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REVIEW ARTICLE

FABRICATION OF METAL MATRIX COMPOSITES: A REVIEW

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ABSTRACT

Traditional Metal Matrix Composites on micron scale offer opportunities to tailor material properties such as hardness, tensile strength, ductility, density, electrical and thermal resistance, wear strength. After the advancement of nanotechnology, it was applied on traditional metal matrix composites and with this vision, MMC on Nano-scale has overcome all the limitations of traditional MMC. For example Carbon Nanotubes exhibit ultrahigh strength and modulus. In the past decades many research work has done in polymer matrix Nano-composites and have various applications. Metallic composites having nanoparticles can offer excellent properties over polymeric composites due to its inherent temperature stability, high wear resistance, high strength, high modulus, high thermal and electrical conductivity. MMC has great potential of application in every field but there use is very limited due to their high cost and difficulties in fabrication. The major issue of concern withthe fabrication of MMC consistsin the low wettability of the reinforcement phase by the molten metal and that's why they cannot fabricate by conventional casting method. Although many alternatives techniques have been developed for the production of MMC. In this paper we will review the various important methods of fabrication of Metal Matrix Composites.

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INTRODUCTION

Nanocomposites are composites in which at least one of the phases shows dimensions in the nanometre range (1nm = 10^{-9} m) (Roy, 1986). Nano-composites is high performance material which exhibits extra ordinary property combination and unique design possibilities. Nano composites are materials that incorporate Nano size particles is a drastic improvement in properties that can include mechanical and electrical or thermal conductivity. The effectiveness of the nanoparticles is such that the amount of materials added is normally only between 0.5 and 5% by weight. The general understanding of these properties is yet to be reached (Schmidt, 2002), even though the first inference on them was reported as early as 1992 (Gleiter, 1992). As in the case of Nano-composites materials can be classified, according to their matrix materials, in three different categories:

- Ceramic matrix Nano-composite
- Metal matrix Nano-composite
- Polymer matrix Nano-composite

Metal Matrix Nano-composite

In the past few years many tremendous work has done in the field of Polymer matrix composites and there are lots of field of application of these polymeric matrix but it has limited properties. After few years metallic matrix has been introduced and this composite material has overcome all the limitation of polymeric matrix composites such as high temperature stability, high tensile strength, electrical and thermal conductivity, high wear resistance. Due to their distinct and excellent properties,it has wide potential application in each field of science. In a material world it brings a new opportunities and opened a new world in the field of research. Metal matrix Nano-composite is also known as reinforce matrix composites. Basically Metal matrix composites consists two components: first is metal and the second one is reinforcement. In all cases the matrix is defined as the metal but pure metal is rarely used so generally in this type of composites materials alloy is used. Some classes of MMC's, like ceramics, diamond tools and hard metals, have different and extensive and, even if they can be considered as traditional materials, they are in continuous evaluation (Rosso, 1997; Ugues, 2001; Ugues, 2002 and Actis Grande, 2002). Metal matrix Nano-composites has studied from many years and that's why it has wide potential application in the aerospace engineering for airframe and spacecraft components.More recently automotive, electronics and recreation industries have been working diffusively with these composites (Mars, 2000). Metal matrix composites have been divided into five major categories:

- Continuous Fiber

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- Discontinuous Fiber
- Whisker
- Wires
- Particulate

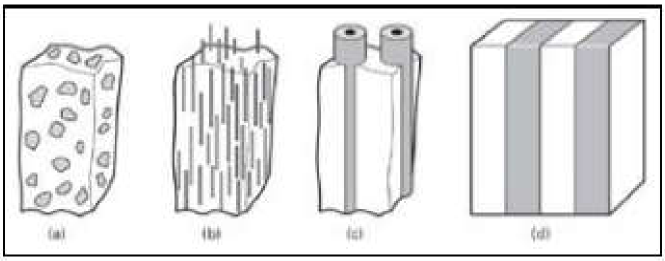

Fig. 1. Types of metal matrix composites

Basically two metals used in metal matrix composites Al and Ti. These metals have varieties in alloy forms and moreover they have less specific gravity comparatively to other metals. The particle reinforced Aluminum matrix composites are widely used in aerospace (Mars, 2000), military (Ibrahim, 1991), automotive industries (Chin, 1999), because of their properties such as high ratio of strength/density, improved elastic modulus, high wear resistance, high thermal conductivity, excellent corrosion resistance (Mars, 2000; Ibrahim, 1991 and Chin, 1999). Al_2O_3 particles are the most commonly used in reinforcement in Al matrix composites and additional of this reinforcement to aluminum alloy has been subject of several research (Mars, 2000; Prasad, 2004 and Kok, 2005). Inspite of all of these advantages of MMC, its uses is still very limited due to the issues with the fabrication of these composites. Basically Ti-based MMC is used where performance is more important than cost. This is where one can obtains high temperature performance unattainable with conventional materials (Ozden, 2007). These kind of Nano-composites cannot be fabricate by regular casting method so there are many alternatives has proposed for the fabrication of MMC.

