AN INVESTIGATION INTO ALUMINUM-BASED METAL MATRIX COMPOSITES

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ABSTRACT

Composite materials are widely used in Aerospace and Automotive domains since quite a long time now. The use of composites in aircrafts body, particularly, use of MMC has been increased due to their enhanced properties such as their low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and Ceramics. This review articles captures and presents the advantages of Aluminum based MMCs, their development and important properties using which new composites can be development through research. This article also gives the knowledge of the fabrication process used for MMCs.

Keywords: *Composites; MMC; Aluminum; Alloys.*

I. INTRODUCTION

In engineering designs, great interest is to search for new materials exhibiting good mechanical properties. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement [1]. For the development of such materials metal matrix composites (MMCs) have been proved to be one of the best selections for such materials. Metal matrix composites (MMCs), like all composites consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. The constituents are combined at a microscopic level and are not soluble in each other. The reinforcing material may in the form of the fibres, particles or flakes. The matrix phase materials are generally continuous. The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material [2]. Examples of composite system include concrete reinforcement with steel, epoxy reinforced with graphite fibers etc. By definition, MMCs are produced by means of processes other than conventional metal alloying. Like their polymer matrix counterparts, these composites are often produced by combining two pre-existing constituents. Aluminum Matrix Composites (AMC), Magnesium Matrix Composites, Titanium Matrix Composites, Copper Matrix Composites are some common types of MMC.

Matrix

The selection of suitable matrix alloys is mainly determined by the intended application of the composite materials. With the development of light metal composite materials that are mostly easy to process, conventional light metal alloys are applied as matrix materials. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. In structural applications, the matrix is usually a lighter metal such as Aluminum, Magnesium, or Titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt - nickel alloy matrices are common [3].

Reinforcement

The second phase is imbedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase. Many of common materials (metal alloys, doped Ceramics and Polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents [2]. The strength of the composite depends primarily on the amount, arrangement and type of fiber (or particle) reinforcement in the resin. Typically the higher the reinforcement content, the greater the strength. Reinforcing materials are strong with low densities while the matrix is usually a ductile, or tough, material. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material [3].

II. ALUMINUM MATRIX COMPOSITE

Aluminum is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It makes up about 8% by weight of the Earth's solid surface. Due to easy availability, High strength to weight ratio, easy machinability, durable, ductile and malleability Aluminum is the most widely used non-ferrous metal in 2005 was 31.9 million tonnes [4].

Aluminum Alloys

Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weld ability, and corrosion resistance. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminum is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminum alloys yield cost effective products due to its low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminum alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminum alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Aluminum alloys are classified as shown in Table 1 below.

Table 1: Uses of various Aluminum Alloys

Aluminum Alloy	*Common Use*
1050/1200	Food and Chemical Industry
2014	Airframes
5251/5052	Vehicle paneling, structures exposed to marine atmospheres, mine cages.
6063	Architectural extrusions (internal and external) window frames, irrigation pipes.
6061/6082	Stressed structural members, bridge cranes, roof trusses, beer barrels.
7075	Armored vehicles, military bridges motor cycle and bicycle frames.

Advantages of Aluminum Alloys

- Light weight, strong
- High service life
- Highly corrosion resistant
- Excellent heat and electricity conductor
- Ductile
- Recyclable

Aluminum Matrix Composites

Aluminum matrix composites (AMCs) have been widely studied since the 1920s and are now used in sporting goods, electronic packaging, armors and automotive industries. Aluminum is the most popular matrix for the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity [5]. They are usually reinforced by Al_2O_3, Sic, and carbon. As proposed by the American Aluminum Association the AMCs should be designated by their constituents: accepted designation of the matrix / abbreviation of the reinforcement’s designation/ arrangement and volume fraction in % with symbol of type (shape) of reinforcement. For example, an Aluminum alloy AA6061 reinforced by particulates of alumina, 22 % volume fraction, is designated as "AA6061/Al_2O_3/22p". Aluminum Matrix Composites are manufactured by one of the following fabrication methods, i.e., Powder metallurgy, Stir casting and Squeeze casting.

