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A REVIEW PAPER ON STIR CASTING OF REINFORCED ALUMINUM METAL MATRIX COMPOSITE

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ABSTRACT

The importance of composites as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 200 are composites. These composites initially replaced Cast Iron and Bronze alloys but owing to their poor wear and seizure resistance, they were subjected to many experiments and the wear behavior of these composites were explored to a maximum extent and were reported by number of research scholars for the past 25 years. In the present study, based on the literature review, the effect of Silicon carbide on Stir cast Aluminium Metal Matrix Composites is discussed. Aluminium Metal Matrix Composites with Silicon carbide particle reinforcements are finding increased applications in aerospace, automobile, space, underwater, and transportation applications. This is mainly due to improved mechanical and tribological properties like strong, stiff, abrasion and impact resistant, and is not easily corroded. In the present scenario, a review of different researchers have been made to consolidate some of the aspects of mechanical and wear behavior of Aluminium Metal Matrix Composites reinforced with Silicon carbide particles in both untreated and precipitation hardened condition.

Keywords: Aluminium alloy, Metal Matrix Composites, Silicon Carbide, Stir casting, Precipitation hardening

I. INTRODUCTION

Aluminum is used widely as a structural material especially in the aerospace industry because of its light weight properties however the low strength and low melting point of aluminum were always a problem. A cheap method of solving these problems was to use a reinforced element such as SiC particles and whiskers (1). The ceramic particle additions make it possible to increase the specific elastic modulus of aluminum and improve aluminum thermal properties (2, 3). Using powder metallurgy (PM) method to produce aluminum composites reinforced with SiC particulates produce a homogenous distribution of reinforcement in the matrix. While other methods of production like casting and thixoforming have the problems of reinforcement segregation and clustering, interfacial chemical reactions, high localized residual porosity and poor interfacial bonding. The rest of the production methods such as spray deposition is very expensive which render its application (4). Powder metallurgy also has the advantage of producing net-shape components minimizing machining process which is a great problem in case of aluminum silicon carbide composite as a result of high tool wear due to the inherent abrasiveness of the hard SiC particles. Also the machining process causes cracking of SiC particles and debonded matrix-reinforcement underneath the machined ssurface (). However the aluminum silicon carbide composite produced by PM has a low strength relatively. This low strength is mainly due to the presence of an oxide layer surrounding the aluminum particle which prevents the welding of the particles during sintering process. This oxide film also prevents grain growth and movement of dislocations at the boundary or through them and produces high strength, brittle, and insensitivity to high temperature exposure composite. As a method to overcome this drawback the composite was extruded after sintering to break the oxide layer and produce welding between the aluminum particles. However this method eliminates the advantage of net shape products also the composite after extrusion shows a non-uniform distribution of the reinforcement in the matrix (6). In this work the problem of bad sintering of aluminum composite was solved by increasing the sintering temperature above the melting temperature of aluminum (660 Co). The high temperature sintering process cause the aluminum surrounded by the oxide layer in the particle to melt and expand in volume to rupture the oxide envelope surrounding it and makes contact with melted aluminum leaking from nearby particles and welding take place. The oxide layer broke into small shell fragments impeded in the aluminum matrix restricting the movement of dislocation and increase strength. The aluminum powder used has a high percentage of aluminum oxide Al_2O_3 in from of thick layer surrounding the particles. No canning: or degassing processes was used before mixing the powder to reduce cost. Seven different compositions were prepared and tested containing 0%, 5%, 10%, 15%, 20%, 25% and 30% weight percent silicon carbide respectively. Compression, microhardness and microstructure samples were prepared and examined from samples at the green state and samples that was sintered at temperatures of 650, 700, 750, 800, 850 and 900 C0 respectively.

Metal matrix composite (MMC) is engineered combination of the metal (Matrix) and hard particle/ceramic (Reinforcement) to get tailored properties. MMC’s are either in use or prototyping for the space shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and a variety of other applications. Like all composites, aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produces a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong, though brittle. Aluminium and silicon carbide, for example, have very different mechanical properties: Young's moduli of 70 and 400 GPa, coefficients of thermal expansion of 24 × 10-6 and 4 × 10-6/°C, and yield strengths of 35 and 600 MPa, respectively. By combining these materials, e.g. A6061/SiC/17p (T6 condition), an MMC with a Young's modulus of 96.6 GPa and a yield strength of 510 MPa can be produced [1]. By carefully controlling the relative amount and distribution of the ingredients of a composite as well as the processing conditions, these properties can be further improved. The correlation between tensile strength and indentation behavior in particle reinforced MMCs manufactured by powder metallurgy technique [2]. The microstructure of SiC reinforced aluminium alloys produced by molten metal method. It was shown that stability of SiC in the variety of manufacturing processes available for melt was found to be dependent on the matrix alloy involved [3].

