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Fabrication Methods of Aluminium Metal Matrix Composite: A State of Review

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Abstract

Aluminium's use in aerospace, marine and automobiles has grown significantly due to its lightweight nature, enhancing fuel efficiency and overall performance. Its corrosion resistance also contributes to longevity, reducing maintenance costs. However, its low hardness, low tensile strength and poor tribological behaviour limit its usage. These demerits can be overcomed by adding specific reinforcement to enrich its properties. As there are two types of fabrication methods for fabrication of MMCs such as Solid state processing and liquid state processing, the above fabrication techniques result in varying mechanical property, tribological property and production cost. So far from the available literature we've found that the liquid state processing is more popular than solid-state processing due to the better dispersion of the reinforcement particles in the matrix materials. The Addition of nanoparticles has been found to be essential to provide requisite strength and hardness to these composites. Overall, study concludes that the hybrid aluminium matrix composites will ensure to serve as an alternative for the unreinforced Al-alloys and ceramic reinforced composites in various automotive applications requiring high strength-to-weight ratio, low cost and superior wear resistance.

Keywords: *Spray Casting, Infiltration, Stir Casting, Carbon Fibre.*

1. Introduction

The material which is obtained when two or more materials are mixed to enhance the physical and the chemical properties of the material is known as composites. [1, 54]. The three major composites are: ceramic matrix composite (CMMC), metal matrix composite (MMC), and polymer matrix composite (PMC) [29]. These three composites have different properties and production methods that portray specific behaviour and capabilities. [2]. This review article outlines about the metal matrix composite (MMC) especially Aluminium Metal Matrix composite (AMMC) as it can offer customised combinations of properties. Due to innovative and exciting technologies, metal matrix composites (MMCs) are constantly evolving and are widely used as well as recognized as a potential material for many industrial applications in various industries [19,21,23,26,50]. Some of these characteristic combinations include high wear resistance, nice damping capacities, high specific rigidity and adequate resistance to corrosion [14,19]. Aluminium alloys, in both academia and industry, are found to be the most commonly used matrix materials. The choice for these materials is influenced by their low energy input requirements, which make them suitable for most of the existing production routes [24,27]. AMMCs are an improved type of MMCs which are able to satisfy the recent demands of improved technology applications in the engineering field, these criteria meet by improved mechanical properties, the convenience to conventional manufacturing methods and a reduction in

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production costs [2,3,13]. It has been noticed that the mechanical and surface characteristics of AMMC's can be improved by adding different reinforcement particles in small percentages (usually 0.5-20%) [4]. From available literature, it is evident that liquid state processing is more familiar than solid-state processing due to the better dispersion of the reinforcement particles in the matrix materials.Also the liquid state method is preferred over others because it is cheaper, simpler, more flexible, and the most economical[16]. There are no limitations on shape, size, and production quantity. Due to its ease and the overall low cost of production, stir casting is the most used liquid state processing method [16,17].

2. Fabrication Method

The different fabrication methods of Al-based MMCs and their advantages and disadvantages were discussed in this part, and are classified as shown in Figure 1.

2.1 Liquid State Process

Spray Casting, Infiltration, And Stir Casting.

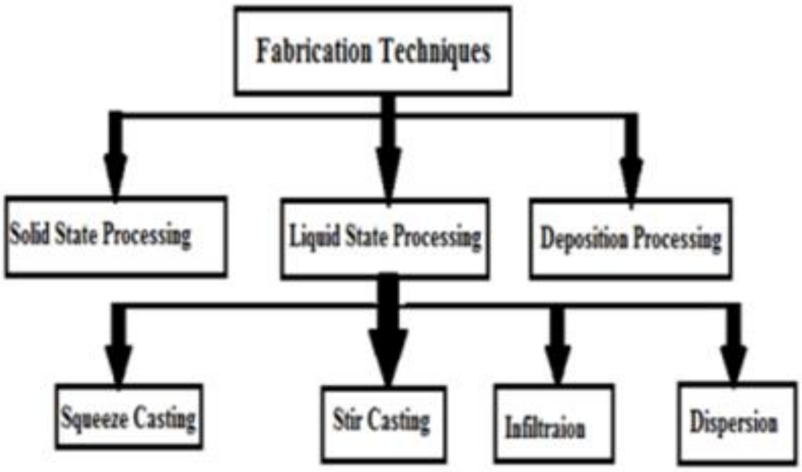

Figure 1 **Classification of Fabrication Techniques [5]**

2.2 Liquid State Fabrication

The liquid state fabrication method for MMCs is simple and easy when compared with the solid state, in this method, reinforcement materials are added as the matrix in fully or partially in the molten state. For the MMCs, liquid-state processing methods are relatively easy compared to solid-state processing, as most of the MMCs were made with aluminium alloys, which have low melting points [7]. Also, the author reports that there are several advantages in using liquid-state processing. These include

- near-net-shaped formation (even complex geometries)
- faster rate of production
- uniform wetting of reinforcements, and dense matrix.

