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A Review on Metal Matrix Hybrid Composite Al/SiC/Gr

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ABSTRACT
In a material composite, when the matrix is a metal or an alloy, then it is known as "metal matrix composite" (MMC). The matrix is basically a metal, but hardly ever a pure one. Except sparing cases, it is generally an alloy. This paper deals with various literature reviews carried on SiC, Gr and hybrid-reinforced composites. After the study of literature review, research gaps were identified, and based on the research gaps, the objectives of the research work were decided. In this paper, a review of cast aluminum matrix composites reinforced with various reinforcements is done. This paper is representing the classification of composites, properties and categories of multiphase composite along with the effect of reinforcement on MMCs. Also, focus on the role of MMC in the field of engineering and technology. This paper also gave a brief review on Al/Sic/Gr–metal matrix hybrid composite along with advantages and disadvantages of MMC materials.

Keywords: *Al/SiC/Gr, aluminum matrix composites, MMC, multiphase composite, reinforcement*

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INTRODUCTION

Composite materials play an important role in the field of engineering as well as advance manufacturing in response to unprecedented demands from technology due to rapidly advancing activities in aviation, aerospace and automotive industries. These new materials include high-performance composites such as reinforced composites. Continuous advancements have led to the use of composite materials in more and more diversified applications. Today, 1600 engineering materials are available in the market; among them, 200 are composite materials.

COMPOSITES

The typical composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties, which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. The constituents of metal matrix composite (MMC) retain their identities, which means these are not dissolved or merged completely into one another. The individual materials that make up composites are called constituents. Most composites have two constituent materials: a binder or matrix (polymers, metals and ceramics) and reinforcement (fibers, particles, flakes and fillers). The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its good properties. The matrix holds the reinforcements in an orderly pattern. Because the reinforcements are usually discontinuous, the matrix also helps to transfer load among the reinforcements [1].

CLASSIFICATION OF COMPOSITES

Composites are classified into various ways by different authors, but in the simplest and broadcast sense, they may be classified as (i) natural, (ii) manmade or synthetic. The composites that occur in nature are called natural composites, such as wood (composed of cellulose fires and lignin support), human or animal body (composed of bones or tissues). Bones, sea shells and elephant tusk are also considered as the examples of natural composites provided by nature [1]. The manmade or synthetic or reinforced composites are classified in two ways: (i) on the basis of matrix used and (ii) on the basis of the geometry of the reinforcement. Based on the matrix phase used, multiphase composites are divided into three categories:

1. Polymer matrix composites (PMCs)
2. Ceramic matrix composites (CMCs)
3. Metal matrix composites (MMCs).

MATRIX MATERIAL

In Lloyd [2], the matrix material should be carefully chosen depending upon its properties and behavior with the reinforcement. As it is the primary constituent in MMC, the matrix alloy should be chosen only after giving careful consideration to its chemical compatibility with the reinforcement, to its ability to wet the reinforcement, and to its own characteristic properties and processing behavior [2]. To obtain the best property in composite system, reinforcement whiskers or particulates and matrix should be physically and chemically compatible as much as possible. In conjunction with unique whisker coatings, compositions of special matrix alloy have been devised to optimize the performance of certain metallic composites [3, 4]. Researchers have proposed a lot of materials, i.e. Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn and Si on the basis of oxidation and corrosion resistance properties [4]. Among these, Al, Ti and Mg are used widely. The most common metal alloys in use are based on aluminum and titanium. Both of them are low-density materials and are commercially available in wide range of alloy compositions. Other alloys are also used for specific cases, because of their own advantages and disadvantages. Magnesium is light, but it is highly reactive to oxygen. Nickel- and cobalt-based super alloys have also found some use, but some of the alloying elements present in the matrices have been found to have undesirable effect (promoting oxidation) on the reinforcing fiber at high temperatures. Desischer [5] explains that aluminum is the one of the best materials for matrix because of its unique combination of excellent mechanical and electrical properties of good corrosion resistance, low density and high toughness with high conductivity. Moreover, Al is cheaper than other light metals like magnesium (Mg). The other advantage of using Al matrix as MMCs is its corrosion resistance which is very important for using composites in different environment [6]. Aluminum-based MMCs offer potential for advanced structural applications when high specific strength and modulus, as well as good elevated temperature resistance, high service temperature and specific mechanical properties are important.

