Aluminium Metal Matrix Composites: Manufacturing and Applications

Lavepreet Singh1*, Sandeep Kumar1, Shivam Raj1, Shivam1 and Piyush Badhani1

1Department of Mechanical Engineering, Galgotias University, Greater Noida, Uttar Pradesh, India
1punstu@gmail.com

Abstract: Aluminium metal matrix composites (AMCs) is widely used in the industrial applications right now. Aluminum metal matrix composites have properties that no other monolithic material can match. Due to their superior strength to conventional materials, aluminium matrix composites (AMCs) have a broad variety of industrial applications. The nature of reinforcing, that can take the form of constant or undefined fibres, has a big influence on the properties of aluminum metal matrix composites. Thus it depends on the fabrication methods for aluminium matrix composites, which are influenced by a number of factors including the type of reinforcement and matrix used, its required degree with surface morphology integrity, as well as physical, mechanical, electro-chemical, and thermal properties. This article provides an overview of the manufacturing processes and different reinforcing elements used during the synthesis of Al-MMCs. Generally, the reinforced particles like carbides, nitrides, and compounds of oxides are used. This paper gives a brief overview on various methods that are being used to manufacture aluminium metal matrix composites. The present study offers a description of the synthesis, mechanical behaviour, and utilisation of aluminium metal matrix composites. The main processing methods for making or production of aluminium metal matrix composites (AMCs) are thoroughly discussed. Finally, questions of commercialization as well as business issues are also discussed.

Keywords: AMC; Matrix; Commercialization; Industrial Aspects; Mechanical Behavior

1. Introduction:

Aluminium metal matrix composites have a wide variety of applications in the automotive sector. Aluminium matrix composites are a high-demand commodity in the aerospace, vehicle, and other engineering applications. A composite is a matter made up of components formed with the help of physically combining already present monolithic materials for generating a single material with different properties from the proposed prototype. Every composite, in general, has two phases: (a) metal matrix; (b) reinforcements. In particular, the matrix is consistent and accompanies the discrete reinforcement process of the composite material. The composites have been distributed into four categories: 1) matrix (ceramic, metal, and carbon), 2) reinforcements (oxide, carbide, and nitride), 3) structure (continuous fibre, short fibre, whisker, and particulate matter), and 4) processing directions, and 5) orientation [1-2]. The form of matrix and reinforcement, its mechanical and thermal properties, and the degree for micro - structural integrity needed are all factors influencing the processing technique selected. The type of reinforcement, the variance for reinforcement materials, as well as the relationship of both the matrix with the reinforcement are all important factors in deciding the composite’s properties of the resulting [3].

Nonmetallic ceramics like Silicon carbide, Carbon, aluminium-di-oxide, Silicon-di-oxide, Boron, are commonly used[4]. Magnesium reinforced composites have received much interest because of their better mechanical and corrosion properties. The majority of Magnese-Aluminium alloys contains
about 8% to 9% Al and a trace of Zn is used to increase its tensile strength of material formed. Resistance to corrosion is improved by adding 0.1–0.3 wt% Mn. Magnesium alloy composites reinforced with silicon carbide (SiC) dispersion particles also have low population density of 2.1–2.2 g/cm³ and have 25–35 percent excellent mechanical properties and quality than without reinforced magnesium alloys. The greater reactivity of Mg makes the production of Magnesium-based composite extremely difficult. Incorrect manufacturing techniques can degrade rather than improve mechanical properties. As a consequence, the reactive species at the interaction amongst SiC particles and the Mg matrix should be closely controlled. Powder metallurgy is used to make Fe-based composite materials because it produces a homogeneous phase with no contact between the matrix and the reinforcement state. Various properties like hardness, strength, fatigue, fracture, and degradation improve in Fe-Al2O3 metal matrix composites, according to Gupta et al. The properties are improved by the creation of iron aluminate (Fe-Al2O4). The above process is generated by the active sintered metal of iron and alumina particles [5–9]. In aluminum metal matrix composites, higher level Al2O3 particulates are widely used, and there is some literature on the use of nanometric Al2O3 particulates. [10,11] Jamwal et al. [12] used a stir casting method to make Al/Al2O3-TiC composites and found that perhaps the wear rate of the composites falls as the reinforcement content increases. Caused by heavy interfacial bonding of matrix material including Al2O3 and TiC, composite compressive modulus has increased about 149.3 MPa.

