PROCESSING METHODS OF METAL MATRIX COMPOSITES-A REVIEW

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Abstract

This article includes a research on Metal matrix composites, as well as MMC production processes. The current advances in metal matrix fabrication processes are discussed in this research. Composites is examined engineered or naturally occurring materials constructed from two or more constituent materials with significantly differing physical or chemical characteristics that remain separate and distinct at the macroscopic or microscopic scale inside the completed structure are referred to as composites. MMCs are composed of a continuous metal matrix and one or more discontinuous reinforcing phases. Metal matrix composites are created using a variety of procedures, including liquid fabrication methods and solid manufacturing methods.

Metal injection moulding, friction stir technique, mechanical alloying, squeeze casting technology, continuous binder-powder coating, and other production procedures are employed by researchers to manufacture metal matrix composites. A lot of work is being done in the field of MMC manufacturing methods, which has reduced their cost to an acceptable level when compared to those treated by powder metallurgy and spray casting.

Key words: Composites, Metal Matrix Composites (MMC), Processes

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2383

1. INTRODUCTION

Metal matrix composites (MMCs) are sophisticated materials that combine the qualities of a strong metallic matrix material, such as aluminium, with the properties of a hard ceramic reinforcement to generate a composite with exceptional material properties. MMCs have been investigated for some years, and their potential benefits over traditional monolithic alloys are becoming more apparent. In the transportation, agriculture, construction, and manufacturing industries, increasing demands for lightweight, high specific strength, excellent high-temperature performance, exceptional corrosion resistance, chemically inert, and energy-saving materials have stimulated a steadily growing activity to develop specific composite materials known as aluminium matrix composites (AMCs). They are lightweight, high-performance materials with the potential to replace traditional materials in a wide range of sophisticated applications [1].

Because of its enhanced strength and stiffness, greater wear resistance, increased hardness without a substantial loss in ductility, improved compressive strength, lower thermal conductivity, and improved dimensional stability, AMCs are gaining popularity. These and other features make AMCs desirable in a variety of fields, including aircraft, cars, marine, medical, electronic packaging, and household appliances [2-6].

According to research, both liquid-phase and solid-phase fabrication processes have been utilised to produce AMCs of the required size and form, which has a substantial impact on defining their mechanical properties. AMCs reinforced with ceramic particles such as SiC, Al_2O_3, $Y_2W_3O_{12}$, and AlN, soft metallic materials such as Cu and high carbon steel chips powder, and soft nonmetallic materials such as fly ash (FA) and aloe vera (AV) powder particles, for example, outperform unreinforced aluminium alloys in terms of mechanical properties. Furthermore, cryogenic treatment may improve the material characteristics of AMCs, which is desirable since it is a low-cost, easy, environmentally friendly, and nondestructive operation [3, 4, 7-11].

2. METAL MATRIX COMPOSITE FABRICATION METHOD

Metal matrix composites are manufactured using liquid phase and solid phase manufacturing processes. In liquid processing, discontinuous phase reinforcement is transformed to continuous phase in the liquid state, and molten metal is cast into the required shape. MMCs are created below the melting temperature of the matrix in the solid-state manufacturing technique.

Though the aforementioned two processes are often employed in the manufacture of MMCs, there is another approach known as reactive processing in which the reinforcement is formed in the matrix by chemical interactions in distinct components.

2.1. Liquid-state processing methods:

It is a highly straightforward, adaptable, and economical technology for manufacturing MMCs in large quantities. This procedure includes squeeze casting, thermal spray, infiltration, compocasting, ultrasonic-assisted casting, stir casting, and the injection of melt-particles using a laser, among other techniques. The metal matrix is heated above melting temperature in the stier casting process, and reinforcing elements are added to a molten matrix using a mechanical stirrer[1].
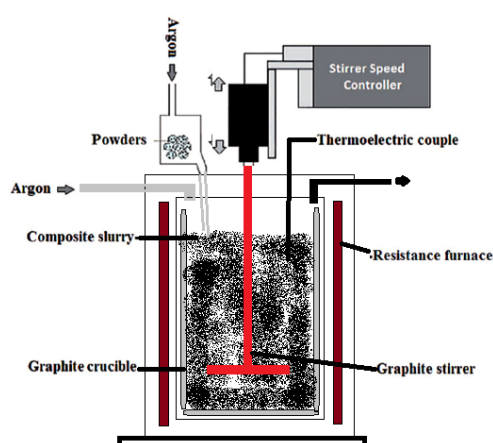

Fig 1 Schematic of crucible and facilities for stir casting process

Liquid state techniques have been widely employed in the production of MMCs. These processes are defined by close interfacial contact and, consequently, by robust bonding. In these processes, the dispersed debris is absorbed into a molten metal matrix, which ultimately solidifies. The dispersed phase-matrix interfacial bonding's quality affects the composite's mechanical

characteristics.Compared to solid state operations, liquid state technologies are simpler and more affordable. These methods also make it possible to produce dense matrices and almost net-shaped components in complicated geometries considerably more quickly [2].Processes like conventional casting operations are frequently used in liquid state processing. Because aluminium has a low melting point and is often utilised, the process uses less energy. Solid state procedures are used more often when working with high melting point matrix materials like titanium alloys. High temperature processing can encourage the production of a brittle interfacial layer between the phases involved, which can have a detrimental influence on the properties of the composite[3][4][5][6]. This is one problem with liquid state processes.