Difficulty in controlling reinforcement distribution and obtaining a uniform matrix microstructure were the main drawbacks in liquid-state processing [12,15]. In liquid-state processing adverse reactions between matrix and reinforcement interfaces are most likely to occur at high temperatures. The formation of brittle compounds is led to by these reactions, which will adversely influence the properties of the composite material. Another disadvantage of these processing methods is the restriction on the quantity of reinforcement added. The viscosity of molten metal is initially decreased but drastically increases with the addition of reinforcements, with the effect becoming more pronounced as the particle size decreases. The segregation of reinforcement is mainly due to the density difference between the matrix and the reinforcement is another major problem. The liquid-state processing methods are widely used for the fabrication of MMCs although there are many disadvantages. The means of producing metal matrix composites were traditionally dominated by metal-casting methods, though segregation issues were at large. The problems were later overcome to varying degrees by developments such as the molten stir casting techniques [23].

2.3 Stir Casting

Currently stir casting is the most popular commercial method of producing aluminium based composites stir casting of MMCs. The stir casting method was first introduced in the year 1968 by S.Ray in the fabrication of alumina particles reinforced aluminium matrix composites[8].The other manufacturing processes used but up to a lesser extent are compo-casting, squeeze casting, friction stir processing, and spray casting[18,28-30]. In this process the base matrix material is melted inside the crucible at an elevated temp, and the optimised mechanical stirring is made into the melt so that the reinforcement particles added into the melt are uniformly dispersed to form a homogeneous casting. This process is simply mixing the solid reinforcement in the liquid metal and then allowing the mixture to solidify in a suitable mould. The reinforcement can be gradually added as the mixture is continuously agitated. In principle, this can be carried out using conventional processing equipment on a continuous or semi continuous basis [7]. Stir casting is appropriate for manufacturing composites with up to 30% volume fractions of reinforcement, to achieve proper mixing of reinforcement into melt which depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification .The factors like geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added has a influence on the distribution of particles[9,15]. The reinforcement, such as ceramic metal or supplementary metals, can be added to the liquid base matrix metal, either without preheating it or by preheating it first. The molten metal is mixed with the addition of reinforcement using a stirrer. These materials, including titanium carbide (TiC), silicon carbide (SiC), and graphite (Gr), should possess melting characteristics. After heating in the crucible, the molten metal is poured into the mould and allowed to solidify [39]. After solidification, the MMC's can be removed from the mould and processed further as per requirement.[10]. The setup for stir casting is shown in Figure 2.

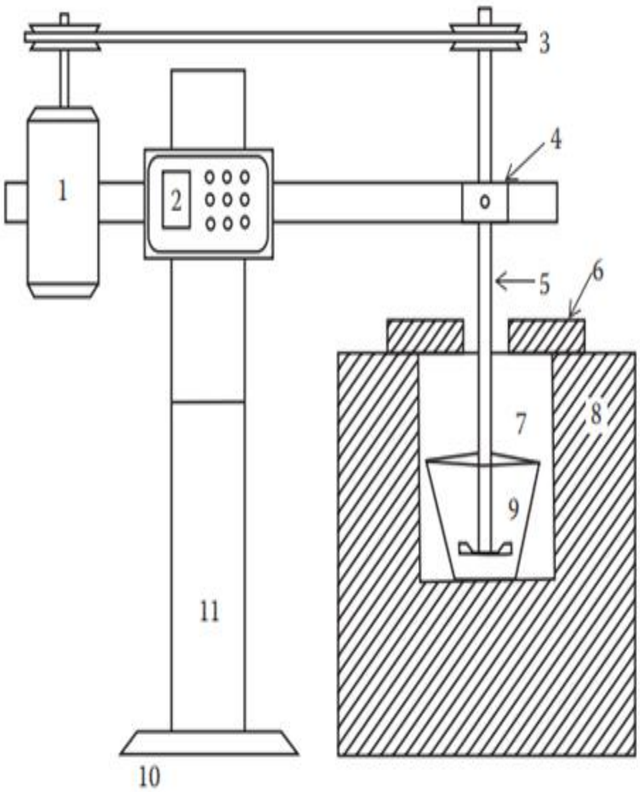

Figure 2 Schematic Representation of Stir Casting Process [7]