Bandil et al. [13] study the impact of Silicon Carbide reinforcing it on Al-Si alloy property. The composites has been made using stir casting. As the % of SiC in composite increases, the density of this is said to decrease. As the SiC content of composites increases, the wearing rate was decreased. The uniform dispersion with SiC particles also helps with corrosion resistance. The maximum corrosion resistance efficiency is 56.58 percent at 20 wt% SiC.

Vinod et al. [14] used a double stir casting method to fabricate A356 alloy RHA-Flyash reinforced hybrid matrix composites and examined the mechanical and physical properties. The incorporation from both organic and inorganic particles increases the mechanical properties, according to the findings.

This paper describes the basic production techniques in order to make Matrix Composites. It also goes over the mechanical properties, corporatization, and implementation of different Al2O3 strengthened aluminium based composites manufacturing methods. This review is indeed a comprehensive review of the various manufacturing processes used for the production of matrix composites throughout period. Aluminium-based composite materials are expected to positively influence in the development and design of components for lighter industries, mainly aviation and transportation.

2. Primary production process for AMCs:

The way of manufacturing path used to fabricate any composites is critical in deciding the composite's final properties [15]. The three major classes of primary processes for producing AMCs on an industrial scale are:

1) Solid-state production processes.
2) Production that take place in a liquid.
3) Methods of deposition production process.

2.1. Solid - state production process for AMCs:

2.1.1. Powder blending & consolidation process (P/M processing): In solid state processes, this procedure, also known as powder metallurgy, seems to be the most commonly used technique. Powder
metallurgy processing is appealing because it uses lower temperatures, allowing for more influence about system kinetic model. The use of composite material compounds and micro structural improvements who are only achievable with rapidly solidified pigments are also possible with this processing techniques. As given below, powder metallurgy composites involve following number of processing steps.

1) The first step involves determining the composition and preparing the pigments which will be components including its combination to be treated throughout subsequent stages, such as metal/metal alloy powders and reinforcement powders.

2) The blended pigments get compressed into some kind of "green form" utilizing uni - axial press or cold isostatic applying pressure. The resulting green form, also known as the green body, is around 80 percent thick.

3) Sintering is achieved with in final stage via warming that green body to the desired processing temperature, which is normally performed in an inert atmosphere [16]. A sintered body's theoretical density is usually 100 percent.

2.1.2. Diffusion bonding process:
Heat-sensitive substances, substances with such a feisty oxide film, and composite materials that are difficult to join using traditional methods were the primary targets of diffusion bonding methods [17]. Diffusion formation is a process that uses mechanical pressure and high temperatures to create a phase that tightly connects the matrix and also fibre [18]. Diffusion bonding is a compression weld technique that requires atoms inter-diffusion through the welding line, which is typically divided by a liquid or solid phase inter-layer. It mainly focuses three interconnected process parameter: a) joining temperature, b) joining power, and c) retention or hold time. The joining force ought to be sufficient to ensure direct contact among both the meeting surfaces and to help in the bending of substrate abrasive particles that fill most empty spaces in the weld area.

2.2. Liquid state processes for AMC production:
2.2.1. Stir casting process:
Within this casting procedure of composite production, a reinforcement is stirred into melted metal. The stir casting method typically starts with the formation of the melt with the desired matrix content, quickly by addition of a reinforcing material and mixing to achieve the desired dispersion. The stir casting of Magnesium-oxide reinforced Al metal matrix composite is shown in Figure 1. This is the process which requires traditional stir mixing and then casting, is among the mainly cost-effective technologies for obtaining greater near-net form parts using metal matrix composites [19].

![Figure 1. Mg oxide reinforced with (Al)matrix composite by stir casting.](image)

The vortex method is the most basic and widely used of all stir casting methods. The vortex technique [20] entails injecting ceramic particles into a vortex of molten material formed by a spinning impeller prior to treatment. The introduction of ceramic particles into the vortex created by stirring molten metal is the first step in the vortex process. After that particles have been fed into the melt, swirl the
mixture to ensure that the particles are uniformly distributed, and eventually, cast the molten mix to receive the ceramic content.

