International Journal of Engineering Technology and Applied Science

(ISSN: 2395 3853), Vol. 3 Issue 4 April 2017

Survey on Microstructure and properties of Ti6Al4V in situ titanium matrix composite

[1]Lokesh Choudhary, [2]Dr. S. S. Chouhan, [3]Ranjeet Kumar
[1]M-Tech Scholar, [2]Director, [3]Professor
[123]Department of Mechanical Engineering, VITS, Bhopal, India

Abstract- Aluminum matrix composites have been emerged as advanced materials that are well suited in automotive, space, aircraft, defense, and in other engineering sectors. Aluminum and its alloys occupy third place among the commercially used engineering materials. Use of aluminum in transport sector has increased from just 6% in 1950 to 28% in year 2010. Consumption of Aluminum casting has increased from 85,000 ton in 1995 to 180,000 ton in year 2010. Among the prime materials currently available to meet the challenges of modern airframe design is aluminum, which has a proven 70-year record of continuous improvement and cost effectiveness. The enormous amount of research and development (R&D) that has gone into Al-based MMCs of every possible alloy with different dispersoids establishing beyond doubt the usefulness of making composites but a choice has to be made with both the base alloy selection and dispersoid size and volume percentage for making engineering components. By suitable choice of the metal matrix and the reinforcement phase, a wide range of property combinations can be obtained. Particle reinforced metal matrix composites (PRMMCs) have become very promising materials due to their significant advantages over conventional materials such as high specific modulus, improved resistance to wear, improved resistance to high cycle fatigue and fatigue crack threshold, higher stiffness-to-weight ratio, low coefficient of thermal expansion and high thermal conductivity. The type, size, shape and relative proportion of the dispersoid govern the mechanical properties of metal matrix composites.

Keywords: Aluminum alloys, Particulate reinforcement, Metal Matrix Composites, Processing.

I. INTRODUCTION

A composite is a material that consists of constituents produced via a physical combination of pre-existing ingredient materials to obtain a new material with unique properties when compared to the monolithic material properties. A composite is a material made with several different constituents intimately bonded. The reinforcement may be in the form of whiskers, particles, plates, rods, etc. The matrix may be metallic, resinous, ceramic or organic. The constituents of a composite do not dissolve or merge completely into each other but act in concert. This yields endless possibilities with infinite combinations, hence making it an 'evergreen' field of study [1]. Now a days the particulate reinforced Aluminum matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components. Cast Aluminum matrix particle reinforced composites have higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys. In composite materials, controlled distribution of one or more reinforcement materials in a continuous metal matrix phase is possible [2-5]. Particle-reinforced metal matrix composites (MMCs) can be manufactured and formed by conventional metal methods. Several researchers have developed methods to describe the strength of particle-reinforced MMCs. The strength of a particle-reinforced MMC is found to be related to the volume fraction and diameter of the particles from the micromechanics approach. The yield strength of particle-reinforced MMCs is much higher than the result predicted by continuum mechanics theories. This incremental increase of the yield strength is due to the much higher dislocation density and smaller sub grain size in the matrix than in the unreinforced alloy with hard particles dispersed in a relatively ductile matrix [6]. Particle reinforced metal matrix composites (PRMMCs) offer relatively isotropic properties compared to short fiber or whisker reinforced counterparts and ability to be formed using conventional metal manufacturing processes such as rolling, forging and extrusion to produce the finished product with low cost . Their mechanical properties, i.e. tensile, hardness and fatigue, depend on some micro-structural parameters such as reinforcement particle distribution, size, volume fraction and orientation [7]. Al and its alloys have been reinforced with hard ceramic reinforcements such as graphite, Si_3N_4, SiC, TiN, BN, MgO and Al_2O_3. Among the different sizes of particulates, only micro and nano-size particulates reinforced in Aluminum based composites has shown their potential superiority by simultaneously improving both the specific mechanical properties and ductility of Aluminum composites at a much reduced amount of reinforcement material [8-10]. The distribution of reinforcement particles and the interfacial reaction between the metal matrix and the reinforcement highly depends on the processing methodology. It is known that the reaction between the matrix and particles is minimized by using solid state processing, i.e. powder metallurgy route. In liquid metallurgy methods, the wetability of the reinforcement particles by molten metal is improved by applying high pressures during casting and also by using some alloying elements as wetting agents.