REINFORCEMENT

Reinforcement increases the strength, stiffness and the temperature resistance capacity, and lowers the density of MMCs. In order to achieve these properties, the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix, and the following aspects must be considered while selecting the reinforcement material. Reinforcements are characterized by their chemical compositions, shape, dimensions and properties as in gradient material, and their volume fraction and spatial distribution in the matrix [7]. Although the largest improvement in properties (strength and stiffness) is obtained with the introduction of fiber reinforcement, the properties of fiber-reinforced composites are not isotropic. Particulate-reinforced MMCs show the advantage of nearly isotropic properties and cost effectiveness. Furthermore, an additional advantage of the particulate-reinforced over fiber-reinforced MMCs is that the most existing processing techniques can be used for fabrication and finishing of the composites, including hot rolling, hot forging, hot extrusion and machining [8–10]. Typically, these ceramics are oxides, carbides and nitrides. These are used because of their combinations of high strength and stiffness at both room and elevated temperatures. Common reinforcement elements are B_4C, SiC, Al_2O_3, TiB_2, boron and graphite. The use of graphite reinforcement in a metal matrix has a potential to create a material with a high thermal conductivity, excellent mechanical properties and attractive damping behavior at elevated temperatures [11]. Alumina and other oxides particles like B_4C, TiO_2, etc. have been used as the reinforcing particles as it is found that these particles increase the hardness, tensile strength and wear resistance of aluminum MMC [12].

METAL MATRIX COMPOSITE

In a material composite, when the matrix is a metal or an alloy, then it is known as MMC. [13]. Generally, MMCs are classified according to the type of used reinforcement and the geometric characteristics of the same. Normally, the main classification of composites can be made in the form of reinforcement groups into two basic categories:

1. Continuous reinforcement composites, constituted by continuous fibers or filaments.
2. Discontinuous reinforced composites, containing short fibers, whiskers or particles.

CHARACTERISTICS OF MMCs

The performance of these materials renders their characteristics in terms of physical and mechanical peculiarity, depends on the nature of the two components (chemical composition, crystalline structure, and in the case of reinforcement, shape and size), the volume/weight fraction of the adopted reinforcement and production technology. In general, the MMCs utilize the properties of the matrix (lightweight, good thermal conductivity, ductility) and of the reinforcement, usually ceramic (high stiffness, high wear resistance, low coefficient of thermal expansion) at the same time. Material characterization can be obtained by comparing the basic metal component in terms of high values of specific strength, stiffness, wear resistance, fatigue resistance and creep, corrosion resistance in certain aggressive environments.

HYBRID COMPOSITES

Hybrid composites can include fibers of two or may be more types, i.e. carbon and glass, glass and aramid, Al_2O_3 and SiC, Al_2O_3 and B_4C, Al_2O_3 and C, and more. The properties of hybrid composites are more excellent than those of single-reinforcement reinforced composites because of interaction of various reinforcement, especially the hybrid effectiveness produced by these reinforcements, such as low thermal expansion coefficient, better wear resistance, high strength, high hardness and low cost. A promising application of these materials is associated with the so-called thermostable structure, which does not change their dimensions under heating or cooling. For some composites, i.e. with glass or boron fibers, the longitudinal coefficient of thermal expansion is positive, whereas for other materials, i.e. with carbon fibers, it is negative. The appropriate combination of fibers with positive and negative coefficients can result in material with zero thermal expansion. The range of applications of composite materials is very large. The hybrid materials used in different fields as electrical, electronics, buildings and public works, road transports, rail transports, marine transports, cable transports, air transports, space transports, sports and recreation.

Al/SiC/Gr–METAL MATRIX HYBRID COMPOSITE

Al/SiC/Gr–metal matrix hybrid composite (MMHC) is one of the important hybrid composites among MMC, which have SiC and graphite (Gr) particles with aluminum matrix. The SiC is very hard and graphite particles provide high resistance-to-wear in hybrid composite.

Ceramic particles such as SiC are commonly added as a second reinforcement material in MMC hybrid composite to an increase in hardness, strength, wear resistance, elastic modulus, and decrease in the thermal expansion coefficient for contact sliding application, i.e. brake disc rotors.

The hybrid MMC like Al/SiC/Gr–MMC is one of the composites which have many unique properties over Al/TiB_2, Al/B_4C and Al/Gr–MMC. The hardness and tensile strength of Al/SiC/Gr composites increase with the increase of the SiC as the second reinforcement.

LIQUID METAL TECHNIQUES

Liquid-state fabrication of MMC involves incorporation of dispersed phase into a molten matrix metal, followed by its solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase p articles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. The simplest and the most cost-effective method of liquid-state fabrication is stir casting. The methods of liquid-state fabrication of MMCs are stir casting, infiltration, gas pressure infiltration, squeeze casting infiltration, pressure die infiltration, deposition processes, etc.