III. LITERATURE REVIEW

S. V. Prasad et al. [6] developed affordable Al MMCs, reinforced with SiC and Al_2O_3, that reduced the weight and increase the engine efficiency, and thereby reduced fuel consumption and vehicle emissions. Considerable reduction in wear and friction is achieved by use of these particulates. Furthermore, increased cylinder pressures (and therefore, higher engine performance) are possible because Al MMCs can withstand high mechanical and thermal loads, and reduce heat losses by permitting closer fit that can be achieved because of lower thermal expansion coefficient of Aluminum MMCs. G. B. Veeresh Kumar [7] examined the base matrix and the reinforcing phase were AA 6061, AA 7075 and particles of Al_2O_3 and SiC of size 20 μm. It is observed that the densities of composites are higher than that of their base matrix, further the density increases with increased percentage of filler content in the composites. It is observed that the tensile strength of the composites is higher than that of their base matrix also it can be observed that the increase in the filler content contributes in increasing the tensile strength of the composite. In microstructure studies it is observed that, the distributions of reinforcements in the respective matrix are fairly uniform. Sanjeev Kumar et al. [8] investigated the effects of Thermal Cycling on Cast Aluminum Composites Reinforced with Silicon Carbide and Fly Ash particles. During this investigation, dry fly ash was used with Aluminum reinforced with SiC and a composite was prepared using Liquid metal stir casting route with the reducing quantity of SiC. During the research, Thermal cycling was carried out on the samples prepared and effects on samples before and after thermal cycling were observed and found improvement. Vishal Sharma et al. [9] investigated the effect of Al- 4.5wt%Cu/ zircon sand/ SiC hybrid composite by stir casting route by controlling various casting parameters. The as-cast samples were observed under optical and scanning electron microscope. Micro structural observations of the as-cast hybrid composite, shows uniform distribution of reinforcement particles and also good interfacial bonding between the particles and the matrix. Micro hardness tester is employed to evaluate the interfacial bonding between the particles and the matrix by indenting the micro hardness indenter on the particle with the varying load (100 gm, 200 gm, and 300 gm) and time (10 sec, 15 sec, 20 sec and 25 sec). It has been concluded that by the variation in hardness at constant load varying time or at constant time varying load, the bond strength can be compared. G.B. Veeresh Kumar [7] this paper deals with the mechanical properties such as hardness, tensile strength and wear resistance etc. of Al6061-SiC and Al7075-Al_2O_3 composites. The composites are prepared using the liquid metallurgy technique, in which 2-6 wt. % of particulates was dispersed in the base matrix in steps of 2. The SiC and Al_2O_3 resulted in improving the hardness and density of their respective composites. Further, the increased %age of these reinforcements contributed in increased hardness and density of the composites. The microphotographs of the composites studied revealed the uniform distribution of the particles in the matrix system. The dispersed SiC in Al6061 alloy and Al_2O_3 in Al7075 alloy contributed in enhancing the tensile strength of the composites. The wear factor K obtained using computerized pin on disc wear tester with counter surface as EN31 steel disc (HRC60) and the composite pin as specimens, demonstrated the superior wear resistance property of the composites. Sanjeev Das et al. [10] observed the effect of alumina and Zircon sand particles of different size and amount have been incorporated in Al-4.5 wt% Cu alloy by stir casting route. It is basically a comparative study on abrasive wear behavior of aluminum metal matrix composite reinforced with alumina and zircon sand particles has been carried out. Microstructures of the composites in as-cast condition show uniform distribution of particles and reveal better bonding in the case of zircon particles reinforced composite compared to that in alumina particles reinforced composite also studied in this. Abrasive wear resistance of both the composites improves with the decrease in particle size. It is observed that the alumina particle reinforced composite shows relatively poor wear resistance property compared to zircon-reinforced composite.

IV. METAL PROPERTIES AFFECTING MMC

A. Tensile strength

Tensile properties dictate how the material will react to forces being applied in tension. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties. The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve [11].

True elastic limit is a very low value and is related to the motion of a few hundred dislocations. Micro strain measurements are required to detect strain on order of 2 x 10 -6 in/in.

Proportional limit is the highest stress at which stress is directly proportional to strain. It is obtained by observing the deviation from the straight-line portion of the stress-strain curve.

Elastic limit is the greatest stress the material can withstand without any measurable permanent strain remaining on the complete release of load. It is determined using a tedious incremental loading-unloading test procedure. With the sensitivity of strain measurements usually employed in engineering studies (10 - 4in/in), the elastic limit is greater than the proportional limit. With increasing sensitivity of strain measurement, the value of the elastic limit decreases until it eventually equals the true elastic limit determined from micro strain measurements.

Yield strength is the stress required to produce a small specified amount of plastic deformation. The yield strength obtained by an offset method is commonly used for engineering purposes because it avoids the practical difficulties of measuring the elastic limit or proportional limit [11].

Ultimate Tensile Strength

The ultimate tensile strength (UTS) or, more simply, the tensile strength, is the maximum engineering stress level reached in a tension test. The strength of a material is its ability to withstand external forces without breaking. In brittle materials, the UTS will at the end of the linear-elastic portion of the stress-strain curve or close to the elastic limit. In ductile materials, the UTS will be well outside of the elastic portion into the plastic portion of the stress-strain curve. On the stress-strain curve above, the UTS is the highest point where the line is momentarily flat. Since the UTS is based on the engineering stress, it is often not the same as the breaking strength. In ductile materials strain hardening occurs and the stress will continue to increase until fracture occurs, but the engineering stress-strain curve may show a decline in the stress level before fracture occurs. This is the result of engineering stress being based on the original cross-section area and not accounting for the necking that commonly occurs in the test specimen. The UTS may not be completely representative of the highest level of stress that a material can support, but the value is not typically used in the design of components anyway [11]. For ductile metals the current design practice is to use the yield strength for sizing static components. However, since the UTS is easy to determine and quite reproducible, it is useful for the purposes of specifying a material and for quality control purposes. On the other hand, for brittle materials the design of a component may be based on the tensile strength of the material.