II. CLASSIFICATION OF COMPOSITES

Based on matrix material, composites are classified into three categories.

Polymer matrix composites (PMCs): polymer matrix also known as FRP- Fiber Reinforced polymers (or plastics). These materials use a polymer based resin as the matrix, and a variety of fibers such as glass, carbon and aramid as the reinforcement.

Metal matrix composites (MMCs): Metal matrix composites are increasingly found its application in the aerospace and automotive industry. These materials use a metal such as Aluminum, magnesium, titanium and copper as the matrix and reinforce it with fibers, particulates or whiskers such as silicon carbide, TiC, B4C and TiO2. Mostly metals are of medium to high density. They have good thermal stability and can be made corrosion resistance by alloying.

Ceramic matrix composites (CMCs): ceramic matrix composites are used in very high temperature environments. These materials use a ceramic as the matrix and reinforce it with short fibers, or whiskers such as those made from silicon carbide and boron nitride. These have great thermal stability and other forms of attack. They are very rigid but mostly brittle and can only be shaped with difficulty.

III. TYPES OF ALUMINUM ALLOYS

Pure Aluminum is relatively soft. To overcome this, the metal can be alloyed with other metals (alloying elements). Most of the Aluminum reaching the market place has been alloyed with at least one other element. There is a long-established international system for identifying Aluminum alloys. The first digit in the four-digit alloy code identifies the major alloying element. Based on the type of alloying element, the Aluminum alloys are divided into 8 groups.

1xxx Series: Contains no alloying elements. The proportion of Aluminum is 99.3 – 99.9% and the rest is formed by tiny impurities. The combination of material properties, especially superior conductivity makes these alloys suitable for applications mainly in electrical and heat-power industry. Materials of this series are considered non-hardenable alloys and have tensile strengths of 40 – 60 MPa.

2xxx Series: the alloying element is copper. Alloys of this series are high strength alloys. The strength is achieved by the heat treatment process. The tensile strength is about 400 MPa on completion of hardening. Alloys of this series are considered not suitable for surface treatments and poor for welding.

3xxx Series: The alloying element is manganese. Alloys of this series are moderate in strength, they have good formability and they are suitable for anodizing and welding.

4xxx Series: The alloying element is silicon.

5xxx Series: The alloying element is magnesium. Alloys of this series are moderate in strength (200–350 MPa). Alloys of this series have excellent resistance to corrosion in aggressive atmosphere and seawater.

6xxx Series: The alloying elements are magnesium and silicon. Alloys of this series are moderate in strength (200 – 350 MPa). The strength is achieved by the heat treatment processing or forming. Alloys of 6xxx series can be easily anodized and high corrosion resistance.

7xxx Series: The alloying element is zinc. Alloys of this series have the highest strength among all series. The tensile strengths ranging between 450– 500 MPa may exceed 600 MPa in some cases. These alloys are prone to stress corrosion, especially when welded.

8xxx Series: The alloying element is other than for the other series (including lithium).