STIR CASTING

In this method, a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal. Stir casting is the cheapest methods of liquid-state fabrication. Owing all these advantages, the stir-casting process is used for the development of hybrid composites in the present research work. The conventional metal-forming technologies for liquid composite material are used for casting. Several factors considered in preparing MMCs by stir-casting method are as follows:

- Maintaining a uniform distributed reinforced material.
- Wettability of the substance.
- Porosity of the composites.
- Chemical reaction between the reinforcement material and the matrix alloy.

In order to achieve the uniform properties of the MMC, the distribution of the reinforcement material in the matrix alloy must be maintained, and the bonding between these substances should be optimized. The porosity levels need to be reduced and chemical reactions between the reinforcement materials and the matrix alloy must be controlled. Figure 1 shows the basic block diagram of stir-casting method [14].

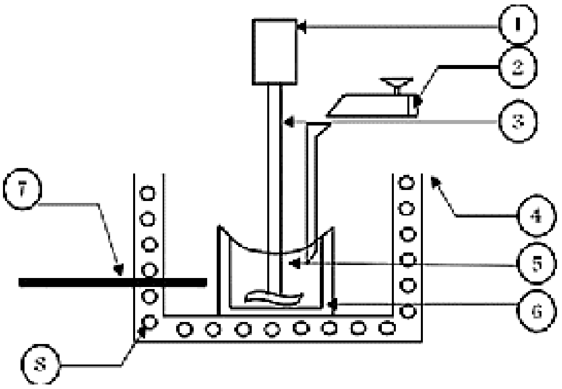

Fig. 1. *Schematic view of the furnace (1). Motor, (2). Shaft, (3). Molten aluminum, (4). Thermocouple, (5). Particle injection chamber, (6). Insulation hard board, (7). Furnace, (8). Graphite crucible.*

LITERATURE REVIEW

Tee et al. [15] studied about Al base composite reinforced by *in situ* TiB_2 particulates was successfully synthesized by the stir-casting technique. In his experiment, 1–3 mm size of composite was produced by optimizing the process variables. In results, tensile strength 61%, yield strength 58% and modules 23% improve, depending upon the volume fraction of TiB_2 incorporated into the Al was achieved. Al matrix was modified with the addition of copper which improved the mechanical properties by a factor of not less than 2.5. With the help of fractographs, a dimpled fracture surface was shown which indicates the retention of relatively high ductility in the presence of coarse $TiAl_3$ associated with the Al-Ti-B system. The exhibition of a clean Al-TiB_2 interface testified to the benefit that had been gained from the *in situ* processing.

Yilmaz and Buytoz [16] studied about the effects of volume fraction, particle size of reinforcement (Al_2O_3) and effects of porosity in the composites on the abrasive wear resistance of compo-casting Al alloy MMCs. They found that the rates of abrasive wear decreased rapidly with increasing volume fraction of Al_2O_3. Further, the rates of abrasive wear decreased with increasing size of Al_2O_3 for the composites containing the same amount of Al_2O_3. The graphite and copper were also used in the matrix in different amounts to study their effects on wear resistance. Finally, it was found that the wear rate of composite decreased with the addition of graphite.

Hashim et al. [17] focused on stirring action that must be efficient enough to disperse the particles in a homogeneous way. He noticed that if stirring takes place in a closed vessel or crucible, then efficiency cannot be seen; so to solve this problem, simulation methods are required to inform experimental research. He included finite element analysis in his research, and employing a specialized computational fluid dynamics package which was used to simulate the fluid flow, and thus dispersion of reinforcement material in a molten matrix alloy is seen during stirring. In this study, optimum stirring conditions were investigated in order to achieve effective flow patterns to disperse the solid particles in the melt, without breaking the surface layer of the melt. Simulation results showed that stirring speed and impeller position in the crucible have a significant effect on the flow behavior of the fluid. Further parameters interacted with various combinations generating suitable conditions for composite mixing. Despite of limitations arising from the simplification of the physical situation, the model was a useful tool in specifying process parameter in the production of MMCs.

SiC particles reinforced in aluminum alloy composites were also studied by Sahin [18]. In his study, AA2014/SiC AMCs were fabricated by liquid metallurgy route which showed an increase in hardness and porosity with increasing wt% of SiC.

