative investigation of mechanical properties of aluminium based hybrid metal matrix composites. *International Journal of Engineering Research and Applications, AET-29th*.

Kumar, S. A., Chaganty, S., Rajesh, V., Reddy, K. S. K., Babu, N., & Shnain, A. H. (2024). Review on development, nanoparticle reinforcement and sustainable materials for enhancement of mechanical properties in aluminium hybrid metal matrix composites. *E3S Web of Conferences, 552*, 01068.

Kumaraswamy, H. S., Bharat, V., & Rao, T. K. (2018). Influence of Mechanical &tribological BehaviourOf Al 2024 MMC Fabricated by Stir Casting Technique-A Review. *Materials Today: Proceedings, 5*(5), 11962-11970.

Lade, J., Mohammed, K. A., Singh, D., Verma, R. P., Math, P., Saraswat, M., & Gupta, L. R. (2023). A critical review of fabrication routes and their effects on mechanical properties of AMMCs. *Materials Today: Proceedings.*

Lakshmi, S., Lu, L., & Gupta, M. (1998). In situ preparation of TiB_2 reinforced Al based composites. *Journal of Materials Processing Technology, 73*(1–3), 160–166.

Lathashankar, B., Tejaswini, G. C., Suresh, R., & Swamy, N. H. S. (2022). Advancements in diffusion bonding of aluminium and its alloys: A comprehensive review of similar and dissimilar joints. *Advances in Materials and Processing Technologies, 8*(4), 4659–4677.

Lazouzi, G., Vuksanović, M. M., Tomić, N. Z., Mitrić, M., Petrović, M., Radojević, V., & Heinemann, R. J. (2018). Optimized preparation of alumina based fillers for tuning composite properties. *Ceramics International, 44*(7), 7442–7449. https://doi.org/10.1016/j.ceramint.2018.01.083

Liu, Y., Chen, X., Gao, M., & Guan, R. (2021). Enhanced strength-ductility synergy in a rheo-diecasting semi-solid aluminum alloy. *Materials Letters, 305*, 130756. https://doi.org/10.1016/j.matlet.2021.130756

Mao, H., Zhang, Y., Wang, J., Cui, K., Liu, H., & Yang, J. (2022). Microstructure, mechanical properties, and reinforcement mechanism of second-phase reinforced TiC-based composites: A review. *Coatings, 12*(6). https://doi.org/10.3390/coatings12060801

Mazahery, A., & Shabani, M. O. (2014). The effect of primary and secondary processing on the abrasive wear properties of compocast aluminum 6061 alloy matrix composites. *Protection of Metals and Physical Chemistry of Surfaces, 50*(6), 817–824. https://doi.org/10.1134/S2070205114060021

Mohan, V. B., Lau, K. T., Hui, D., & Bhattacharyya, D. (2018). Graphene-based materials and their composites: A review on production, applications and product limitations. *Composites Part B: Engineering, 142*, 200–220. https://doi.org/10.1016/j.compositesb.2018.01.013

Moona, G., Walia, R. S., Rastogi, V., & Sharma, R. (2018). Aluminium metal matrix composites: a retrospective investigation. *Indian Journal of Pure & Applied Physics (IJPAP), 56*(2), 164-175.

Narciso, J., Molina, J. M., Rodríguez, A., Rodríguez-Reinoso, F., & Louis, E. (2016). Effects of infiltration pressure on mechanical properties of Al–12Si/graphite composites for piston engines. *Composites Part B: Engineering, 91*, 441-447.

Oguntuyi, S. D., Johnson, O. T., & Shongwe, M. B. (2021). Spark plasma sintering of ceramic matrix composite of ZrB_2 and TiB_2: Microstructure, densification, and mechanical properties—A review. *Metals and Materials International*, *27*(7), 2146–2159. https://doi.org/10.1007/s12540-020-00874-8

Ojarigho, E. V., Akpobi, J. A., & Evoke, E. (2024). Optimization of selected squeeze casting parameters on the mechanical behaviour of aluminium alloy. *Journal of Applied Sciences and Environmental Management, 28*(2), 431–439. https://doi.org/10.4314/jasem.v28i2.15

Pandey, U., Purohit, R., Agarwal, P., Dhakad, S. K., & Rana, R. S. (2017). Effect of TiC particles on the mechanical properties of aluminium alloy metal matrix composites (MMCs). *Materials Today: Proceedings, 4*(4), 5452–5460.