1. Variable speed motor, 2. speed controller, 3. pulley drive, 4. bearing assembly, 5. stirrer shaft, 6. insulating cover, 7. melting crucible, 8. furnace, 9. impeller, 10. base, 11. pedestal.

2.4 Squeeze Casting

Squeeze casting is one of the other important methods in the liquid process. It is suitable for the

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manufacture of Aluminium based composite materials. The squeeze casting infiltration process is widely used for the production of net shape MMCs, with control over shapes, chemistry, volume fraction and distribution of reinforcement [15]. The infiltration process of squeeze casting is also a forced process, allowing the user to select liquid phase fabrication of MMCs in which the mould serves as a movable part and applies pressure by means of hydraulic press [15,20,22]. The advantages of this method are that reinforcing materials does not require surface pretreatment; due to the effect of high pressure, the time that the melt and the reinforcing material are in contact at the high temperatures is short, so there is no need to worry about serious interfacial reactions [6]. The ram continues to move during solidification is the main difference between this process and conventional pressure die casting, hence deforming the growing dendrite and compensating the freezing contraction. In addition, the ram movement is slower and the applied pressure is often greater than that used in typical die casting [7,19]. The quality of the product is dependent on the squeeze cast process parameters used in manufacturing. The casting quality is influenced by the following factors in decreasing order: melt quality, equipment and tooling, melt temperature, die temperature, time delay before pressurization, squeeze pressure, and time duration. Less flexibility in part geometry, high machining requirements, lower productivity, and greater cost were the main drawbacks of squeeze casting, and the steps involved were represented in Figure 3.

a. Molten Metal Poured into The Pre-Heated Die
b. Application of Squeeze Pressure
c. Solidified Casting [9]

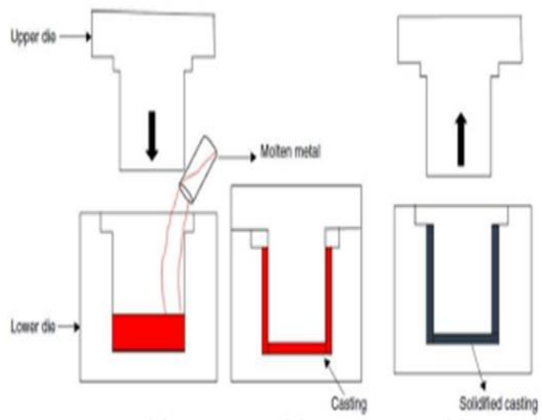

Figure 3 Schematic Representation of the Sequence of Steps Involved in Squeeze Casting

3. Liquid Metal Infiltration

Liquid metal infiltration of ceramic preform is apparently the best suited fabrication method to produce metal matrix composite components with a variety of complex shapes having high volume fraction of reinforcement [19]. Infiltration is a liquid-state fabrication method, in which a porous preform (reinforcement) such as ceramic particles, fibres, woven etc. are impregnated in a molten matrix metal, which fills the pores between the dispersed-phase inclusions. In this process where molten metal wets the reinforcement and the flow may be made about mutually by the forces of capillarity; otherwise to overcome the resisting forces a mechanical force need to be applied due to drag and capillary. The function of pressure required in combining the matrix and the reinforcement is determined by the friction effects due to the viscosity of the molten matrix as the ceramic preform is filled by it. Though the ceramic preform is wetted by the liquid alloy is dependent on different factors such as alloy composition, ceramic preform material and surface morphology, temperature and time [15]. Synthesis of porous ceramic performed with sufficient mechanical strength, uniform pore distribution, pore size, and porosity level is one of the crucial steps involved in the infiltration processing of composites [11]. A few restrictions exist in terms of material choice for Metal Infiltration. For instance, the reinforcement one must have a greater matrix

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thermal expansion coefficient. The need for special care during the solidification process is required to ensure void-free shrinkage, low wetting angle, large surface tension, and a large capillary radius for easy infiltration are considered as major disadvantages of Metal Infiltration [25]. However, in liquid metal infiltration accurate fibre placement and control of fibre spacing will be very difficult, and the classification of Infiltration Process were represented in Figure 4.

