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METAL MATRIX COMPOSITE: A REVIEW ON REINFORCEMENTS OF ALUMINIUM AND METHODOLOGIES

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Abstract: In manufacturing, metal matrix composites (MMCs) are used for many applications due to their lightweight, strong surface, and mechanical properties. Because it has valuable applications in the defence and space fields, its possible low cost and easy to use applications are worth exploring. Aluminium metal matrix composites (AMMCs) are good materials for various applications, due to their good properties both physically and mechanically. When reinforcements are added into the metallic matrix, it enhances the fracture toughness, wear resistance, creep resistance, and fatigue resistance compared to conventional engineering materials. Herein, a comprehensive review is made on the preparation of metallic MMCs by different routes and materials, as well as an overview of the effects of addition on different reinforcements in aluminium alloy, highlighting their advantages and disadvantages. This paper also discusses the agglomerating phenomena, matrix bonding, the problems that result in particle distributions, then suggests a novel method for preparing functionally graded MMCs.

Keywords: Metal matrix composites, Aluminium, Reinforcements, Methodology

I. INTRODUCTION

Metal matrix composites (MMCs) are metals that are reinforced with other metals, ceramics or organic materials. These composites are fabricated by distributing the reinforcements in a metal matrix. In most cases, reinforcements are used to improve a metal's properties, such as strength, stiffness and conductivity. Most attention has been paid to aluminum and its alloys as the base metals in metal matrix composites [1]. There are various applications of aluminum MMCs in aerospace, automobiles, aircraft, and other fields [2]. As well as being stable, the reinforcements should also be nonreactive at the specific working temperature. Reinforcements commonly used include silicon carbide (SiC) and aluminum oxide (Al_2O_3). In addition to improving tensile strength, hardness, density, and wear resistance of Al and its alloys, SiC strengthens them as well [3]. Intensive shearing improves the particle dispersion, which is extremely significant in the characteristics of the Al MMC. The compressive strength and wear resistance of Al_2O_3 reinforcement are excellent. Boron Carbide is one of the most difficult elements to work with. It has a high elastic modulus and is resistant to fracture. Boron Carbide (B_4C) added to the Al matrix enhances hardness but does not considerably improve wear resistance [4]. Fibers are an essential type of reinforcements because they meet the required requirements and transmit strength to the matrix constituent, affecting and increasing the desirable characteristics. In most cases, zircon is employed as a hybrid reinforcement. It considerably improves wear resistance [5]. Because of their low cost and availability as a waste byproduct in thermal power plants, the usage of fly ash reinforcements has expanded throughout the previous decade. It improves the Al MMC's electromagnetic shielding effect. This research examines several elements such as (a) the influence of various reinforcement (b) mechanical behaviour such as strength, wear, fatigue behaviour, and so on, based on the claimed potential benefits of MMC. c) the technique of processing and its consequences (b) the application of the AMMC specialty was explored.

Many of the MMC possess excellent properties when compared to single metal matrix. These MMCs may be engineered to have excellent durability, ductility, tensile modulus, thermal conductivity, and other properties [6, 7]. As a result of the unique characteristics that may be included into MMC, they are suited for a wide variety of applications, including electrical, aerospace, robotics, and many others [8]. MMC may be made in a variety of ways, including solid-state, liquid-state, semisolid-state, and in-situ manufacturing techniques.