Aldas et al. [19] investigated experimentally and theoretically the particle distribution in particulate MMC. Pb 20%, SiC reinforcement and Sn alloy were mechanically stirred and casted into a cylindrical mold filled with inert gas pressure. With sectioning and microscopic investigation techniques, particle distribution in the cast is determined at different locations. The authors found that particle fraction is decreased along the axis of the mold. The regions which closed the boundary wall are determined as the possible clustering areas.

Balasivanandha et al. [20] worked on effect of stirring speed and stirring time on distribution of particles in cast MMC. In this work, high silicon content of aluminum alloy–silicon carbide metal matrix composite material with 10% SiC was successfully synthesized by using different stirring speeds and stirring times. Optical microscope and scanning electron microscope were used to examine the microstructure of the produced composites. The Brinell hardness test was performed on the composite specimens from the base of the cast of the top. The results revealed that stirring speed and stirring time influenced the microstructure and the hardness of composite. Microstructure analysis revealed that the particle clustering was more at lower stirring speed with lower stirring time. The distribution of particles was better at higher stirring speed and stirring time. The hardness test results also revealed that stirring speed and stirring time had their effect on the hardness of the composite. The uniform hardness values were achieved at 600 rpm stirring speed with 10 minutes stirring time. But beyond certain stir speed, the properties degraded again.

Aigbidion and Hassan [21] studied about the effect of silicon carbide reinforcement on microstructure and properties of cast Al–Si–Fe/SiC particulate composites. AA/SiC AMCs manufactured by stir-casting process exposed a fall in percentage elongation and density with an increase in tensile strength, hardness and porosity.

Hassan et al. [22] investigate the influence of graphite and/or silicon carbide particle addition on the hardness and surface roughness of Al–4 wt% Mg alloy. Due to increased porosity in AA/Gr composite, there was a decrease in hardness with increase in wt% of graphite (Gr).

Akhlaghi and Bidaki [23] studied about the effect of graphite content on dry sliding and oil impregnated sliding wear behavior of Al2024-Gr composite which was produced by *in situ* powder metallurgy method. They reported that fracture toughness and hardness of composites decrease with increase in wt% of GR in Al2024/Gr composites fabricated by *in situ* powder metallurgy process.

Suresha and Sridhara [24] studied the dry sliding wear behaviour of Al matrix composites (AMCs) with 10 reinforcements of graphite (Gr) and (SiC) particulate. They noticed the effect of % reinforcement, sliding distance on stir-cast Al/SiC/Gr hybrid composites, load, sliding speed, and Al/Gr and Al/SiC composites. The authors concluded that wear of hybrid composites has capability to increase beyond reinforcement of 7.5%. From these values, it was clear that the hybrid composites exhibit better wear characteristics. Similarly, in Al/Gr composites, optimal % reinforcement was around 8.2%. But one drawback was found that in Al/SiC composites, wear continuously decreased with increased % reinforcement. If speed increases, wear is reduced and if load or sliding distance or both increase, then wear is reduced. Wear of all the composites is affected by the % reinforcement, load, sliding speed and sliding distance.

Kumar et al. [25] studied the experimental results of the mechanical and tribological properties of Al6061-SiC composites. The composites of Al6061 containing 2–6 wt% SiC were prepared using liquid metallurgy technique (stir-casting route). The experimental results showed that the density of the composites increased with increased SiC content. The hardness of Al6061/SiC composites was found to increase with increased SiC content in the matrix, but the ductility decreased. The ultimate tensile strength of the composites was also found to be higher than that of base matrix. The wear resistance of the composites containing SiC was higher than that of the matrix material. Overall, the authors concluded that Al6061–6 wt% SiC exhibited superior mechanical and tribological properties compared with Al6061, Al6061–2 wt% SiC and Al6061–4 wt% SiC composites.

Sharifi et al. [26] investigated the fabrication and characterization of bulk Al/B_4C nanocomposites. In their experiment, they mixed the nanoparticles of B_4C with a pure Al powder to produce Al/B_4C powder. For this purpose, they used the ball milling process. Al/B_4C powders containing different amount of B_4C (5, 10, and 15 wt%) was subsequently hot pressed to produce bulk nanocomposite samples. The average particle size of Al powder was about 60 μm. The sizes of B_4C nanoparticles were between 10 and 60 nm. Ball milling was executed at a rotation speed of 600 rpm and the ball–powder mass ratio of 10:1. Consolidated samples were characterized by hardness, compression and wear tests. Vickers indenter at the load of 100 g was used to determine the hardness of cross section of powders. X-ray diffractometry (XRD) was used to follow the structural changes of powders after milling and hot pressing. Friction and wear properties of the samples were determined by using a pin-on-disk wear test machine. On the basis of the tests, it was observed that the hardness of the sample increased as compared to the pure Al. The sample with 15 wt% B_4C had the optimum properties. This sample had a value of 164 HV which is significantly higher than 33 HV for pure Al. Also, by ultimate compressive increasing the B_4C content, the wear resistance of the nanocomposites also increased.