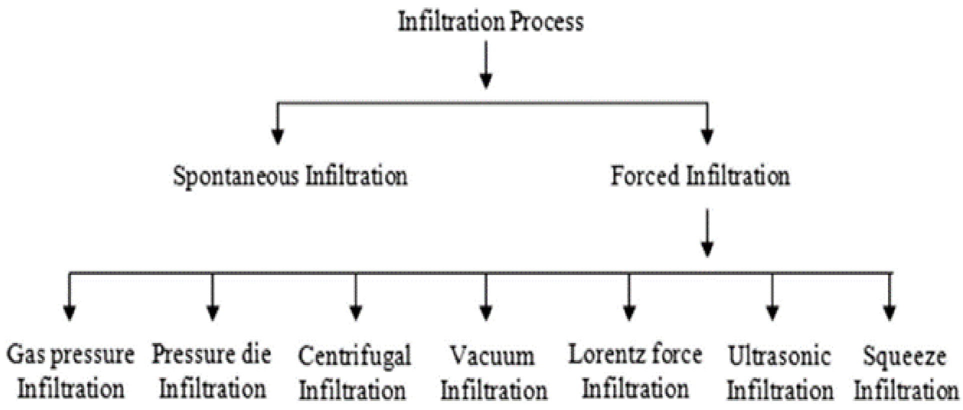

Figure 4 **Classification of Infiltration Process for the Fabrication of Metal Matrix Composites**

3.1 Solid-State Process

powder metallurgy, diffusion bonding and Friction stir processing.In solid-state processing traditional methods such as melting and casting are avoided, and the fabrication occurs in the solid state. In this process, the metal matrix is formed below the melting temperature of the matrix and The solid-state fabrication method is categorised into the following parts,

3.2 Powder Metallurgy

This technique is used for the preparation of discontinuous reinforced AMMCs [32]. This method consists of three steps 1) Mixing or blending, 2) Compaction, 3) Sintering [46,47,55]. At first the Metal alloy powder is mixed with ceramic whisker/short fibre/particles in dry condition or in liquid suspension and fed into a mould of the desired shape [33,49]. B. D. Christensen,I. W. Donaldson,D. P. Bishop [34] die compacted in a floating die using an Instron 5594-200HVL load frame with a 1 MN load capacity. All samples were compacted at 200 MPa to form the required part. During sintering, the samples are heated in a protective atmosphere with a temperature below the melting temperature.

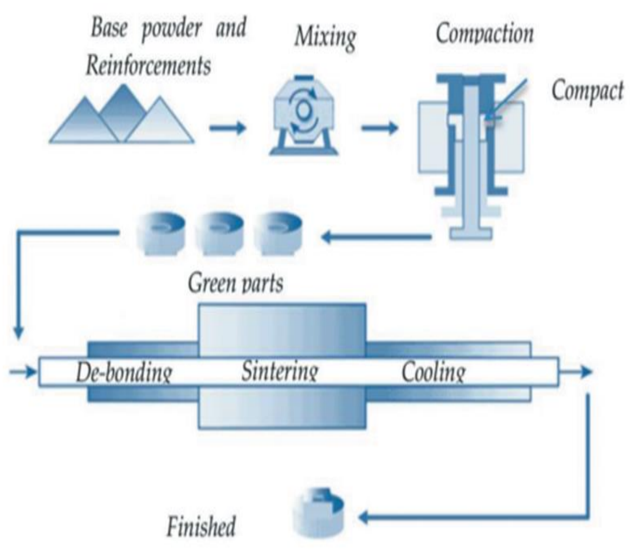

Figure 5 **Schematic Representation of Powder Metallurgy Process [31]**

As a result of the process, the porous structure in the piece disappears and it gains strength and stiffness stably. Harding MD, Hexemer RL, Donaldson IW, Bishop DP [35] done sintering of Al–Zn–Mg–Cu Alloy at 878 K ± 5 K for 20 min. The Figure 5 shows the powder metallurgy process. In the PM process,

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the resultant composites presented superior mechanical properties. On the other hand, long time sintering unconventional PM methods leads to grain growth and loss of the unique properties of composites with refined microstructure [45]