Pandit, P. P., Shukla, R. K., & Chauhan, P. S. (2023). Analysis and investigation of efficacy of the nanoparticles on the mechanical properties of aluminium metal matrix composites: A review. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.08.122

Panwar, N., & Chauhan, A. (2018). Fabrication methods of particulate reinforced aluminium metal matrix composite–A review. *Materials Today: Proceedings, 5*(2), 5933–5939.

Parashivamurthy, K. I., Kumar, R. K., Seetharamu, S., & Chandrasekharaiah, M. N. (2001). Review on TiC reinforced steel composites. *Journal of materials science*, 36, 4519-4530.

Patidar, D., & Rana, R. S. (2017). Effect of B_4C particle reinforcement on the various properties of aluminium matrix composites: A survey paper. *Materials Today: Proceedings, 4*(2), 2981–2988.

Patil, I. S., Anarghya, A., Rao, S. S., & Herbert, M. A. (2022). Experimental investigation of tensile fractography and wear properties of Al-12.5 Si alloy reinforced with ZrO_2 using spray deposition method. *Materials Today Communications, 30*, 103217.

Pilania, G., Thijsse, B. J., Hoagland, R. G., Lazić, I., Valone, S. M., & Liu, X. Y. (2014). Revisiting the Al/Al_2O_3 interface: Coherent interfaces and misfit accommodation. *Scientific Reports*, *4*(1), 4485.

Polmear, I. (2005). *Light alloys: From traditional alloys to nanocrystals*. Elsevier.

Prashar, G., & Vasudev, H. (2021). A comprehensive review on sustainable cold spray additive manufacturing: State of the art, challenges, and future challenges. *Journal of Cleaner Production*, *310*, 127606. https://doi.org/10.1016/j.jclepro.2021.127606

Prathap Singh, S., Ananthapadmanaban, D., Elil Raja, D., Sonar, T., Ivanov, M., Prabhuraj, P., & Sivamaran, V. (2023). Investigating the microstructure, tensile strength, and acidic corrosion behaviour of liquid metal stir casted aluminium-silicon carbide composite. *Advances in Materials Science and Engineering*, Volume 2023, Article ID 2131077, 11 pages, https://doi.org/10.1155/2023/2131077

Qadir, J., Lewise, A. S., Wessley, G. J. J., & Samuel, G. D. (2023). Influence of nanoparticles in reinforced aluminium metal matrix composites in aerospace applications–A review. *Materials Today: Proceedings*, https://doi.org/10.1016/j.matpr.2023.06.414

Raj, P. M., Vennila, C., NK, A. K., Sasikala, R., Anandaram, H., & Alagarsamy, M. (2024). Artificial neural network-based investigation of zirconium diboride nanoparticles reinforced in an aluminium alloy matrix. *2024 International Conference on Optimization Computing and Wireless Communication (ICOCWC)*, 1–7.

Ramanathan, A., Krishnan, P. K., & Muraliraja, R. (2019). A review on the production of metal matrix composites through stir casting–furnace design, properties, challenges, and research opportunities. *Journal of Manufacturing Processes, 42*, 213-245.

Ramanjaneyulu, R., RajaGopal, K., & DurgaPrasad, B. (2023). Development and evaluation of mechanical properties of aluminium alloys and boron fiber composite material by powder metallurgy route. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.05.564

Ramesh, C. S., Pramod, S., & Keshavamurthy, R. (2011). A study on microstructure and mechanical properties of Al 6061–TiB_2 in-situ composites. *Materials Science and Engineering: A, 528*(12), 4125-4132.

Ramnath, B. V., Elanchezhian, C., Jaivignesh, M., Rajesh, S., Parswajinan, C., & Ghias, A. S. A. (2014). Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites. *Materials & Design, 58*, 332–338.

Rangrej, S., Pandya, S., & Menghani, J. (2023). Effects of TiB_2 reinforcement proportion on structure and properties of stir cast A713 composites. *Canadian Metallurgical Quarterly, 62*(4), 678–689.

Ravindran, S., Mani, N., Balaji, S., Abhijith, M., & Surendaran, K. (2019). Mechanical behaviour of aluminium hybrid metal matrix composites–A review. *Materials Today: Proceedings, 16*, 1020-1033.

Rooy, E. L., & Kaufman, J. G. (2004). *Aluminum alloy castings: Properties, processes, and applications* (No. B-ASM-002). SAE Technical Paper.