II. SILICON CARBIDE REINFORCED AMC

Tamer Ozbenet al. [9] looked at the mechanical and machinability characteristics of Al-MMC supplemented with SiC particles. Tensile strength, hardness, and density of Al MMC material improved when the reinforcement ratio was raised, while impact toughness decreased. Under varied temperature circumstances, Sedat Ozdenet al. [10] studied the impact behaviour of Al and SiC particles reinforced with AMC. Clustering of particles, particle cracking, and poor matrix-reinforcement bonding all influenced the impact behaviour of composites. The impact behaviour of all materials was not significantly affected by the test temperature. Srivatsan et al. [8] studied the fracture behaviour of 7034/SiC/15p-UAand 7034/SiC/15p-PAmetal matrix composites during high cycle fatigue. With an increase in temperature, the modulus, strength, and ductility of the two composite microstructures decreased. The under-aged microstructure showed a greater reduction in cycle fatigue life than the peak-aged microstructure. In addition, raising the load ratio resulted in increased fatigue strength for a given ageing state. Maik Thunemann et al. [11] investigated the characteristics of preceramic-polymer-bonded SiC-based AMMCs. As a binder, polymethylsiloxane (PMS) was utilised. Preforms with a polymer composition of 1.25 wt. percent were stable enough to allow composite processing. It is thus demonstrated that the PMS-derived binder gives the SiC preforms the necessary strength without compromising the mechanical characteristics of the Al/SiC composites. The performance of stir cast Al_2O_3 and SiC reinforced metal matrix composite material was investigated by Sujan et al. [12]. The composite material has outstanding physical and mechanical properties such as a low coefficient of thermal expansion of 4.6 x 10^{-6}C a high ultimate tensile strength of 23.68% as well as impact resistance and high tensile strength. high stiffness depending on the result. Composite materials have the potential to e used as lightweight components in automoiles. Compared with $AlAl_2O_3$ composites it was found that adding AlSiC reinforcement particles to the composites reduced the wear rate. Zhang Peng et al. [13] investigated the effect of grain aggregation on the flow ehavior of Al MMCs reinforced with SiC particles. The results show that during tensile strain grain clustering has a greater influence on the mechanical response of the matrix than the elastic response and plastic deformation is also greatly affected. A particle clustering microstructure will have a higher particle reproduction rate than a random particle distriution. Balasivanandha Prahuet et al. [1] analyzed the influence of stirring speed and stirring time on the distriution of particles in SiC AMC. The study focused on high silicon aluminum with 10% SiC synthesized using different stirring speeds and times. Analysis revealed that at lower incentive speeds, the group of particles is much in some places, pushing them, distribution as a result of the hardness and hardness of the mixture. The uniform hardness value has been completed at 600 rpm with 10 minutes agitation. Tzamtzis et al. [15] Dealing particles al / sic proposed under the cut depth of rheoprocess. Current treatments such as conventional trash casting techniques often create gathered particles in ductile matrixs and therefore, these integrated materials have extremely low flexibility. While Rheoprocess has greatly improved the distribution of reinforcement in the matrix by allowing sufficient shear stress to be applied to the grain clusters embedded in the liquid metal to overcome the average cohesive strength or tensile strength. of the cluster. Valencia Garcia et al. [16] proposes an alternative technique for forging composites with SiC-reinforced AlSi metal matrix composites. This method of preparation increases resistance to mechanical stretching. This method is more economical by reducing production steps as well as time and energy costs. Narayana Murty et al. [17] Grain-reinforced metal matrix composites. They have suggested, from a productivity perspective, to select regions with high strain rates where mass values are high and efficiency is high for high volume machining operations and regions with lower strain rates. for secondary metalworking operations. Palanikumar and Karthikeyan [18]. Factors affecting surface roughness when machining granular Al/SiC composites. Parameters such as feedrate, shear rate, SiC volumetric percentage have been optimized to achieve minimum surface roughness using response graphs, feedback tables, identification histograms. frequency, interaction histogram, and analysis of variance (ANOVA). The feedrate is the factor that has the most influence on surface roughness, followed by the cutting speed and SiC volume %. Recommended machining conditions are low cutting speed with high feedrate and depth of cut for rough and medium turning operations.