Measures of Ductility (Elongation and Reduction of Area)

The ductility of a material is a measure of the extent to which a material will deform before fracture. The amount of ductility is an important factor when considering forming operations such as rolling and extrusion. It also provides an indication of how visible overload damage to a component might become before the component fractures. Ductility is also used a quality control measure to assess the level of impurities and proper processing of a material. The conventional measures of ductility are the engineering strain at fracture (usually called the elongation) and the reduction of area at fracture. Both of these properties are obtained by fitting the specimen back together after fracture and measuring the change in length and cross-sectional area. Elongation is the change in axial length divided by the original length of the specimen or portion of the specimen. Reduction of area is the change in cross-sectional area divided by the original cross-sectional area. This change is measured in the necked down region of the specimen. Like elongation, it is usually expressed as a percentage.

B. Hardness

Hardness is the resistance of a material to localized deformation. The term can apply to deformation from indentation, scratching, cutting or bending. In metals, ceramics and most polymers, the deformation considered is plastic deformation of the surface. For elastomers and some polymers, hardness is defined at the resistance to elastic deformation of the surface. The lack of a fundamental definition indicates that hardness is not be a basic property of a material, but rather a composite one with contributions from the yield strength, work hardening, true tensile strength, modulus, and others factors. Hardness measurements are widely used for the quality control of materials because they are quick and considered to be non-destructive tests when the marks or indentations produced by the test are in low stress areas. There are a large variety of methods used for determining the hardness of a substance.

C. Toughness

The ability of a metal to deform plastically and to absorb energy in the process before fracture is termed toughness. The emphasis of this definition should be placed on the ability to absorb energy before fracture. Recall that ductility is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough. The key to toughness is a good combination of strength and ductility. A material with high strength and high ductility will have more toughness than a material with low strength and high ductility. Therefore, one way to measure toughness is by calculating the area under the stress strain curve from a tensile test. This value is simply called “material toughness” and it has units of energy per volume. Material toughness equates to a slow absorption of energy by the material. There are several variables that have a profound influence on the toughness of a material. These variables are Strain rate (rate of loading), Temperature, Notch effect. A metal may possess satisfactory toughness under static loads but may fail under dynamic loads or impact. As a rule ductility and, therefore, toughness decrease as the rate of loading increases. Temperature is the second variable to have a major influence on its toughness. As temperature is lowered, the ductility and toughness also decrease. The third variable is termed notch effect, has to do with the distribution of stress [2].

D. Wear resistance

Wear occurs as a natural consequence when two surfaces with a relative motion interact with each other. Wear may be defined as the progressive loss of material from contacting surfaces in relative motion. We know that one third of our global energy consumption is consumed wastefully in friction. Wear causes an enormous annual expenditure by industry and consumers. Most of this is replacing or repairing equipment that has worn to the extent that it no longer performs a useful function. For many machine components this occurs after a very small percentage of the total volume has been worn away.

E. Corrosive Resistance

Corrosion is a slow, progressive or rapid deterioration of a metal's properties such as its appearance, its surface aspect, or its mechanical properties under the influence of the surrounding environment: atmosphere, water, sea water, various solutions, organic environments, etc. In the past, the term "oxidation" was frequently used to designate what is now a day's commonly called "corrosion". Nevertheless, the former was the right word because corrosion also is an electrochemical reaction during which the metal is oxidized, which usually implies its transformation into an oxide, i.e. into the state in which it existed in the mineral [12].

V. FABRICATION PROCESS

Accordingly to the temperature of the metallic matrix during processing the fabrication of MMCs can be classified into three categories:

- Liquid phase processes,
- Solid state processes, and
- Two phase (solid - liquid) processes

Liquid Metal Techniques

Liquid state fabrication of Metal Matrix Composites 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 particles (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 [13].

Stir Casting Method of Fabrication of MMC

Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies [13].

Stir Casting is characterized by the following features:-

- Content of dispersed phase is limited (usually not more than 30 vol. %).
- Distribution of dispersed phase throughout the matrix is not perfectly homogeneous
- There are local clouds (clusters) of the dispersed particles (fibers).
- There may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrix phase.
- The technology is relatively simple and low cost [28].

VI. CONCLUSION

The current paper shows the importance of blending of Aluminum alloys in metal matrix composites. The paper discusses about the properties affecting the performance of Aluminum Matrix Composites. Also, the AMC can be easily synthesized by using Stir Casting Method. With the addition of Aluminum as reinforcement, the toughness, hardness, strength, corrosive and wear resistance of the composite can be increased easily.

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