Among discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production [4], and allows very large sized components to be fabricated. The cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth [5]. In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion.

The next step is the solidification of the melt containing suspended dispersoids under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including the difficulty of achieving a uniform distribution of the reinforcement material, wettability between the two main substances, porosity in the cast metal matrix composites, and chemical reactions between the reinforcement material and the matrix alloy. In order to achieve the optimum properties of the metal matrix composite, the distributionof the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. The literature review reveals that the major problem was to get homogenous dispersion of the ceramic particles by using low cost conventional equipment for commercial applications. In the present work, a modest attempt has been made to compare the dispersion of SiC particles in Al matrix fabricated with the help of different processes viz.

(a) without applying stirring process

(b) with manual stirring process

(c) a two-step mixing method of stir casting. An effort has been made to establish a relationship between hardness, impact strength and weight fraction of SiC in particle reinforced MMC’s developed with the help of two - step mixing method of stir casting technique.

1.1 Metal Matrix Composites

Metal matrix composites (MMCs) reinforced with ceramic or metallic particles are widely used due to their high specific modulus, strength and wear resistance. Furthermore, MMCs have been considered as an alternative to monolithic metallic materials or conventional alloys in a number of specialized applications [14]. In particular, aluminum matrix composites (AMCs) have been reported to possess higher wear resistance and lower friction coefficient with increasing volume fraction of reinforcement particles, compared to aluminum alloys without reinforcement.

Metal matrix composites are materials that have a metal or metal alloy as the matrix phase. The dispersed phase may be particulates, fibers, or whiskers that normally are stiffer, stronger, and/or harder than the matrix.

1.2 General Consideration

Three main types of MMCs can be classified according to these reinforcement; continuous-fiber, discontinuous-fiber, and particulate reinforced. Continuous-fiber reinforced MMCs possess higher stiffness and strength because of continuous filaments. . Many types of discontinuous and particulate reinforced MMCs have been produced. These materials have the engineering advantage of higher strength, greater stiffness, and better dimensional stability than the unreinforced metal alloys. Discontinuous-fiber reinforced MMCs are produced mainly by powder metallurgy and melt infiltration process. Whisker dispersion produces higher strength and stiffness than particulate ones. Nevertheless, the powder metallurgy processing and melt infiltration methods are more expensive.

1.3 What is a Composite?

As defined by Jartiz, [31] Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form.

Van Suchetelan [61] explains composite materials as heterogeneous materials consisting of two or more solid phases & the combination has its own distinctive properties.

1.4 Characteristics of MMCs

Metals are extremely versatile engineering materials. The broad use of metallic alloys in engineering shows not only their strength and toughness but also the relative simplicity and low cost of fabrication of engineering components by a wide range of manufacturing processes.

The necessity of achieving better properties that those obtained in monolithic metals has allowed the development of different kinds of MMCs. However, the cost of achieving appropriate improvements remains a challenge in many potential MMC applications.

One of the main problems is focused on ensuring the optimum degree of chemical contact (or wetting) between the fibers or reinforcements and the matrix. In many systems, wetting is inhibited by oxide films or surface chemistry features of the reinforcing phase.[69]

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the ‘reinforcement, whereas the continuous phase is termed as the ‘matrix’.

1.5 Classification of Composites

Composite materials can be classified in different ways [68]. Classification based on the geometry of a representative unit of reinforcement is convenient since it is the geometry of the reinforcement which is responsible for the mechanical properties and high performance of the composites. The two broad classes of composites are:

1.5.1 Based on Matrix Material

- Metal Matrix Composites (MMC)
- Polymer Matrix Composites (PMC)

1.5.2 Based on Reinforcing Material Structure

- **Particulate Composites**

Hard particles dispersed in a softer matrix increase wear and abrasion resistance.

Soft dispersed particles in a harder matrix improve machinability. Composites with high electrical conductivity matrices (copper, silver) and with refractory dispersed phase (tungsten, molybdenum) work in high temperature electrical applications.

When dispersed phase of these materials consists of two-dimensional flat platelets (flakes) which are laid parallel to each other, material exhibits anisotropy (dependence of the properties on the axis or plane along which they were measured

- **Fibrous Composites**

Dispersed phase in form of fibers (Fibrous Composites) improves strength, stiffness and Fracture Toughness of the material, impeding crack growth in the directions normal to the fiber.