III. ALUMINIUM OXIDE REINFORCED AMC

Park et al. [19] studied the impact of Al2O3 in Aluminum for volume fractions ranging from 5 to 30% and discovered that increasing the volume fraction of Al_2O_3 affected the MMC's fracture toughness. This is due to the decrease in the inter-particle distance between the micronuclei. Park and associates. [20] investigated the polycyclic fatigue properties of Al_2O_3 microspheres reinforced with alloy 6061 AlMgSi with volume fractions ranging from 5% to 30%. They discovered that the powder metallurgy treated composite had a greater fatigue strength than the unreinforced alloy and the liquid metallurgy produced composite. Kok [21] used the vortex method to fabricate Al_2O_3 particle reinforced 2024 Al alloy composites and studied their mechanical properties, determining that the optimum pouring temperature was 700 C, the preheated mould temperature was 550 C, the stirring speed was 900 rev/min, the particle addition rate was 5 g/ min, the stirring time was min, and the applied pressure was 6 MPa. The application of pressure enhanced the wettability and bonding between Al alloy/Al_2O_3 particles, but it lowered the porosity. Abhishek Kumar et al. [22] used the electromagnetic stir casting process to study the characteristics of A359/Al_2O_3 MMC. They found that the electromagnetic agitation produced MMC with reduced grain size and excellent grain-matrix surface bonding, as well as increased stiffness and tensile strength. The heat deformation and wear resistance of powder metallurgy aluminium metal matrix composites were investigated by Abouelmagd [23]. The inclusion of Al_2O_3 and Al_4C_3 increased the hardness and compressive strength of the material. The inclusion of Al_4C_3 increased the MMC's wear resistance. Kannan and Kishawy [24] used orthogonal cutting experiments to investigate the impact of cutting settings and particle characteristics on micro-hardness variations in machined Al_2O_3 particulate reinforced AMC. They discovered that near the machined surface layer, the micro-hardness is greater. Low volume fraction and coarse micro-hardness fluctuations were greater.

IV. BORON CARBIDE REINFORCED AMC

Bo Yao et al. [25] looked at the strength of trimodal aluminium metal matrix composites and the elements that impact it. The experimental results show properties such as nanoscale dispersion of crystalline and amorphous Al_2O_3, AlN and Al_4C_3, high dislocation density in the NCAl and CGAl domains, intercomponent interfaces, as well as The concentration and distribution of nitrogen contribute to increased resistance. Vogt et al. [27] studied frozen aluminum alloy boron carbide nanocomposite sheets produced by three methods: (1) HIP followed by high strain rate forging (HSRF), (2) HIP followed by two forging semi-isotropic step (QIF) and (3) three-step QIF. The take a look at results showed that the HIP/HSRF plate exhibited higher strength with less malleability than the QIF plates, which had similar mechanical properties. The in- rumpled strength and reduced malleability of the HIP/ HSRF plate is attributed to the inhibition of dynamic recrystallization throughout the high strain rate shaping procedure. Mahesh adult male et al. [26] investigated the characteristics of surface quality on machining hybrid aluminium-B_4C-SiC metal matrix composites victimisation taguchi methodology. The cutting speed was shown to be the most relevant parameter, followed by the feed rate. Furthermore, it was determined that feed rate had no substantial impact on surface quality. Barbara Previtali et al. [4] looked into the impact of using the traditional investment casting process on aluminium metal matrix composites. The wear resistance of SiC reinforced MMC and B_4C reinforced MMC were compared, and the experiments revealed that SiC reinforced MMC has a higher wear resistance than B_4C reinforced MMC.

V. METHODOLOGY

Figure 1 shows the classification of MMC preparation methods.