IV. PARTICULATE REINFORCEMENTS

The introduction of the reinforcement plays a key role in both the mechanical and thermal ageing behavior of the composite material. The role of the reinforcement is crucial in the micro deformation behavior. Incorporation of hard second phase particles in the alloy matrices to produce MMCs has also been reported to be more beneficial and economical due to its high specific strength and corrosion resistance properties. SiC, TiC, TaC, WC, B4C are the most commonly used particulates to reinforce in the metal or in the alloy matrix or in the matrices like Aluminum or magnesium. A major and potential problem of particle-reinforced composites is a non-uniform microstructure, often resulting from the manufacturing process, which can lead to the presence of clusters of particles, or regions without reinforcement. This intrinsic material in homogeneity can give a wide scatter in strength and ductility, wear resistance, fracture toughness and also in the fatigue behavior [11]. There are essentially two types of particle reinforced composites, large particle reinforced and small particle reinforced composites. It is not strictly the physical dimensions of the particles by which the materials are classified; rather it is the mechanism of reinforcement. In a small particle reinforced material the mechanism is on a molecular level and the particles may be dispersed into or precipitated from the matrix. Large particle reinforcement, as the name suggests, involves larger particles and a distribution of the load between phases. Whatever their geometry the particles are small relative to the size of the structure and evenly distributed through it. The particles may improve the fracture strength of the composite over that of the matrix by preventing or impeding crack propagation through the matrix, either physically blocking and stopping cracks or diverting and splitting them so as to hamper their progression across the piece. They may also improve the stiffness and strength of the composite over that of the matrix, by carrying a proportion of the load.

V. PROCESSING OF METAL MATRIX COMPOSITES

In general the most common manufacturing MMC technologies are divided primarily into two main parts: primary and the secondary. The primary processing is the composite production by combining ingredient materials (powdered metal and loose ceramic particles, or molten metal and fiber performs), but not necessarily to final shape or final microstructure and the secondary processing is the step which obviously follows primary processing, and its aim is to alter the shape and microstructure of the material (shape casting, forging, extrusion, heat treatment, machining). Secondary processing can change the constituents (phase, shape) of the composite. So, MMCs can be made by different ways.

Powder Metallurgy

The powder metallurgy is one of the popular solid state methods used in production of metal matrix composites. Powder processing methods in conjunction with deformation processing are used to fabricate particulate or short fiber reinforced composites. This typically involves cold pressing and sintering, or hot pressing to fabricate primarily particle or whisker reinforced MMCs [12]. The matrix and the reinforcement powders are blended to produce a homogeneous distribution; it is usually used for high melting point matrices and avoids segregation effects and brittle reaction product formation prone to occur in liquid state processes. This method permits to obtain discontinuously particle reinforced AMCs with the highest mechanical properties. These AMCs are used for military applications but remain limited for large scale production.

Powder metallurgy process is mainly consists of three phases. The first phase gives the preparation of the powder that is the constituents of the mixture and it follows the successive stages, In the second phase the powder products are mixed together with the reinforcement , The third process is the process of consolidation, during which the powders of worked mixture are welded together by sintering to form final product. Ceramics or other particles and then compacted in the desired forms.

Diffusion Bonding

Diffusion bonding is a common solid-state processing technique for joining similar or dissimilar metals. Inter diffusion of atoms between clean metallic surfaces, in contact at an elevated temperature, leads to bonding. The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction. Among the disadvantages are long processing times, high processing temperatures and pressures (which makes the process expensive), and a limitation on the complexity of shapes that can be produced. There are many variants of the basic diffusion bonding process, although all of them involve simultaneous application of pressure and high temperature.

Stir Casting

The simplest and most commercially used technique is known as 'vortex technique' or 'stir casting technique' it is attractive because of simplicity, low cost of processing, flexibility, most economical for large sized components to be prepared as well as production of near net shaped components. The vortex technique involves the introduction of pretreated ceramic particles into the vertex of molten alloy created by the rotating impeller. Figure 1 shows the stir casting set up.

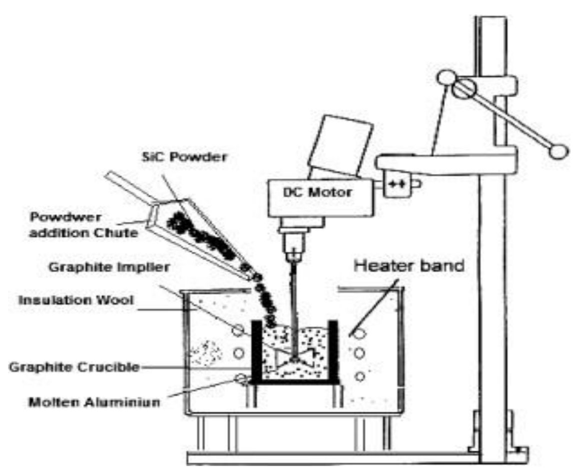

Figure 1 Stir casting method

An interesting recent development in stir casting is a two-step mixing process. In this process, the matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. This two-step mixing process has been used in the fabrication of aluminum. Among all the well-established metal matrix composite fabrication methods, stir casting is the most economical. For that reason, stir casting is currently the most popular commercial method of producing aluminum based composites [13].