Sabari, K. (2024). Retracted: Investigating the fatigue behaviour of TiO_2 nanoparticle reinforced AA7071 aluminium alloy. *Journal of Environmental Nanotechnology*, *13*(2), 127–134.

Samal, P., Vundavilli, P. R., Meher, A., & Mahapatra, M. M. (2020). Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties. *Journal of Manufacturing Processes*, 59, 131-152.

Sambathkumar, M., Gukendran, R., Mohanraj, T., Karupannasamy, D. K., Natarajan, N., & Christopher, D. S. (2023). A systematic review on the mechanical, tribological, and corrosion properties of Al 7075 metal matrix composites fabricated through stir casting process. *Advances in Materials Science and Engineering, 2023*(1), 5442809.

Sambatkumar, M., Dhanish, L. G., Ganesh, S. S., & Dhivagar, V. (2024). Experimental investigation on mechanical properties of aluminium 8011 hybrid metal matrix composite. *Social Science Research Network*, *2024*(1), 1-17 *https://ssrn.com/abstract=4772429*

Samsu, Z., Othman, N. K., Jamil, M. S. M., Yazid, H., & Alias, M. S. (2023). Corrosion behaviour of aluminium matrix composite reinforced with boron carbide in 3.5% NaCl. *International Journal of Nanoelectronics and Materials (IJNeaM), 16*(December), 451–461.

Samuel, A. U., Araoyinbo, A. O., Elewa, R. R., & Biodun, M. B. (2021). Effect of machining of aluminium alloys with emphasis on aluminium 6061 alloy–A review. *IOP Conference Series: Materials Science and Engineering, 1107*(1), 012157. https://doi.org/10.1088/1757-899X/1107/1/012157

Senapati, A. K., Sahoo, S. K., Singh, S., Sah, S., Padhi, P. R., & Satapathy, N. (2016). A comparative investigation on physical and mechanical properties of MMC reinforced with waste materials. *International Journal of Research in Engineering and Technology*, *5*(3), 172-178.

Sandeep, Prakash, U., Tewari, P. C., & Khanduja, D. (2014). Analysis of powder metallurgy process parameters for relative density of low carbon alloy steel using design of experiments tool. *Applied Mechanics and Materials, 592*, 72–76.

Senthil, S., Raguraman, M., & Manalan, D. T. (2021). Manufacturing processes & recent applications of aluminium metal matrix composite materials: A review. *Materials Today: Proceedings, 45*, 5934-5938.

Seshappa, A., & Anjaneya Prasad, B. (2021). Characterization and investigation of mechanical properties of aluminium hybrid nano-composites: Novel approach of utilizing silicon carbide and waste particles to reduce cost of material. *Silicon*, *13*, 4355–4369.

Sharma, A. K., Bhandari, R., Aherwar, A., & Pinca-Bretotean, C. (2020). A study of fabrication methods of aluminum based composites focused on stir casting process. *Materials today: proceedings*, *27*, 1608-1612.

Sharma, P., Khanduja, D., & Sharma, S. (2014). Tribological and mechanical behavior of particulate aluminum matrix composites. *Journal of Reinforced Plastics and Composites, 33*(23), 2192-2202.

Sharma, S. K., Saxena, K. K., Kumar, K. B., & Kumar, N. (2022). The effect of reinforcements on the mechanical properties of AZ31 composites prepared by powder metallurgy: An overview. *Materials Today: Proceedings*, *56*, 2293–2299.

Soltani, S., Azari Khosroshahi, R., Taherzadeh Mousavian, R., Jiang, Z. Y., Fadavi Boostani, A., & Brabazon, D. (2017). Stir casting process for manufacture of Al–SiC composites. *Rare Metals, 36*(7), 581–590. https://doi.org/10.1007/s12598-015-0565-7

Somegowda, S. B., Honnaiah, M. S., & Bettaiah, G. K. (2023). Characterization of aluminium alloy LM6 with B4C and graphite reinforced hybrid metal matrix composites. *Engineering Proceedings*, *59*(1), 72.

Sun, M., Bai, Y., Li, M., Fan, S., & Cheng, L. (2018). Structural design of laminated B_4C/TiC composite fabricated by reactive melt infiltration. *Journal of Alloys and Compounds*, *765*, 913–920. https://doi.org/10.1016/j.jallcom.2018.06.271

Surappa, M. K. (2003). Aluminium matrix composites: Challenges and opportunities. *Sadhana*, 28, 319-334.