2.2.2. The method of infiltration:

Within this pressing process, the melt is injected into a preform created during the reinforcing step to completely fill all of that open porosity. The friction effect caused by the viscosity, and its melted matrix, which occupies the composite preform, determine the pressure needed to combine the matrix and reinforcement. Various factors, such as alloy composition, ceramic preform content and crystal structure, temperature, and time, affect the wetting of the ceramic preform due to the liquid alloy. Figure 2 shows method of infiltration:

![Figure 2](image)

**Figure 2.** Using pressurised N2 gas, mechanical force has been showed to infiltrate the preform.

2.2.3. Forced Infiltration process:

The outer pressure is used to direct the penetration of melted material within permeable reinforcement in the forced infiltration process. This procedure can be divided among a number of groups, as shown in figure 3: (a) The penetration mechanism using a pressure die. (b) The infiltration of gas pressure. (c) Penetration by squeeze casting. (d) The vacuum infiltration method. (e) Method of using Lorentz force infiltration. (f) Method of using ultrasonic infiltration. (g) Phase of using centrifugal infiltration.

![Figure 3](image)

**Figure 3.** The method of infiltration and the various processes of infiltration.

2.2.4. Processing by In-situ (reactive processing):

This category includes processes such as liquid with gas, liquid with solid, liquid with liquid, and combined salts reaction. In this process chemical reactions among components or even among element and compound lead to formation of reinforcing states in the matrix material during the composite fabrication process [21]. The in-situ formed reinforcing processes become thermally stable, independent of foreign material contamination, include smaller dimensions, and more evenly distributed in the matrix, resulting in enhanced particle-matrix bonding in in-situ manufactured composite [22]. Figure 4 shows in-situ mechanism:
Figure 4. A eutectic alloy is processed by in-situ controlled one directional solidification process [22].

2.3. Method of deposition:

2.3.1. Physical Vapour Deposition process (PVD): This deposition is being utilized to create matrix composites, which is a time-consuming procedure. The whole process entails moving a fibre via a slight positive pressure region of the metal to still be collected, where condensation occurs, resulting in a relatively thick coating upon this material [23-24]. A powerful electrons light is directed onto edge of the a trusted platform feed stock to create fumes. The coated fibres are packed or arrayed as well as assembled in a pressing process or we can say HIP process to achieve the best composite content. PVD process that exist categorized as:

1. Vaporization also characterization techniques.
2. Sputtering techniques.

In the above stated first method, a gun generates a large electric field (EB) that vaporises the composite materials and causes the metallic moisture to encapsulate upon this fiber. In the sputtering method, ions from the manufacturing gas (such as argon) strike a piece of coating, breaking away molecules first from workpiece material and leaving a residue upon this material.

2.3.2. Spray Deposition Procedure:

This techniques are classified among two categories based on how much the given droplet flow is generated by either the melted baths (osprey procedure) or through continuous flow with cold hand into some kind of area of high temperature infusion (thermal spray procedure)[25]. The spray deposition method is visualized in figure 5.

Figure 5. Process of spray deposition [25].

3. Mechanical behaviour of aluminium matrix composites as a feature of processing parameters:

Composite materials (MMCs) have a higher elastic modulus, fracture resistance, and strength properties. Also they are perhaps more heat, wear, also resistant to corrosion.

Rahimian et al. used powder metallurgy to build Al-Al2O3 composites in order to examine the effect of alumina crystal structure, heating rate, and sintering temperature on the reinforcement material's specific entities [26]. The size of the particles of the aluminium being used was 3, 12, and 48m, with
temperature of sintering ranging from 500 to 600 °C including time of sintering ranging from 30 to 90 minutes. When the time of sintering was raised from 45 to 90 minutes, the amount of residential construction increased. Furthermore, higher sintering temperature changes contribute to the emergence of a structural performance, which results in higher membrane permeability.

In an experimental environment, Rabiei et al. [27] investigated the crack durability of aluminum metal matrix composites with particles of different reinforcees. To compare the findings to fracture toughness, the model of Hahn–Rosenfield was used. This Hahn–Rosenfield design being discovered to have a credibility range of 5–10m for reinforcing particles. The design has been tweaked for calculate the break resilience among matrix composites including higher particle reinforcement.