Fabrication methods of MMC

MMCs has superior properties amongst all the metals and composites but their fabrication rate is too much limited because of its low wettability and because of this these composites cannot be fabricate by regular casting. Due to the increased use of metal matrix composites and in order to reduce the production costs, different fabrication techniques have been developed during the last few years (Mars, 2000; Prasad, 2004 and Schwartz, 1997). Thus Some important methods of fabrication will be described in this paper. These processes are classified on the basis of temperature of the metallic matrix during processing (Kamat, 1983). These process are classified into five different Categories:

- Liquid phase process
- Solid-liquid process
- Deposition technique
- In situ process
- Two phase(solid-liquid) Process

Liquid state fabrication of Metal matrix composites

In liquid state method dispersed phase is mixed with molten metal matrix metal by its solidification. In this process selection of ceramic reinforcement according to metal alloy should be done very carefully. . In addition to compatibility with the matrix, the selection criteria for a ceramic reinforcement includes the following factors (Ramu, 2009): (a) elastic modulus, (b) tensile strength, (c) density, (d) melting temperature, (e) thermal stability, (f) size and shape of the reinforcing particle, (g) coefficient of thermal expansion, and (h) cost. To get excellent mechanical properties and good interfacial bonding (wetting) between dispersed phase and the liquid, matrix should be obtain. Moreover for increasing wettability we can coat the dispersed phase (fibers, ceramic particles). Further liquid state method can be performed by various method I.e. Stir casting, Infiltration like gas pressure infiltration, Squeeze casting infiltration or Pressure die infiltration. The liquid-phase processes have reached an advanced stage of development and fine ceramic particulates of silicon carbide or aluminum oxide are added to a variety of aluminum alloy matrices (RACK, 1988; CROWE, 1985; NAIR, 1985; Duralcan Metal-Matrix Composites, 1989).

Stir casting

It is a liquid state fabrication method of metal matrix Nano-composites. In this method dispersed phase ceramic particles, fibers) is mixed with molten metal by means of mechanical stirring. Melt size as large as 6.8 metric tons are commercially available (see the entry of Alcan of 5 of (Mehrabian, 1988), supporting an annual production capacity of 30,000 metric tons (Evans, 2003) sStir casting method is a one of the most promising and cost effective. After this method liquid composites material can be cast by conventional casting method.

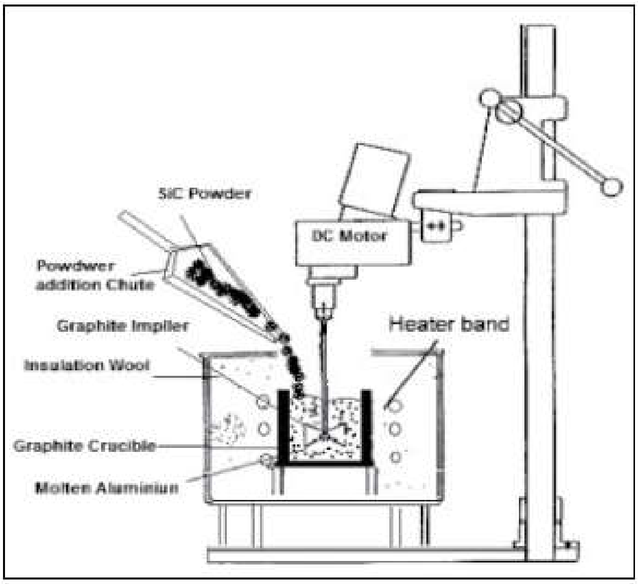

Fig. 2. Stir casting

Infiltration

It is also a liquid state fabrication method of metal matrix composites. In this process preformed dispersed phase particles react with the molten metal, which is used to fill the space between the dispersed phase inclusions. In infiltration process the motive force can be either capillary force of the dispersed phase (spontaneous infiltration) or an external pressure (gaseous, mechanical, electromagnetic, centrifugal or ultrasonic) applied to the liquid matrix phase (forced infiltration). There are number of infiltration methods have been developed i.e. gas pressure infiltration, CVD-infiltration, and ultrasonic infiltration methods. Among these methods, the ultrasonic infiltration is the simplest method to fabricate the CF/Al wires (Rittner, 2000 and Yang, 1993).