It can be difficult to achieve a uniform distribution of the dispersed material in the molten alloy without having any of the particles float, settle, or aggregate. The viscosity of the liquid composite varies fast when the dispersed material is added and the solidification process gets going.Controlled viscosity during particle inclusion and solidification is crucial for a successful operation that produces uniform dispersed material distribution. These problems are quite typical in the stir casting process [7][8][9].

To restrict unwanted reactions and promote wetting, an appropriate chemical treatment or coating can be applied to the dispersed material, or wetting agents can be added to the melt to reduce the formation of oxides, induce positive interfacial reactions, and aid to lower interfacial energy.The beneficial characteristics of the coating can be defeated if the coating of the particles is exposed to air before penetration [10][11][12][13].

A composite made of 20 weight percent B4C/AA6061 was created by Dou et al. [14] and different characteristics, including friction and wear, were examined by altering the load and sliding velocity. It demonstrates that mass loss rises from the point of application of load to the point of sliding time while a very little reduction is observed with increasing sliding velocity.

At 20 minutes of sliding duration, 240rpm sliding velocity and 30 N applied load delimitation was discovered as mass loss and friction coefficient increased. The stir-cast MMCs may be employed for uniform reinforcement distribution and strong interfacial bonding. Al/B4C, Al/SiC, and Al/Al2O3 composites with 6-20 vol% reinforcement were prepared via stir-casting by Shorowordi et al. [14].

Ramesh et al. [15] used a stir casting technique to reinforce preheated TiB2 particles at 0, 4, 8, and 12 wt% in the AA7075 alloy at 850 _C as preheating of reinforcement particles before dispersion into a molten metal can improve the wettability of reinforcement particles with the molten matrix.

Due to the density differences between the matrix and reinforcement particles, it has been shown that while stir-casting, the particles tend to sink or float after being wetted on the molten metal. This causes non-homogeneous dispersion. Different defects result from the non-homogeneous dispersion of reinforcing particles.

In order to prevent clustering and agglomeration of the particles, Auradi et al. [16] created AA6061/B4C composites with 5 and 7 wt% of particles at 750C. Additionally, they used K2TiF6 flux using a two-step addition melt stirring process to increase wettability and prevent agglomeration.

Poovazhagan et al. [17] used an ultrasonic cavitation-assisted casting process to create a nano composite matrix with refind grains as compared to an unreinforced counterpart. The AA6061/ nano-B4Cp composite demonstrated high ductility and impact resistance, as well as dry sliding wear resistance, evenly dispersed particles, improved dislocation density, hardness, and tensile strength.

J. J. Moses et al.[18] used the stir casting procedure to create a composite using AA6061 as the matrix and warmed 15wt% TiC reinforcement particles. The research was conducted. The investigation was carried out to increase the ultimate tensile strength (UTS) of the base matrix employing ceramic particles by varying factors such as stirring speed (300rpm), stirring duration (15min), blade angle (30°), and casting temperature (830°C). To prevent oxide development of the composite for wettability, 2wt% Mg and argon gas were supplied throughout the procedure. Following the aforesaid criterion, AA6061/15% TiC has a maximum UTS of 240 MPa.

Prabhu et al. [19] investigated the influence of stirring speed and duration on microstructure. He discovered that clustering occurred in certain areas at lower speeds and stirring times, whereas no reinforcement (SiC) inclusion was detected in others.Increased stirring speed and stirring duration resulted in more homogenous SiC dispersion in the Al matrix and higher hardness, with the best results obtained at 600 rpm and 10 minutes of stirring time.

In their modified stir casting approach, Samal et al. [20] added particle SiC and Mg turnings to tiny cylindrical capsules using a hollow spindle stirring mechanism in place of a solid shaft stirrer. With the inclusion of an alloying element and reinforcement at the same time, the approach was proven to be stable for removing the fading impact of immunisation.