Effect of the strength increase becomes much more significant when the fibers are arranged in a particular direction (preferred orientation) and a stress is applied along the same direction.

- **Laminate Composites**

Laminate composites consist of layers with different anisotropic orientations or of a matrix reinforced with a dispersed phase in form of sheets.

1.6 Why a Composite?

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications.

Unlike conventional materials (e.g., steel), the properties of the composite material can be designed considering the structural aspects. The design of a structural component using composites involves both material and structural design. Composite properties (e.g. stiffness, thermal expansion etc.) can be varied continuously over a broad range of values under the control of the designer. Whilst the use of composites will be a clear choice in many instances, material selection in others will depend on factors such as working lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience & skills the designer in tapping the optimum potential of composites.

1.7 Applications of MMCs

Aluminum Matrix Composites (MMC) are used for manufacturing automotive parts (pistons, pushrods, brake components), brake rotors for high speed trains, bicycles, golf clubs, electronic substrates, cores for high voltage electrical cables, aeronautical and aerospace components.

1.8 Aluminum Metal Matrix Composites (MMC)

This is the widest group of Metal Matrix Composites.

Matrices of Aluminum Matrix Composites are usually based on aluminum-silicon (Al-Si) alloys and on the alloys of 2xxx , 6xxx and 7xxx series.

1.9 Heat Treatable 2XXX Series Aluminum Alloys

Table 1: Standard Alloy Designation

Alloy series	Detail
1XXX	99% Pure Aluminium
2XXX	Cu containing alloy
3XXX	Mn containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Mg and Si containing alloy
7XXX	Zn containing alloy
8XXX	Other alloys

Copper is the principal alloying element, though other elements (Magnesium) may be specified. These alloys require solution heat treatment to obtain optimum properties; in the solution heat-treated condition, mechanical properties are similar to, and sometimes exceed, those of low-carbon steel. In some instances, precipitation heat treatment (aging) is employed to further increase mechanical properties. This treatment increases yield strength, with attendant loss in elongation; its effect on tensile strength is not as great. The alloys in the 2xxx series do not have as good corrosion resistance as most other aluminum alloys, and under certain conditions they may be subject tointergranular corrosion. Alloys in the 2xxx series are good when some strength at moderate temperatures is desired. These alloys have limited weldability, but some alloys in this series have superior machinability.

II. MATERIAL SELECTION

2.1 Matrix Material

One very crucial issue to consider in selection of the matrix alloy composition involves the natural dichotomy between wettability of the reinforcement and excessive reactivity with it [39]. Good load transfer from the matrix to the reinforcement depends on the existence of a strongly adherent interface. In turn, a strong interface requires adequate wetting of the reinforcement by the matrix. However, the attainments of wetting and aggressive reactivity are both favored by strong chemical bonding between the matrix and reinforcement. Adjusting the chemical composition to accomplish this delicate compromise is difficult as many subtleties are involved. To illustrate the complexity, several examples concerning alloying additions to aluminum matrix metal relative to Silicon carbide whiskers, Boron reinforced and Graphite reinforced aluminum composites and the effect of insidious impurities from various origins have been documented by numerous investigators [11,18].As a rule of alloying element addition, the added element should not form intermetallic compounds with the matrix elements and should not form highly stable compounds with the reinforcements. The best properties can be obtained in a composite system when the reinforcement whiskers or particulates and matrix are as physically and chemically compatible as possible. Special matrix alloy compositions, in conjunction with unique whisker coatings, have been devised to optimize the performance of certain metallic composites [14].

2.2 Why Al Matrix Selection?

Now a day's researchers all over the world are focusing mainly on aluminum [54] because of its unique combination of good corrosion resistance, low density and excellent mechanical properties. The unique thermal properties of aluminum composites such as metallic conductivity with coefficient of expansion that can be tailored down to zero, add to their prospects in aerospace and avionics. The choice of Silicon Carbide as the reinforcement in aluminum composite is primarily meant to use the composite in missile guidance system replacing certain beryllium components because structural performance is better without special handling in fabrication demanded by latter's toxicity [62]. Recently aluminum-lithium alloy has been attracting the attention of researches due to its good wettability characteristics [14].

2.3 Reinforcement

The selection of reinforcement depends on the type of reinforcement, its method of production and chemical compatibility with the matrix & the various aspects of the reinforcement materialsuch as Size,Shape,Surface morphology,Structural defects,Surface chemistry,Impurities.Even when a specific type has been selected, reinforcement inconsistency will persist because many of the aspect cited above in addition to contamination from processing equipment and feedstock may vary greatly [46,52].