Gas pressure infiltration

It is forced infiltration method of liquid state fabrication of metal matrix composites. In this type of infiltration method we use high pressure gas to apply pressure on the molten metal and force it to penetrate into preformed dispersed phase. Simple small parts like automotive engine piston are manufactured by this process.

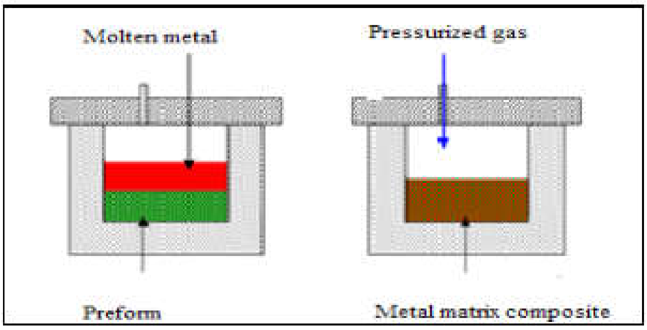

Fig. 3. Gas pressure infiltration

Squeeze casting

This pressure is also known as pressure die infiltration. It is forced infiltration method. In this movable mold part(ram) is used for applying pressure on the molten metal and forcing it to penetrate into the preformed dispersed phase, placed into the lower fixed mold part as shown in fig 4.The principles of squeeze casting technology, which can be applied to process discontinuous fiber reinforced metal (Cheng, 1993). The most important parameters that are determined to be significant are the die temperature, the design of gates to control the squeeze pressure applied to molten aluminum alloy as it fills the mold (Richardson, 1987; Schwartz, 1983; Luce, 1988). Optimization of process parameters is must in the squeeze casting process (Young, 1997; Engineered Materials Hand Book, 1987; Ejiofor, 1997).

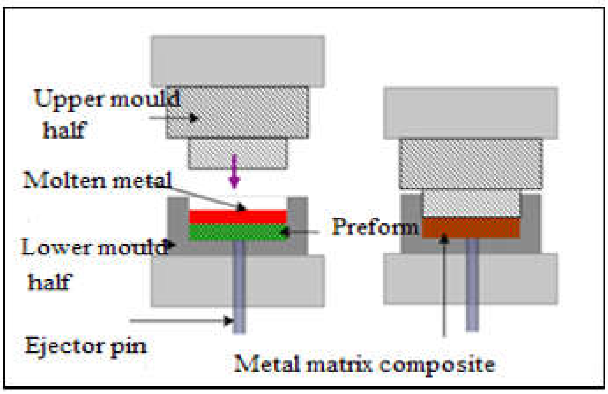

Fig. 4. Squeeze casting

Solid state fabrication of Metal matrix Nano-composites

Solid state fabrication of the metal matrix composites is a process in which mmc are formed due to the formation of bonding between matrix metal and dispersed phase due to mutual diffusion occurring between them in solid state at low pressure and high temperature. These process are currently used for cemented carbides and for diamond tools, however they have good potential also for other system, i.e. Al-based MMC (Gingu, 1998).

Diffusion Bonding

To join similar and dissimilar metals this is very common and simple solid state fabrication method. In contact at high temperature, inter diffusion of atoms between the clean metallic surface leads to bonding. This method can produce large amount of metal matrix Nano-composite and control the orientations of fiber and volume fraction. Diffusion bonding is Used to make sheets, blades, vane shafts, structural components.

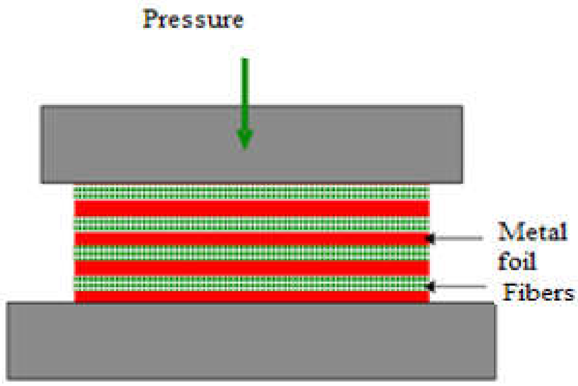

Fig. 5. Diffusion bonding

Powder Metallurgy

In solid state fabrication method blending of rapidly solidified powders with particulates, platelets or Whiskers takes place. Fabrication can understand by given flow chart. The method described below, due to its simplicity, is applied widely for the production of composite materials with magnesium alloys matrix (Kehler, 1995), aluminum alloys matrix (Kaczmar, 1992) and copper matrices (Han, 1996; Kaczmar, 1989; Warrier, 1984).