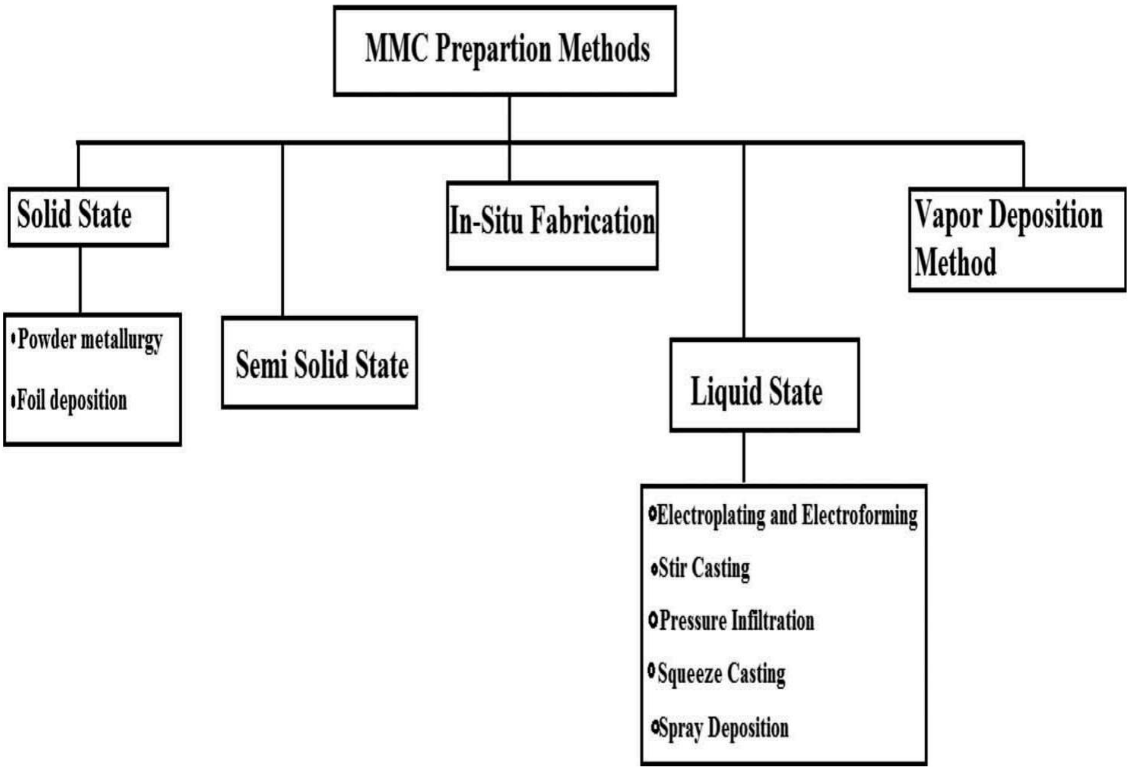

Figure 1. Classification of MMC based on MMC preparation methods

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DETAILED MMC PREPARATION METHODS

5.1. Solid-state methods

5.1.1. Powder blending and consolidation (powder metallurgy)

The matrix (base metal matrix powder and reinforcement powder) is mechanically mixed in a proper ratio before being treated with cold pressing, sintering, forging, and extrusion in the powder blending technique of MMC preparation. Green refers to the solid formed by pressing powders. When green is predominantly sintered, cold plastic work is conducted, however when green is made with cold pressure working, hot plastic work is performed in the end. MMC composed of magnesium alloys [27], aluminium alloys [28, 29], and copper matrix alloys [30–32] are often produced using the powder metallurgy process. Figure 2 depicts the powder metallurgy process for MMC preparation, with steps 1 and 2 depicting direct squeeze casting and indirect squeeze casting, respectively. The stages of indirect squeeze casting of MMC are represented by steps 2(a) and 2(b). Mechanical alloying is a method of creating composites by mechanically mixing the reinforced particles with the base metal matrix. Using a high-energy ball mill, also known as an attritor, hard material particles are disseminated into a comparatively soft metal matrix. Forging and hot iso-static pressing were used to further prepare the so-formed composite matrix [33–35].

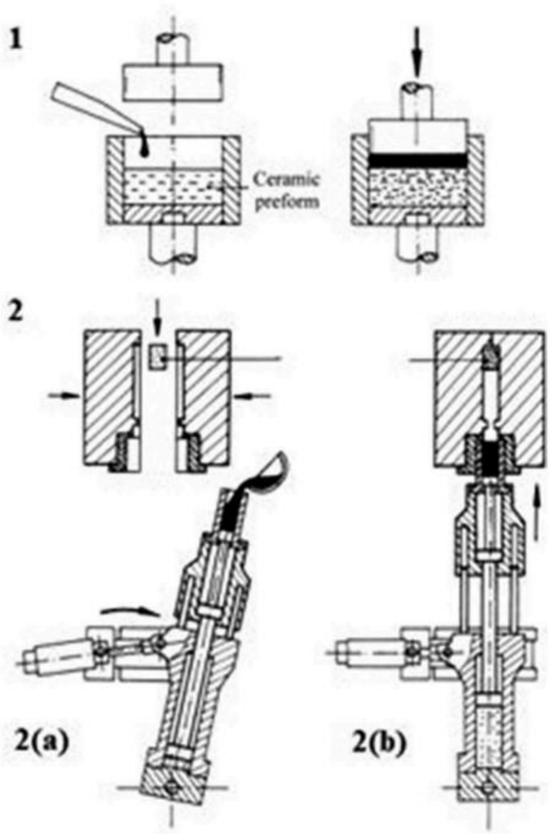


Figure 2. Powder metallurgy method of MMC preparation

5.1.2. Foil diffusion bonding

Multilayers of various metals are stacked in a specific pattern and pressed into a single composite with reinforced long fibres in foil deposition procedures. Various issues arise while producing MMC of various materials with a large temperature difference between melt and deformation [36]. To circumvent these issues, the foil deposition bonding technique [37] offers a viable alternative because no microstructure deterioration occurs. However, some materials, such as alumina matrix, resist solid-state bonding, thus chemicals are required to protect the antioxidant layer [38]. Figure 3 depicts the MMC preparation technique of foil deposition.