3.3 Diffusion Bonding

Nikhil Bharat & P.S.C Bose [31,42-43] says that diffusion bonding is a solid phase fabrication method used for the manufacturing of monofilament metal matrix composite. Diffusion bonding occurs as a result of diffusion of the interface atoms of the bonded materials[42,44].Matrix and reinforcements are stacked and then pressed at high temperature to complete the bonding process[48].S Venugopal, U Elaiyarasan [36-38figur] used diffusion bonding of Rolled plates of 5 mm thick AA7075 aluminium alloys using SiC papers and the most optimal parameters are found to be bonding temperature of 510 °C, bonding pressure of 13 MPa and holding time of 45 min with the desirability of 0.82.The Figure 6 shows the steps of diffusion bonding process.

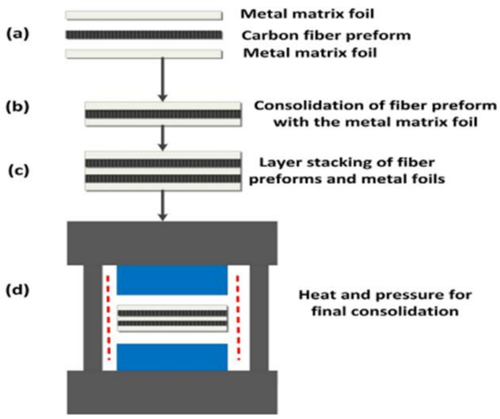

Figure 6 Diffusion Bonding Set-Up for The Synthesis of Carbon Fibre-MMC [31]

3.4 Friction Stir Processing

The friction stir processing method evolved from the friction stir welding technology and involves similar processes and principles [51,52]. Friction Stir Processing is a solid-state surface alteration and surface engineering technique employed for development of Metal Matrix Composite surfaces. It enables alteration of the surface, control of microstructure enhancement of wear and improvement in mechanical properties [39,53]. In this process heat is generated by the use of stir, which can rotate at any fixed rpm. For development of surface layer composite a grove is made on the metal matrix sheet and reinforcements are placed on it. The heat generated by friction between sheet and stir tool is used for the mixing of reinforcement and matrix [32]. It consists of a non-consumable tool having two components, i.e. pin and shoulder. High speed and downward force are applied to the tool such that high frictional heat is generated which makes the material plasticised. Due to plastic deformation, the grain structure will be recrystallised which enhances the mechanical properties, fatigue life as well as strength of the material, as shown in Figure 7 [31].

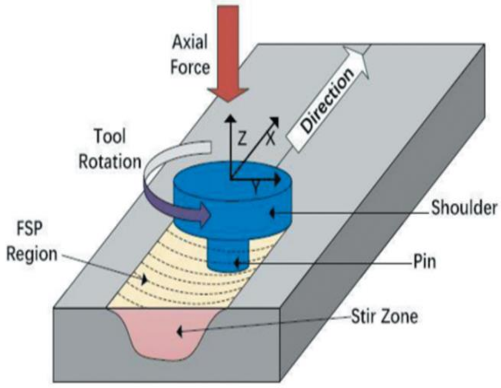

Figure 7 Schematic Representation of Friction Stir Processing [31]

J.J. Pang F.C. Liu J. Liu M.J. Tan D.J. Blackwood [40] conducted Friction stir process (FSP) in both air and water on aluminium alloy AA7075, and it is concluded that FSP done on air has high tensile strength and FSP done on water has less corrosion rate. S. Chainarong, P. Muangjunburee, S. Suthummanon [41] conducted Friction Stir Processing on the material SSM 356 aluminium alloys and performed 3 experiments on varying speeds and compared hardness and the tensile strength of the aluminium alloy are mainly obtained and compared through this experiment and found that properties improve with the speed.

Conclusion

From the literature survey, it is found that fabrication methods play a vital role in the enhancement of material properties. The fabrication techniques are

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mainly divided into two types, liquid state processing and solid-state processing. In the liquid state processing route, stir casting is found to be better than squeeze casting and infiltration processes solid-state processing route powder metallurgy is chosen due to the possibility of addition of very high reinforcement. The main aim of the review is to fabricate the AMMC in a cost effective manner for different applications. This review concludes the cost-effective method for the fabrication of aluminium metal matrix composite by stir casting is one of the simple and economical technique as compared to other methods and this technique can be used for mass production and it is found that for developing a particulate reinforced AMMCs. Stir casting is the most universal approach.

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