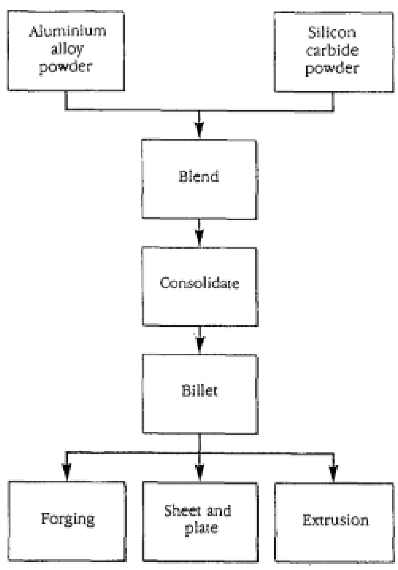

Fig. 6. Flow chart showing key fabrication steps for a powder metallurgy metal-matrix composite

The steps includes: (i)sieving of the rapidly solidified particles, (ii) blending of the particles with the reinforcement phase(s), (iii) compressing the reinforcement and particle mixture to approximately 75% density, (iv) degassing and final consolidation by extrusion, forging, rolling or any other hot working method. . By powder metallurgy methods, composite materials reinforced by dispersion particles (Abkowitz,, 1993; Anonym, 1995; Doel, 1996 and Mordike, 1991), platelets (Kainer, 1993), non-continuous (Kaczmar, 1993 and Kainer, 1993) and continuous (Bowman, 1995) are manufactured. Powder metallurgy is Mainly use to produce small objects (especially round) bolts pistons, valves, high-strength and heat resistant materials.

Deposition technique

In this type of fabrication method of metal matrix composites coating individual fibers in a tow with the matrix material needed to form the composite followed by diffusion bonding to form a consolidated composite plate or structural shape takes place. One of the biggest drawback of this process is this time consuming. There are numerous deposition techniques are available I.e. immersion plating, electroplating, spray deposition, chemical vapor deposition (CVD), and physical vapor deposition (PVD), spray forming.

Spray forming

In this type of fabrication method of Metal matrix composite a spray gun is used to atomize a molten metal alloy matrix, into which heated silicon carbide particles are injected as shown in fig 8. Dipping or immersion plating is just like to infiltration casting except that fiber tows are continuously passed through baths of molten metal, slurry, sol, or organometallic precursors. Spray casting is Used to produce friction materials, electrical brushes and contacts, cutting and grinding tools.

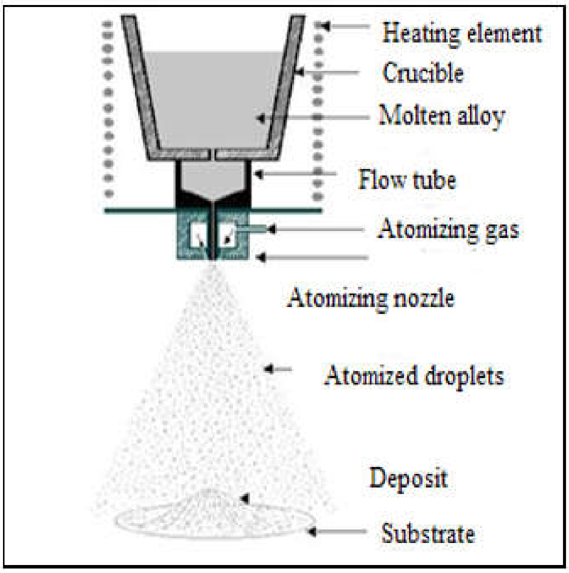

Fig. 7. Spray Forming

Electroplating

In this type of deposition technique involves a coating from a 10 µm solution containing the ion of the desired material in the presence of an electric current. Fibers are wound on a mandrel, which act as a cathode, and placed into the plating bath with anode of the desired matrix material.

Spray Deposition

This type of deposition technique of fabrication of metal matrix composites involves winding fibers onto a foilcoated drum and spraying molten metal onto them to form a monotype. The source of molten metal can be powder or wire feedstock which is melted in a flame, arc, or plasma torch.