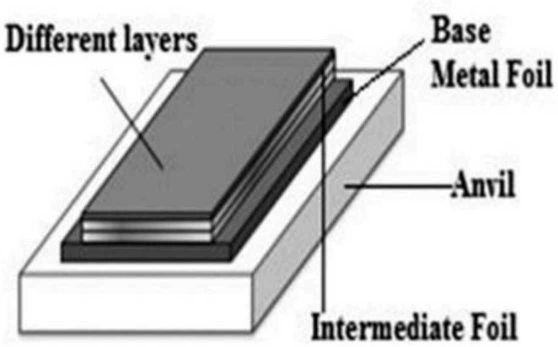


Figure 3. Foil deposition method of MMC preparation.

5.2. Liquid state methods

There are several techniques for making MMC that are dependent on the development of a liquid state. Some of them are described in depth below, along with how they function.

5.2.1. Electroplating and electroforming

Electroplating and electroforming of various particles or layers on the surface of a metal substrate such as alumina or tungsten allows for a variety of composite formations. This approach is primarily utilised to surface clad magnetic foreign particles onto the surface of non-conducting materials' substrates [40,41]. This method may be used to increase micro-hardness, wear resistance, and surface roughness while also combining other qualities including thermal, magnetic, and electrical conductivity [42, 43]. Various nickel-based MMCs, such as Ni-Cu [27], Ni SiC [29], Ni-WC [44], Ni-TiO2 [31], and others, have been developed to enhance the mechanical characteristics of substrate metals, particularly the surface properties. As shown in Figure 4, electroplating of various materials is accomplished using an oxidation and reduction reaction, with the substrate metal plate serving as the anode, and other particles deposited using an electrolyte bathtub and a solid plate of the material to be deposited serving as the cathode. After executing the electrolytic process, nonconductive materials like aluminium can be turned conductive by placing nickel particles on it [45].

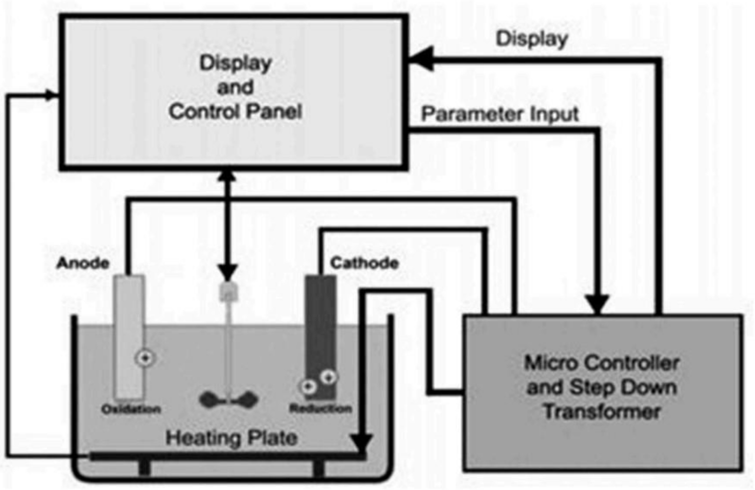


Figure 4. Electroplating method of MMC preparation

5.2.2. Stir casting

Stir casting is one of the most popular MMC preparation processes because the structural qualities of produced MMC are considerably superior to those of other MMC preparation techniques. The constant stirring action of liquid state metal makes the resulting MMC composition less faulty and more homogeneous [46]. The reinforcement is directly incorporated in the molten bath of the base metal matrix in this process, and the working temperature is higher than the melting point of the base metal. However, one of the drawbacks of stir casting-based MMC preparation is the necessity of a melting temperature of reinforcing material (three times that of the base metal matrix) [47–49]. Stir casting is often used to make aluminum-based alloys for a variety of applications, including pistons, braking discs, and cylinder liners [50,51]. The stir casting-based MMC preparation technique is depicted in detail in Figure 5. Various studies have looked into this MMC preparation approach for various reinforcing compounds.