Suryakant, & Yadav M. (2023). Tensile strength enhancement via heat treatment in directly recycled aluminium alloy (AA6065). *International Journal of Scientific Research in Science and Technology*, 241–246. https://doi.org/10.32628/ijsrst52310537

Tao, P., & Wang, Y. (2019). Improved thermal conductivity of silicon carbide fibers-reinforced silicon carbide matrix composites by chemical vapor infiltration method. *Ceramics International*, *45*(2), 2207–2212. https://doi.org/10.1016/j.ceramint.2018.10.132

Tekale, S. N., & Dolas, D. R. (2022). Study of fabrication methods and various reinforcements with aluminium for automotive application–A review. *Materials Today: Proceedings*, *62*, 2768–2773.

Trinh, S. N., & Sastry, S. (2016). Processing and properties of metal matrix composites. *Mechanical Engineering and Materials Science Independent Study*, *10*, 1-16.

Ujah, C.O., Popoola, A.P.I., Popoola, O.M., Aigbodion, V.S. (2019). Enhanced tribology, thermal and electrical properties of Al-CNT composite processed via spark plasma sintering for transmission conductor. *Journal of Materials Science*, *54*(22), 14064–14073. https://doi.org/10.1007/s10853-019-03894-x

Vaudreuil S., Bencaid S.E., Vanaei H.R., El Magri A. (2022). Effects of power and laser speed on the mechanical properties of AlSi7Mg0. 6 manufactured by laser powder bed fusion *Materials* 15 (23), 8640, https://doi.org/10.3390/ma15238640

Velavan, K., Palanikumar, K., Thirumal, K., Kannan, K. R., Kannan, M., & Arunkumar, P. (2023). Mechanical characterization of aluminium alloy LM25 reinforced with TiC and graphite for structural applications. *Materials Today: Proceedings*, *72*, 2049–2055.

Venkatesan, S., & Xavior, M. A. (2018). Analysis of Mechanical Properties of Aluminum Alloy Metal Matrix Composite by Squeeze Casting–A Review. *Materials Today: Proceedings*, *5*(5), 11175-11184.

Venugopal, S., Seeman, M., Seetharaman, R., & Jayaseelan, V. (2022). The effect of bonding process parameters on the microstructure and mechanical properties of AA5083 diffusion-bonded joints. *International Journal of Lightweight Materials and Manufacture*, *5*(4), 555–563.

Verma, D., Gope, P. C., Maheshwari, M. K., & Sharma, R. K. (2012). Bagasse fiber composites: A review. *Journal of Materials and Environmental Science*, *3*(6), 1079–1092.

Vinod, B., Ramanathan, S., & Anandajothi, M. (2019). A novel approach for utilization of agro-industrial waste materials as reinforcement with Al–7Si–0.3 Mg matrix hybrid composite on tribological behaviour. *SN Applied Sciences*, *1*, 1-15. https://doi.org/10.1007/s42452-018-0066-z

Wang, P., Liu, F., Wang, H., Li, H., & Gou, Y. (2019). A review of third-generation SiC fibers and SiCf/SiC composites. *Journal of Materials Science and Technology*, *35*(12), 2743–2750. https://doi.org/10.1016/j.jmst.2019.07.020

Wang, Z., Liu, X., Zhang, J., & Bian, X. (2004). Reaction mechanism in an Al-TiO_2-C system for producing in situ Al/(TiC+ Al_2O_3) composite. *Journal of Materials Science*, *39*(2). 667–669.

Ward-Close, C. M., Chandrasekaran, L., Robertson, J. G., Godfrey, S. P., & Murgatroyde, D. P. (1999). Advances in the fabrication of titanium metal matrix composite. *Materials Science and Engineering: A*, *263*(2), 314–318.

Woo, K. D., & Zhang, D. L. (2004). Fabrication of Al–7wt% Si–0.4 wt% Mg/SiC nanocomposite powders and bulk nanocomposites by high energy ball milling and powder metallurgy. *Current Applied Physics*, *4*(2-4), 175-178.

Zeng, M., Ling, Y., Zhang, P., Dong, X., Li, K., & Yan, H. (2023). Improvement of interfacial interaction and mechanical properties in aluminum matrix composites reinforced with Cu-coated carbon nanotubes. *Materials Science and Engineering: A*, *870*, 144918.

Zykova, A. P., Tarasov, S. Y., Chumaevskiy, A. V., & Kolubaev, E. A. (2020). A review of friction stir processing of structural metallic materials: Process, properties, and methods. *Metals*, *10*(6), 1–35. https://doi.org/10.3390/met10060772