Chemical vapor deposition (CVD)

This type of deposition technique is carried out at the high temperature, in which vaporized component decomposes or reacts with another vaporized chemical on the substrate to form a coating on that substrate.

In situ fabrication of metal matrix composites In this type of fabrication method reinforcement phase forms the in-situ. The composite material is formed in one step from an appropriate starting alloy, thus avoiding the difficulties inherent in combining the separate components.

Two phase process

This is a method to fabricate the metal matrix composites. Two phase process is similar to spray deposition, compo casting, etc. involve the mixing of ceramic and matrix in a region of the phase diagram where the matrix carries both solid and liquid phases. Two phase process of fabrication of MMC include the Osprey, rhea- casting and the variable co-deposition of multiphase materials (VCM).

Osprey deposition

In the Osprey process of fabrication of MMC the reinforcement particulates are brought into contact with stream of molten alloy which is subsequently atomized by jets of inert gas. The final sprayed mixture is collected on a substrate in the form of reinforced metal matrix billet. This approach was introduced by ALCAN as a modification of the Osprey process (White, 1988; White, 1989 and Willis, 1988), Fig. 9. This process is combination of blending and consolidation steps of the powder metallurgy process and gives the major savings and excellent result in the production of metal-matrix composites.

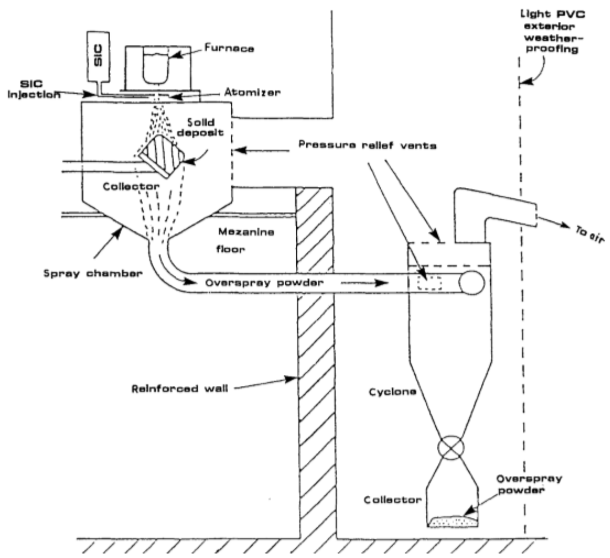

Fig. 8. Schematic diagram of the modified Osprey technique

Rheocasting

In this type of fabrication method, fine ceramic particulates are added to a metallic alloy matrix at a temperature within the s-liquid range of the alloy. After this subjected to agitation of mixture to form a low viscosity slurry. This behavior, which has been observed for fraction solids as high as 0.5, occurs during stirring and results in breaking of the solid dendrites into spheroidal solid particles which are suspended in the liquid as fine-grained particulates (SPENCER, 1972 and MEHRABIAN, 1972). This approach has been successfully utilized in die casting of aluminum- base and copper-base alloys (MEHRABIAN, 1972 and FASCETTA, 1973). This rheocasting method has been successfully utilized by Mehrabian and co-workers (FASCETTA, 1973 and MEHRABIAN, 1877), to incorporate up to 30 wt.% aluminum oxide and silicon carbide, and up to 21 wt. % glass particles (size 14-340 gm. diameter) in a partially solidified, 0.40-0.45 volume fraction solid of A1-5%Si-2%Fe alloy. The most of the particulates were found to be homogeneously distributed in the matrix.

Conclusion

In present time, in every field we need high stiffness, light weight material, and good mechanical properties like high tensile strength, high wettability. In the past 20 years, MMC have progressed from laboratories to the commercial world and with the numerous excellent mechanical properties. Currently automotive, aerospace and many industries are utilizing the benefits of these materials due to its tremendous properties.To make this material more familiar, researchers and scientist are looking for more easy and cost effective way to produce MMCbecause uses of these materials can bring a new revolution to the material world. Now a days, according to the type of MMC, different methods are using to fabricate the MMC but still the above methods which are mentioned, is not that much cost effective. Moreover they are time consuming process. There are lots of work to do in the field of metal matrix composite materials. The major problems in fabrication of these material is that they can't be fabricate by regular casting process and due to this the methods se used to fabricate these materials become very costly , thus we need to do lots of work for making its production easy and cost effective.

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