Rohatgi and co-workers [1, 12, 42] have studied mica, alumina, silicon carbide, clay, zircon, and graphite as reinforcements in the production of composites. Numerous oxides, nitrides, borides and carbides were studied by Zedalis *et al.* as reinforcements for reinforcing high temperature discontinuously reinforced aluminum (HTDRA). It has been inferred from their studies that HTDRA containing TiC TiB2, B4C, Al2O3, SiC exhibit the highest values of specific stiffness.

It is proven that the ceramic particles are effective reinforcement materials in aluminum alloy to enhance the mechanical and other properties [13,36]. The reinforcement in MMCs are usually of ceramic materials, these reinforcements can be divided into two major groups, continuous and discontinuous. The MMCs produced by them are called continuously (fiber) reinforced composites and discontinuously reinforced composites.

2.4 Continuous fiber reinforcement

According to T.W.Chou *et al.* [67] the term fiber may be used for any material in an elongated form that has a minimum length to a maximum average transverse dimension of 10:1, a maximum cross sectional area of 5.1X10-4 cm2 and a maximum transverse dimension of 0.0254 cm. Continuous fibers in composites are usually called filaments, the main continuous fibers includes boron, graphite, alumina and silicon carbide.

The advantage of discontinuous fibers is that they can be shaped by any standard metallurgical processes such as forging, rolling, extrusion etc.

2.5 Short fibers

Short fibers are long compared to the critical length (lc = d Sf / Sm where d is the fiber diameter, Sf is the reinforcement strength and Sm is the matrix strength) and hence show high strength in composites, considering aligned fibers. Nevertheless, misoriented short fibers have been used with some success as AMC (Aluminum Matrix Composite) reinforcement [7,35]. Short fibers are still used mainly for refractory insulation purposes due to their low strength compared with others, but they are cheaper than fiber and whisker

2.6 Whiskers

Whiskers are characterized by their fibrous, single crystal structures, which have no crystalline defect. The relative freedom from discontinuous means that the yield strength of a whisker is close to the theoretical strength of the material.

Presently, silicon carbide whisker reinforcement is produced from rice husk, which is a low cost material. The physical characteristics of whiskers are responsible for different chemical reactivity with the matrix alloy [19].

2.7 Particulates

Particulates are the most common and cheapest reinforcement materials. These produce the isotropic property of MMCs, which shows a promising application in structural fields. Initially, attempts were made to produce reinforced Aluminum alloys with graphite powder [68], but only low volume fractions of reinforcement had been incorporated (<10%). Presently higher volume fractions of reinforcements have been achieved for various kinds of ceramic particles (oxide, carbide, nitride). The SiC particulate- reinforced aluminum matrix composites have a good potential for use as wear resistant materials. Actually, particulates lead to a favorable effect on properties such as hardness, wear resistance and compressive strength. The choice of reinforcement is not as arbitrary as this list of composites might suggest, but is dictated by several factors [14].

2.8 Aluminum Matrix Composites

Aluminum Matrix Composites (MMC) is reinforced by Alumina (Al_2O_3) or silicon carbide (SiC) particles (particulate Composites) in amounts 15-70 vol%; Continuous fibers of alumina, silicon carbide, Graphite (long-fiber reinforced composites); Discontinuous fibers of alumina (short-fiber reinforced composites);

Aluminum Matrix Composites are manufactured by the following fabrication methods:

1. Powder metallurgy(sintering);
2. Stir casting;
3. Infiltration.

The following properties are typical for Aluminum Matrix Composites:

- High strength even at elevated temperatures; High stiffness (modulus of elasticity);
- Low density; High thermal conductivity;
- Excellent abrasion resistance.

2.9 Mechanical Properties

MMCs [8] and the influence of the manufacturing route on the MMC properties has also been reviewed by several investigators [41, 43]. Improvement in modulus, strength, fatigue, creep and wear resistance has already been demonstrated for a variety of reinforcements [24, 48]. Of these properties; the tensile strength is the most convenient and widely quoted measurement and is of central importance in many applications

2.10 Microstructure

The most important aspects of the microstructure is the distribution of the reinforcing particles, and this depends on the processing and fabrication routes involved.