Squeeze Casting

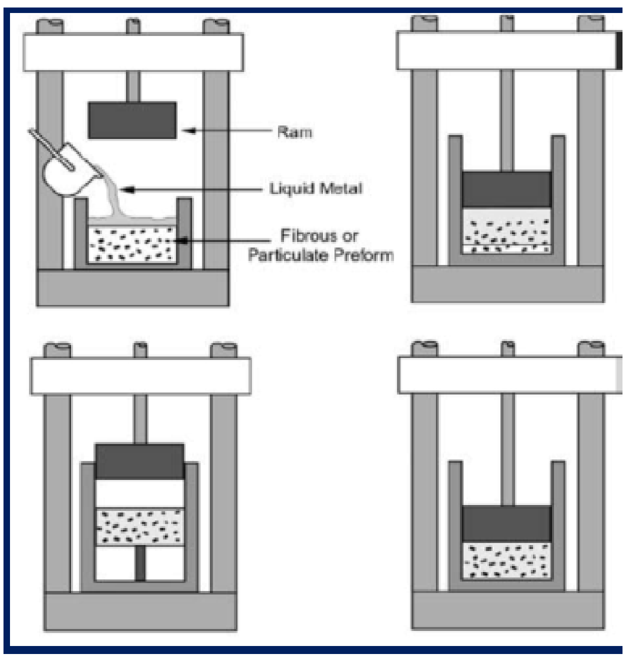

Figure 2: Squeeze casting or pressure infiltration process

Squeeze casting is also known as liquid metal forging, is a combination of casting and forging process (figure 2). The molten metal is poured into the bottom half of the pre-heated die. As the metal starts solidifying, the upper half closes the die and applies pressure during the solidification process. The amount of pressure thus applied is significantly less than used in forging, and parts of great detail can be produced. Coring can be used with this process to form holes and recesses. The porosity is low and the mechanical properties are improved. Both ferrous and non-ferrous materials can be produced using this method.

Compo-casting

Compo-casting is a liquid state process in which the reinforcement particles are added to a solidifying melt while being vigorously agitated. It has been shown that the primary solid particles already formed in the semi-solid slurry can mechanically entrap the reinforcing particles, prevent their gravity segregation and reduce their agglomeration [14]. These will result in better distribution of the reinforcement particles. The lower porosity observed in the castings has been attributed to the better wettability between the matrix and the reinforcement particles as well as the lower volume shrinkage of the matrix alloy.

VI. APPLICATIONS

Among the various types of MMCs, Aluminum based composites have found in various engineering applications such as for cylinder block liners, vehicle drive shafts, automotive pistons, bicycle frames, etc. Hard particles such as B4C, Al2O3 and SiC are commonly used as reinforcement phases in the composites [15-16]. The applications of particle reinforced aluminum alloy matrix composites are gradually increasing for pistons, cylinder heads, connecting rods etc. The first high volume application is the successful Aluminum Toyota-piston ring, reinforced with short Saffil fibers and produced by squeeze casting. New generation advanced integrated circuits are generating more heat than previous types. Thermal fatigue may occur due to a small mismatch of the coefficient of thermal expansion between the silicon substrate and the heat sink (normally molybdenum). This problem can be solved by using MMCs with exactly matching coefficients (e.g. Al with boron or graphite fibers and Al with SiC particles). The already well known advantages of Al-based composites are leading to several applications in various leisure and sporting goods. Typical applications are fishing rods, tennis and squash rackets, bicycle frames, golf club heads. The inherent high damping properties of most MMCs are also useful in damping out vibrations in the space satellite during launch procedures. Glass reinforced plastics are used in many automotive applications including body panels, bumpers, dashboards, and intake manifolds [17]. Brakes are made of particulate composite composed of carbon or ceramics particulates. Cermets contain hard ceramic particles dispersed in a metallic matrix. Examples; tungsten carbide or titanium carbide embedded cobalt or nickel used to make cutting tools.