4. Corporatization of aluminium metal matrix composites:

Aluminium matrix compounds (AMCs) are being tested for validation as an alternative to industrial applications due to their low weight and high strength. One of the international markets for matrix composites products and technologies is construction, building materials, and other industrial sectors. Knowing the need of markets and industry research, the worldwide aluminum-based composite materials marketplace is forecast to attain a new high point with in coming years. The cost/performance ratio of ceramic composite materials, such as that of other materials, is the most important factor for companies when deciding whether to use ceramic composite materials in their goods. Pretty much across the board, massive commercial need for ceramic composite materials is expected to happen very soon [28-29].

The demand for aluminum composites is being increasing by the use of lightweight and high tensile strength components. Although most manufacturers have begun to use aluminum-based composites in their manufacturing processes, from very small units to large products. Industrial production, construction equipment, and other manufacturing industries are among the global markets for aluminum-based composite products and technologies. Because of their multifunctional properties such as stiffness, strength, and wear resistance, their demand will rise.

5. Commercial uses of aluminium metal matrix composites in industries:

Because of its high strength to its composite materials, many manufacturers were forced to prefer ceramic composites over aluminum alloys. Following are some applications:

- Aviation or aerospace sector: Airplane wing and supporting structure, fuel tank, fighter aircraft, and transport aircraft.
- Design & construction material: Ceramic materials give construction materials more strength and stiffness, making it a great choice for material selection in development.
- Athletics and wellness: The production of athletic apparel with boron(B) and silicon carbide(SiC) strengthening in aluminium gives higher strength while leading to the possibility.

Conclusion:

Each of the methods mentioned above has its own set of benefits and drawbacks. This article evaluates how a different reinforcement combination is used in AMCs and how it influences their performance. Several factors can affect the manufacturing methods chosen, including cost of production, process performance, preferred quality of products, and applications, among others.

- Powder metallurgical processing is appealing for a multitude of reasons, such as the ability to better monitor system metabolic pathways.
- The diffusion bonding method is simple to use, highly efficient, adaptable to a variety of situations, and produces an uniform joint product. Complex parts and structures are not appropriate for this method.
- Among the most cost-effective methods for manufacturing large relatively close formed parts from metal matrix composites is stir mixing accompanied through casting. The above process cannot easily be said to produce nanocomposites because nano-sized
ceramic particle reinforced with metal matrix composites materials manufactured using traditional stir casting methods generally include poor nanoparticle distribution with high porosity.

- In metal matrix composites manufactured using the infiltration technique, some porosity of localized variation with in volume fraction of a reinforcement are frequently observed. The whole method can be seen as an extremely versatile, nearby net shape fabrication method that provides excellent micro structural control.
- Some voids and localized variations in the particle size including its reinforcing are usually found in MMCs manufactured using the infiltration technique.
- The in-situ developed contamination-free reinforcing states spread more evenly in the matrix, resulting in greater particle–matrix attachment.
- The matrix surface morphology has extremely fine sizes and low separation, which is a key advantage of the deposition process.
- Spray diffusion becomes incredibly beneficial also for processing of difficult-to-prepare materials (alloying elements metal matrix composites).