2.2 Solid-state processing methods:

Below the melting point of the matrix, MMCs are made using a solid-state processing method. Powder metallurgy, high energy ball mills, spark plasma sintering, cold spraying, diffusion bonding, and friction stir processing are among the solid-

state processes that are included. In the process of powder metallurgy, fine powders are combined and blended before being vacuum-degassed, compressed, and finally given a desired form in a controlled environment by the sintering process. Powder metallurgy is favoured in the production of intricately formed precision components because to its excellent mechanical and structural qualities and uniformity. Aluminum matrix composites reinforced with ceramic particles are reasonably simple to produce and almost isotropic when compared to composites reinforced with fibres. A cost-effective approach for creating complicated components with high strength, precise dimensions, little scrap loss, and fewer subsequent machining processes is powder metallurgy. However, powder metallurgy might not be appropriate for mass production due to the high cost of alloy powder requirements and complicated process procedures. The detailed schematic depiction of the processes in the powder metallurgy process is shown in Fig. 2.
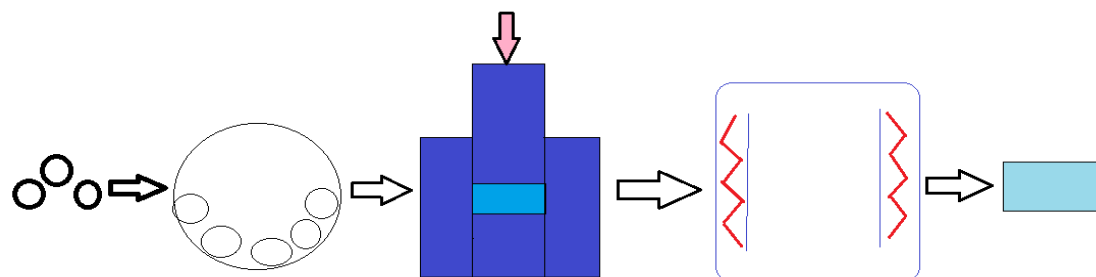
Fig:2Powder metallurgy process steps in detail.

To determine the function of the micro alloying element Cu in AA6061/B4C composites, Zhou et al. produced an AA6061/26 wt% B4C composite by [21]using the powder metallurgical technique at hot-pressed temperatures of 560 °C and 620 °C. In the 620 °C hot-pressed composite, the reinforcement matrix reactions produce Al3BC and MgB2 and Cu segregated at the precipitates-matrix interfaces and also increase the nucleation of the precipitates, in contrast to the 560 °C hot-pressed composite where Q phase was the main Cu-contained precipitates.

By using 5 and 10% precipitator fly ash from the Tuticorin thermal power station in India, Balamurugan et al. [22] investigated the impact of sintering time, compaction pressure, and temperature on the mechanical and wear behaviour of Cu/fly ash composites produced by powder metallurgy while keeping in mind that various parameters, such as volume fraction of reinforcements, green density, compact pressure, sintered density, etc. can govern the resulting MMCs. With increasing process parameters, it was discovered that the compression strength, density, hardness, and wear resistance increased. Maximum 171 HV hardness was achieved for the composite reinforced with 10 wt% fly ash at 450 MPa compaction pressures, 900 C compaction pressures, and 60 min. sintering time. Maximum wear resistance was achieved at 90 min. sintering time.

By using a theoretical calculation connection for the coefficient of friction of the hybrid nanocomposites, Akbarpour et al. [23] investigated the wear and friction behaviour of powder metallurgical Cu/SiC + MWCNT hybrid nanocomposites. The hybrid nanocomposites demonstrated better wear resistance and lower friction coefficients than copper. Due to a uniform lubricant layer on the worn surface, the 2 vol% SiC + 4 vol% CNT reinforced Cu matrix hybrid composite exhibited higher wear resistance, greater hardness, and lower coefficients of friction and oscillation than other hybrid composites. Delamination and flake formation-spalling were found to be the hybrid nanocomposites' primary wear-related phenomena.

Gao et al. [24] examined the impact of ageing and reinforcement particle content on the AA6061/B4Cp neutron absorber composites' mechanical response and microstructure development. Additionally, it was noted that the relative density of composites marginally dropped from 99.70% to 99.47% with increasing B4C concentration.

In the matrix and close to the interfaces, Mg2Si precipitates and dislocations were observed. The peak-aged composites' ultimate tensile strength increased from 342.2 to 451.0 MPa with an increase in B4Cp content, and the yield strength went from 301.6 to 381.5 MPa as a result of the use of B4C particle reinforcement. On the opposite side, during the same amount of ageing time, the electrical conductivity reduced and the failure strain dropped from 18.4% to 7.9%.