REFERENCES

[1] Mohamed A. Taha, “Practicalization of cast metal matrix composites (MMCCs)”, Materials and Design, 22 (2001), 431-441.

[2] Bekir Sadık Unlu, “Investigation of tribological and mechanical properties Al2O3–SiC reinforced Al composites manufactured by casting or P/M method”, Materials and Design, 29 (2008), 2002–2008.

[3] Ahmet Hascalik and Nuri Orhan, “Effect of particle size on the friction welding of Al2O3 reinforced 6061Al alloy composite and SAE 1020 steel”, Materials and Design, 28 (2007), 313–317.

[4] Fevzi Bedir, “Characteristic properties of Al–Cu–SiCp and Al–Cu–B4Cp composites produced by hot pressing method under nitrogen atmosphere”, Materials and Design, 28 (2007), 1238–1244.

[5] Halil Arik, “Effect of mechanical alloying process on mechanical properties of a-Si3N4 reinforced aluminum-based composite materials”, Materials and Design, 29 (2008), 1856–1861.

[6] Hideki Sekine and Rong Chent, “A combined microstructure strengthening analysis of SiCp/Al metal matrix composites”, Composites, 26 (1995) 183- 188.

[7] Recep Ekici , M. Kemal Apalak , Mustafa Yıldırım , Fehmi Nair, “Effects of random particle dispersion and size on the indentation behavior of SiC particle reinforced metal matrix composites”, Materials and Design, 31 (2010) , 2818–2833.

[8] D.K. Dwivedi, “Adhesive wear behaviour of cast Aluminum–silicon alloys: Overview”, Materials and Design, 31 (2010), 2517–2531.

[9] Madeva Nagaral, V Auradi, S. A. Kori, “Dry sliding wear behavior of graphite particulate reinforced Al6061 alloy composite materials”, Applied Mechanics and Materials, 592-594 (2014), 170-174.

[10] S.M. Seyed Reihani, “Processing of squeeze cast Al6061–30vol% SiC composites and their characterization”, Materials and Design, 27 (2006), 216–222.

[11] Rasit Koker, Necat Altinkok, Adem Demir, “Neural network based prediction of mechanical properties of particulate reinforced metal matrix composites using various training algorithms”, Materials and Design, 28 (2007), 616–627.

[12] C. Santosa, S. Ribeiro, K. Strecker, D. Rodrigues Jr. , C.R.M. Silva, “Highly dense Si3N4 crucibles used for Al casting: An investigation of the aluminum–ceramic interface at high temperatures”, Journal of Materials Processing Technology, 184 (2007), 108–114.

[13] B. Abbasipour, B. niroumand, S. M. Monir, “Compo-casting of A356-CNT composite”, Trans. Nonferrous Met. Soc. China, 20(2010), 1561−1566.

[14] Rupa Dasgupta, “Aluminum alloy-based metal matrix composites: A potential material for wear resistant applications”, International Scholarly Research Network ISRN Metallurgy Volume 2012, Article ID 594573, 14 pages doi:10.5402/2012/594573.

[15] G. G. Sozhamannan, S. Balasivanandha Prabu, V. S. K. Venkatagalapathy, “Effect of Processing Parameters on Metal Matrix Composites: Stir Casting Process”, Journal of Surface Engineered Materials and Advanced Technology, 2012, 2, 11-15.

[16] Madeva Nagaral, Bharath V and V Auradi, “Effect of Al2O3 particles on mechanical and wear properties of 6061Al alloy metal matrix composites”, Journal of Material Science and Engineering, 2013, 2:1, doi:10.4172/2169-0022.1000120.

[17] D. Brabazon, D.J. Browne, A.J. Carr, “Mechanical stir casting of Aluminum alloys from the mushy state: process, microstructure and mechanical properties”, Materials Science and Engineering A, 326 (2002), 370- 381.