During subsequent pouring of the composite melt, the particle content may vary from one casting to another or even it can vary in the same casting from one region to another. Therefore uniform distribution of the particles in the melt is a necessary condition for uniform distribution of particles in the castings. The properties of composites are finally dependent on the distribution of the particles. Hence the study of the distribution of the particles in the composite is of great significance. Several investigators [52,62] have examined the fracture samples of different metal matrix composites; it was observed that the fracture occurred mainly through the matrix in a ductile manner.

III. PRODUCTION OF MMCs

Jasmi Hashim *et al.* (2007) [27] proposed modified stir casting method to remove various deficiencies of normal stir casting process. In a normal practice of stir casting technique, cast metal matrix composites (MMC) is produced by melting the matrix material in a vessel, then the molten metal is stirred thoroughly to form a vortex and the reinforcement particles are introduced through the side of the vortex formed. From some point of view this approach has disadvantages, mainly arising from the particle addition and the stirring methods. During particle addition there is undoubtedly local solidification of the melt induced by the particles, and this increase the viscosity of the slurry. A top addition method also will introduced air into the slurry which appears as air pockets between the particles.

Rajan *et al.* (2007) studied the effect of three different stir casting techniques on the structure and properties of fly ash particles reinforced Al-Si -Mg alloy composite. Among liquid metal stir casting, compo-casting (semi-solid processing), and modified compo- 32 casting followed by squeeze casting routes were evaluated. Modified compo casting resulted in a uniformly distributed and porosity-free fly ash particle-dispersed composites.

Jayaseelan *et al.* (2010) [63] compared the extrusion characteristics of Al-SiC produced by two methods namely powder metallurgy & stir casting. Stir cast specimens exhibited finer microstructure & high hardness as compared to specimens produced by powder metallurgy. They also possessed higher strength.

Alaneme & Aluko (2012) studied the double stir-casting method to cast the Al (6063) scrap billets and silicon carbide in order to produce 3, 6, 9 and 12 % by volume of SiC reinforcements in the composite. The Al (6063) billets were charged into the furnace and melting was done till a temperature of 750°C was attained. The melt was then allowed to cool to 600°C. They found that this stage, the silicon carbide and dehydrated borax mixture was added into the melt and mixture was stirred for about 20 minutes.

Gopalakrishnan & Murugan (2012) drew attention to production of Metal matrix composite (MMC) by enhanced stir-casting method for improved specific strength, high temperature and wear resistance application. Al-TiCp composite is having a good potential and the composite was produced in an argon atmosphere by using an enhanced stir-casting method. The specific strength of the composite increased with addition of higher % of TiC.

Naher *et al.* (2004) produced Al-SiC composites by using liquid and semi solid stir-casting technique.Stirring speed ranged from 200 to 500 rpm. 10% volumes of 30 micrometer diameter sized SiC particles were used. The main aim was to produce a uniform distribution of SiC in the aluminium matrix. Faster solidification, after ceasing of mixing improved the uniformity of the SiC distribution significantly.

Nabil Fat Halla *et al.* (1988) [45] compared the microstructure and mechanical properties of modified and non-modified stir-cast commercial aluminium alloys A-S7G03 and A-S4G. This stir-cast structure slightly improved the mechanical properties in comparison to those of conventionally cast alloys, however the fracture of the stir-cast alloys revealed intergranular brittle fracture. The addition of 0.02% strontium, in the form of AI-5 mass% Sr master alloy, during stir casting modified the eutectic silicon into a very fine spheroidal morphology, while the phase particle showed the same morphology as the stir-cast alloys. This novel structure resulted in significant improvement of mechanical properties. The elongation of the modified stir-cast alloys was five times greater than that of the non-modified one.

Among various manufacturing methods, *stir casting is one of the low cost and efficient method* to produce a composite. Among various surface finishing processes.

IV. STIR CASTING

The chosen four blade stirrer from the cold model study is connected to a 15 mm diameter hollow steel shaft. Inside the hollow shaft a rod of diameter 5 mm is concentrically placed The bottom end of the rod is attached to a tapered graphite plug. The mating hole is drilled in the crucible. Initially the shaft is placed at a level above the top surface of the crucible and the rod consisting plug closes the hole. After the Matrix material melts, the melt will be stirred at 500 rpm and then the reinforcement will be introduced in the vortex. The stirring is continued for about 3-4 min.

V. CONCLUSIONS

The literature survey shows that variety of work has been done to improve properties of Aluminum Metal Matrix Composites reinforced with particulate Silicon carbide .Also characterization of the produced MMCs presentedin the survey clearly shows the advantage of enhanced properties of these composites and that’s why newer and newer applications of these materials will come to fore in the future.

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