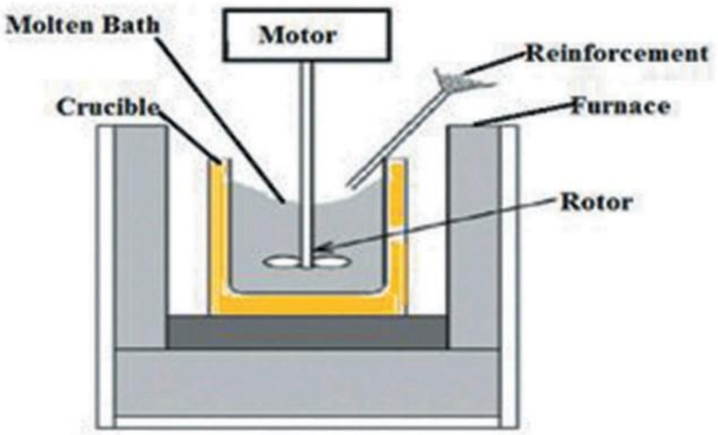
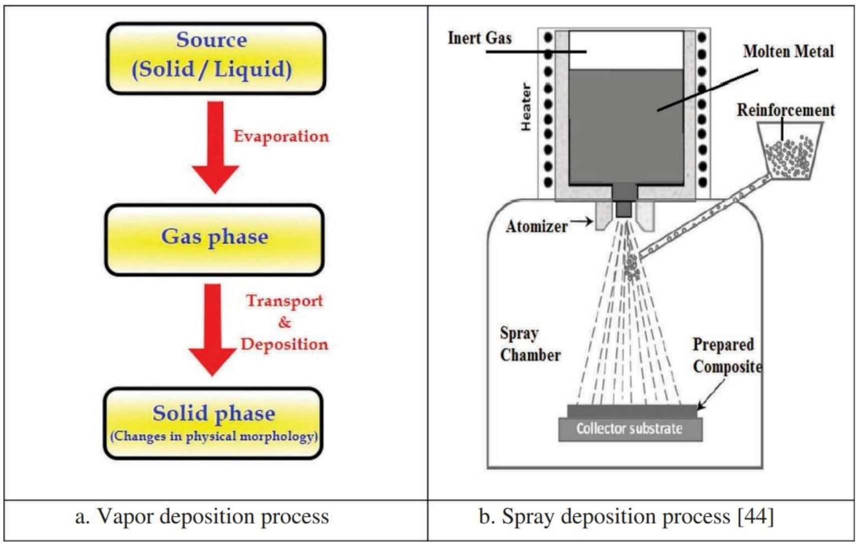


Figure 5. Stir casting-based MMC preparation method

5.3. Various other techniques of MMC preparation

Other MMC preparation techniques exist, but little research has been done on them, such as (a) reactive processing, in which a chemical reaction occurs between two metal matrices and molten material is then intermixed with a stirrer and composite is prepared, (b) spray deposition, in which molten metal is sprayed on the foreign reinforcement particles and composite is prepared [52–54], and (c) vapour deposition, in which molten metal is sprayed on the foreign Figure 6(a) depicts the vapour deposition method's process flow diagram, whereas Figure 6(b) depicts the MMC preparation spray deposition process.