In order to create AA6061/TiB2/Al2O3 hybrid composites, Selvamet al. [25] used controlled environment electric stir casting to create an in-situ reaction between Ti and H3BO3 powders in molten aluminium. Al-Ti-H3BO3 reaction produced hexagonal and cubic-shaped TiB2 and spherical

Al_2O_3 at 950°C, and the Al matrix grains were refined from 103 lm at b0 weight percent to 14 lm at 15 weight percent. The composites' micro hardness and tensile strength were found to be increased to 122 HV and 287 MPa at 15 weight percent, respectively, by the addition of nanoscale thermodynamically stable Al_2O_3 and TiB_2 particles with strong interfacial bonding.

In a work by David Raja Selvam et al. [26], the researchers create AA7075/ZrB_2 MMCs by in-situ reacting inorganic salts KBF_4 and K_2ZrF_6 with Al melt by stir casting technique, and they investigate the impact of temperature on the dry sliding wear behaviour of the produced composites.

David Raja Selvam et al. [26] produce AA7075/ZrB_2 MMCs by in-situ reaction of KBF_4 and K_2ZrF_6 inorganic salts with Al melt by stir casting, and investigate the influence of temperature on the dry sliding wear behaviour of the generated composites.

At both low and high temperatures, the ZrB_2 particles sharpen the Al matrix grains and increase wear resistance. The ZrB_2 particles displayed thermodynamic stability without disintegration at high temperatures. The MMCs wore out fast at hot temperatures.

Zhu etal[27] investigated how artificially aged AA6092/SiC/powder metallurgy composites and naturally aged AA6092 composites influenced strength. Because of natural ageing following artificial ageing The strength of both the composite and the alloy was found to diminish, although the drop in strength was found to be lower in the composite than in the alloy. However, the unfavourable effect of natural ageing was larger for the composite than for the alloy because the precipitate of natural ageing was lower. However, because the precipitate coarsening produced by natural ageing was weaker in the composite and more metastable L phases containing Cu occurred in the composite than in the alloy, the negative effect of natural ageing was larger in the composite than in the alloy.

The utilisation of low-cost, high-strength B4C-Al neutron absorber materials with good thermal stability is required for dry storage of spent nuclear fuels. Zan et al. [28] created AA6061/B4C composites with different hot-pressing temperatures using powder metallurgy. Increased hot pressing temperatures from 560°C to 630°C resulted in the creation of Al_3BC and $Mg(Al)B_2$ compounds, as well as an improvement in the mechanical properties of the composites. At both room and elevated temperatures, the tensile strength of the sample hot-pressed at 630 C was 4059% greater than that of the sample hot-pressed at 560°C. Furthermore, even after 8000 hours of annealing at 400°C, the mechanical characteristics of the sample hot-pressed at 630°C remained steady.

J. Wang et al. [29] investigated reinforced aluminium flakes with 0.3 weight percent graphene nanosheets. The graphene oxide/aluminum composite powder was first heated for two hours at 550°C in an argon environment. After being compressed and fused into billets, the graphene Nano sheets/aluminum composite was sintered at 580°C and hot-extruded at 440°C. In the final tensile strength test, the inclusion of graphene nanosheets enhanced the composite's tensile strength by 62 percent.

TiO_2 was studied by Kumar and Rajadurai [30] in relation to the Al-15 percent SiC base matrix. TiO_2 was added in weight-based increments of 0%, 4%, 8%, and 12%. Prior to cold compacting the composite powder at 800 MPa, powders were evenly mixed and warmed to 200°C. At 650°C for two hours, the green compact was sintered, and the furnace was then cooled for eight hours. As a consequence, the composite's final density and micro hardness test outcomes demonstrated a continual improvement with increasing TiO_2 content.

MW radiation was utilised by Bharathi et al. [31] to sinter FGM composed of Al/SiC powders. The composite with layers of 0, 20, 40, 60, and 80% SiC was successfully created, and it showed a notable rise in elastic module by increasing the quantity of SiC from the bottom (pure Al) to the top (80% SiC), respectively, from around 70 to more than 300 GPa. Additionally, the composite was heated for one minute at 700°C in an oxyacetylene flame, then quenched five times in oil for each sample as part of the thermal test; nevertheless, no layer delamination was noticed.

3. CONCLUSIONS

Metal matrix composites are becoming more popular as a result of their unique behaviour and high strength-to-weight ratio. Every industry, including automotive, sports, aircraft, construction, and marine, benefits from composites, particularly metal matrix composites. MMCs are manufactured using a variety of procedures like as stir casting, powder metallurgy, infiltration, and so on, as explained in this work. Researchers are developing new methods like as mechanical alloying, metal injection moulding (MIM), continuous binder powder coating (CBPC), and others to manufacture these MMCs to fulfil the demands of diverse industries. Selected research is being conducted to enhance current MMC materials, and procedures and architectures to develop a second generation of materials are available.

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