References:
[1] Miracle DB. Metal matrix composites — from science to technological significance. Comp Sci Technol2005;65:2526–40.
[2] Rosso M. Ceramic and metal matrix composites: routes and properties. J Mater Proc Technol 2006;175:364–75.
[3] Singh N, Banerjee S, Parkash O, Kumar D. Tribological and corrosion behavior of (100-x)(Fe70Ni30)-(x) ZrO2 composites synthesized by powder metallurgy. Mater Chem Phys2018;205:261–8.
[4] Kaczmar JW, Pietrzak K, WąsosinAsk W. The production and application of metal matrix composite materials. J Mater Proc Technol 2000;106:58–67.
[5] Gupta P, Kumar D, Parkash O, Jha AK. Structural and mechanical behaviour of 5% Al2O3-reinforced Fe metal matrix composites (MMCs) produced by powder metallurgy(P/M) route. Bull Mater Sci 2013;36(5):859–68.
[6] Gupta P, Kumar D, Parkash O, Jha AK. Effect of sintering on wear characteristics of Fe-Al2O3 metal matrix composites. Proc Inst Mech Eng J: J Eng Trib 2013;228(3):362–8.
[7] Gupta P, Kumar D, Quraishi MA, Parkash O. Corrosion behavior of Al2O3 reinforced Fe metal matrix nano composites produced by powder metallurgy technique. Adv Sci Eng Med 2013;5(4):366–70.
[8] Gupta P, Kumar D, Quraishi MA, Parkash O. Effect of sintering parameters on the corrosion characteristics of iron-alumina metal matrix nano composites. J Mater Sci2015;6(1):155–67.
[9] Kumar UJP, Gupta P, Jha AK, Kumar D. Closed die deformation behavior of cylindrical iron–alumina metal matrix composites during cold sinter forging. J Inst Eng India Series D 2016;97(2):135–51.http://dx.doi.org/10.1007/s40033-015-0089-1.
[10] Surappa MK, Rohatgi PK. Preparation and properties of cast aluminium-ceramic particle composites. J Mater Sci1981;16(4):983–93.
[11] Rahmana MH, Al Rashed HMM. Characterization of carbide reinforced aluminium matrix composites. Procedia Eng2014;90:103–9.
[12] Jamwal A, Yates UK, Gupta P, Aggarwal A, Sharma BP. Fabrication and characterization of Al2O3–TiC-reinforcedaluminium matrix composites. In: Advances in industrial and production engineering. Singapore: Springer; 2019. p. 349–56.
[13] Bandil K, Vashishth H, Kumar S, Verma L, Jamwal A, Kumar D, et al. Microstructural, mechanical and corrosion behavior of Al–Si alloy reinforced with SiC metal matrix composite. J Comp Mater 2019.http://dx.doi.org/10.1177/0021998319856679.
[14] Vinod B, Ramanathan S, Ananthi V, Selvakumar N. Fabrication and characterization of organic and inorganic reinforced A356 Aluminium matrix hybrid composite by improved double-stir casting. Silicon 2019;11(2):817–29.
[15] Olszówka-Myalska A, Szala J, Cwajna J. Characterization of reinforcement distribution in Al/(Al2O3)p composites obtained from composite powder. Materials characterization2001;46(2–3):189–95.
[16] Garg P, Gupta P, Kumar D, Parkash O. Structural and mechanical properties of graphene reinforced aluminum matrix composites. J Mater Environ Sci 2016;7(5):1461–73.
[17] Feest EA. Metal matrix composites for industrial application. Mater Des 1986;7(2):58–64.
[18] Casati R, Vedani M. Metal matrix composites reinforced by nano-particles — a review. Metals 2014;4(1):65–83.
[19] Su H, Gao W, Feng Z, Lu Z. Processing, microstructure and tensile properties of nano-sized Al2O3 particle reinforced aluminum matrix composites. Materials & Design 2012;36:590–6, 1980-2015.
[20] Contreras A, Lopez VH, Bedolla E. Mg/TiC composites manufactured by pressure less melt infiltration. Scr Mater 2004;51(3):249–53.
[21] Sahin Y, Acilar M. Production and properties of SiCp-reinforced aluminium alloy composites. Compos A Appl Sci Manuf 2003;34(8):709–18.
[22] Chawla KK, Chawla N. Metal-matrix composites. University of Alabama at Birmingham and Arizona State University. 2013.
[23] Mubarak A, Hamzah E, Toff MRM. Review of physical vapour deposition (PVD) techniques for hard coating. J Mekanikal 2005;20:42–51.
[24] Chaudhury SK, Panigrahi SC. Role of processing parameters on microstructural evolution of spray formed Al–2Mg alloy and Al–2Mg–TiO2 composite. J Mater Process Technol 2007;182(1-3):343–51.
[25] Agarwal A, McKechnie T, Seal S. Net shape nano structured aluminum oxide structures fabricated by plasma spray forming. J Therm Spray Technol 2003;12(3):350–9.
[26] Rahimian M, Ehsani N, Parvin N, Baharvandi HR. The effect of particle size, sintering temperature and sintering time on the properties of Al–Al2O3 composites, made by powder metallurgy. J Mater Proc Technol 2009;209:5387–93.
[27] Rabiei A, Vendra L, Kishi T. Fracture behavior of particle reinforced metal matrix composites. Compos A Appl Sci Manuf 2008;39:294–300.
[28] Gupta P, Kumar D, Quraishi MA, Parkash O. Influence of processing parameters on corrosion behavior of metal matrix nano composites. J Mater Environ Sci 2016;7(7):2505–12.
[29] Gupta P, Kumar D, Parkash O, Jha AK, Sadasivuni KK. Dependence of wear behavior on sintering mechanism for iron-alumina metal matrix nano composites. J Mater Chem Phys C 2018;220:441–8.