Kalaiselvan et al. [27] worked on the fabrication of Al (6061-T6) AMCs reinforced with various weight percentages of B_4C particulates by stir-casting method. K_2TiF_6 flux was added into the melt to improve the wettability of B_4C particles in the matrix. The microstructures and mechanical properties of the fabricated AMCs were analyzed. The optical microstructure and scanning electron microscope (SEM) images showed the homogeneous dispersion of B_4C particles in the matrix. The reinforcement dispersion has also been identified with XRD. The authors found that by increasing the weight percentage of B_4C particulates in the aluminum matrix, the mechanical properties like hardness and tensile strength can be improved.

Kumar et al. [28] studied on mechanical and dry sliding wear of Al6061-SiC composites. Silicon carbide (SiC), hard ceramic particles with extraordinary mechanical strength, is used as reinforcement in the development of AMCs. AA6061/SiC AMCs fabricated by liquid metallurgy process showed a rise in tensile strength, hardness, density with a reduction in ductility with increasing wt% of SiC.

Uthayakuma et al. [29] studied the dry sliding wear behavior of aluminum reinforcement with 5% B_4C hybrid composite using a pin-on-disc tribometer. Wear performance of the hybrid composites was evaluated over load ranges of 20–100 N, at the sliding velocities from 1 to 5 m/s. 1100 aluminum alloy has been chosen as matrix material and SiC and B_4C as reinforcements. The average particle size of the SiC (5 wt%) particles was 10 µm and of B_4C (5 wt%) was 65 µm. The authors used the focused ion beam (FIB) technique to characterize the tribo-layers that were formed at the worn surfaces of the composites. The authors concluded that the hybrid composites retain the wear resistance properties up to load of 60 N and sliding speed ranges 1–4 m/s. The enhancement of wear resistance with small amount of SiC and B_4C is achieved by the cooperating effect of reinforcement particles.

Prashant et al. [30] studied about preparation and evaluation of mechanical and wear properties of Al6061 reinforced with graphite particulate MMC. He described that AA6061/Gr AMCs manufactured by stir-casting process exposed a fall in hardness and density with an increase in tensile strength and porosity with increased wt% of reinforcement.

Kumar and Murugan [28] analyzed the metallurgical and mechanical properties of AMC (6061-T6) reinforced with aluminum nitride particles (AlNp). The MMC was prepared by the modified stir-casting method with bottom pouring arrangement in controlled argon environment. To increase the wettability of aluminum nitride particles with molten Al matrix, 2% Mg was also added. The composite was prepared with different weight percentages (viz. 0, 5, 10, and 20) of AlNp and analyzed their metallurgical and mechanical properties. They concluded that, with the addition of AlNp in the Al matrix, the properties like macro-hardness, micro-hardness, yield strength and ultimate tensile strength were improved, but the percentage elongation decreased.

Baradeswaran and Perumal [31] studied about the wear and mechanical characteristics of Al7075/graphite composites. They conveyed that tensile strength and hardness of AA7075/Gr AMCs fabricated by liquid casting technique decreased with increased wt% of graphite reinforcement.

ADVANTAGES AND DISADVANTAGES OF MMCs

Compared to monolithic metals, PMCs and CNCs, MMCs have higher strength-to-density ratio and stiffness-to-density ratios, improved fatigue resistance, and lower creep rate with good wear resistance and radiation resistance.

Some of the disadvantages of MMCs compared to monolithic metals, PMCs and CMCs are as follows: costly material system and technology is not that much good. Its fabrication methods for fiber-reinforced systems (accept the casting) are very complex service experience.

CONCLUSION

The performance advantages of MMC materials include their tailored mechanical, physical and thermal properties in light of their low density, high specific modulus, high strength, high thermal conductivity, good fatigue response, control of thermal expansion, high abrasion and wear resistance, etc. Some of the typical applications of MMCs include their use in fabrication of satellite, missile, helicopter structures, structural support, piston, sleeves and rims, high-temperature structures, drive shaft, brake rotors, connecting rods, engine block liners, various types of aerospace and automotive applications, etc. The superior mechanical properties of MMCs drive their use.

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