a. Vapor deposition process

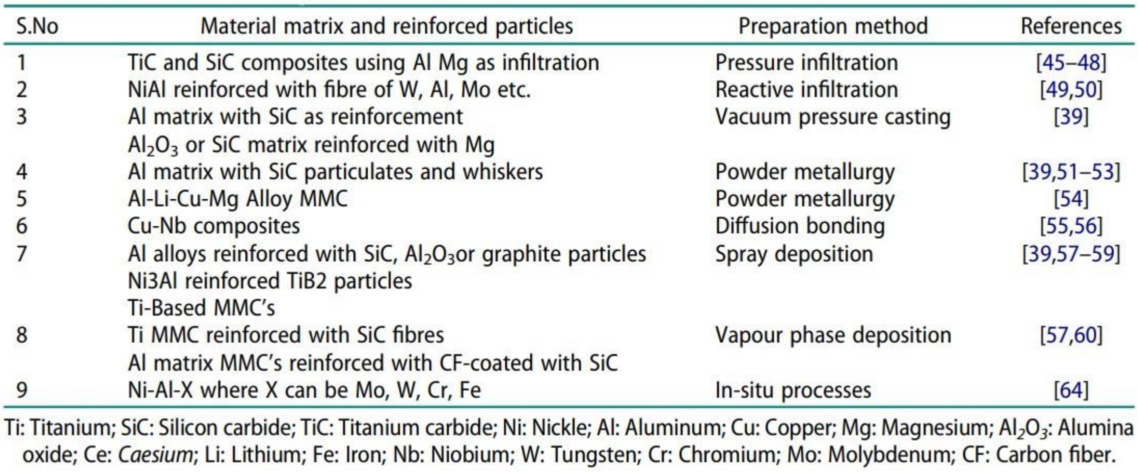
b. Spray deposition process [44]

Figure 6. (a). Vapour deposition process. (b). Spray deposition process

5.4. Various materials used as MMC

Several studies [55–75] have investigated MMC preparation methods for a variety of applications utilising various substrate matrix materials and reinforcement. The ingredients and techniques used to create MMCs are listed in Table 1.

Table 1. Commonly prepared MMC through various routes.



S.No	Material matrix and reinforced particles	Preparation method	References
1	TiC and SiC composites using Al Mg as infiltration	Pressure infiltration	[45–48]
2	NiAl reinforced with fibre of W, Al, Mo etc.	Reactive infiltration	[49,50]
3	Al matrix with SiC as reinforcement Al_2O_3 or SiC matrix reinforced with Mg	Vacuum pressure casting	[39]
4	Al matrix with SiC particulates and whiskers	Powder metallurgy	[39,51–53]
5	Al-Li-Cu-Mg Alloy MMC	Powder metallurgy	[54]
6	Cu-Nb composites	Diffusion bonding	[55,56]
7	Al alloys reinforced with SiC, Al_2O_3or graphite particles Ni3Al reinforced TiB2 particles Ti-Based MMC's	Spray deposition	[39,57–59]
8	Ti MMC reinforced with SiC fibres Al matrix MMC's reinforced with CF-coated with SiC	Vapour phase deposition	[57,60]
9	Ni-Al-X where X can be Mo, W, Cr, Fe	In-situ processes	[64]

Ti: Titanium; SiC: Silicon carbide; TiC: Titanium carbide; Ni: Nickle; Al: Aluminum; Cu: Copper; Mg: Magnesium; Al_2O_3: Alumina oxide; Ce: *Caesium*; Li: Lithium; Fe: Iron; Nb: Niobium; W: Tungsten; Cr: Chromium; Mo: Molybdenum; CF: Carbon fiber.

VI. CONCLUSION

In order to increase the engineering use of AMCs, several challenges must be overcome, including processing methods, impact reinforcement, the effect of reinforcement on mechanical characteristics, and its related applications. The key results drawn from previous research might be stated as follows: - SiC reinforced Al MMCs outperform Al_2O_3 reinforced MMCs in terms of wear resistance. SiC-reinforced Al MMCs are suitable materials for brake drums because of their high wear resistance, but they cannot be used in brake linings because the brake drums will be damaged.

A comprehensive review of available methods and materials for preparing MMC was conducted, and it was discovered that while many studies have been conducted on the preparation of MMC via traditional routes such as powder metallurgy, spray deposition, fold deposition, chemical reaction, pressure infiltration, stir casting, and so on, very few studies have been reported on hybridised routes of MMC preparation, which may be beneficial. Through a case study, a new approach has been described in which functionally graded MMC may be synthesised easily using three-stage hybridization. Functionally graded MMC has the potential to revolutionise MMC applications in structural and non-structural engineering. The aerospace sector might benefit greatly from functionally graded MMC since it would result in low-cost MMCs with the requisite functional qualities at the product's needed position.

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