STUDY ON VARIOUS PRODUCTION TECHNIQUES FOR DEVELOPMENT OF METAL MATRIX COMPOSITES

Sarbjit Singh

PEC University of Technology, Chandigarh (India)

ABSTRACT

Metal matrix composites (MMCs) materials are presently undergoing active development in the whole world. The benefits of using MMCs materials lie in the advantage of attaining properties combination that can result in a number of service benefits. The development of MMCs may encompass primary issues like selection and distribution of constituent phases, the characteristics of the interface and the possible tailoring of constituents. There are numerous production methods available for production of the MMCs materials; there is no unique route in this respect. Owing to the choice of matrix material and reinforcement and of the type of reinforcement, the production methods can vary substantially. Processing of MMCs can be classified according to whether the matrix is in solid, liquid, or vapor phase while it is being combined with the reinforcement. The present paper explores the various techniques used by the researchers for the production of metal matrix composites.

Keywords: Metal Matrix Composites, Stir Casting; Liquid Casting; Solid State Casting

I INTRODUCTION

The composites can be defined as the "macroscopic combination of two or more distinct materialshaving different properties that are combined together to achieve a desired balance ofproperties for a given range of applications".Over the last few decades, Metal Matrix Composites (MMCs) have been developed as a material systemoffering marvelous blend of properties for imminent applications.The principal benefits offered by thesematerials are their enhanced mechanical properties,mainly in the areas of wear, strengthand stiffness.The MMCs have numerous advantages over monolithic materials as well as Polymer Matrix Composites (PMCs). With respect to monolithic materials the MMCs offer the following advantages [1];

- Weight saving due to superior strength to weight ratio
- Excellent dimensional stability
- Higher elevated temperature stability
- Considerably enhanced fatigue strength

With respect to PMCs, the MMCs have the following advantages;

- Greater strength and rigidity
- Upper working temperature
- Superior electrical conductivity

- Superior thermal conductivity
- Superior transverse properties
- Enhanced joining characteristics
- Radiation survivability
- Slight or no adulteration

All metal matrix composites have a metal or a metallic alloy as the matrix. The reinforcement can be metallic or ceramic. In general, there are three kinds of metal matrix composites, i.e., particle reinforced MMCs, short fiber or whiskers reinforced MMCs and continuous fiber reinforced MMCs. The size, volume fraction and its distributionwill give rise to either increase or decrease in various mechanical properties of a composite material. Particle reinforced MMCs have assumed special importance for the following reasons;

- Particle reinforced MMCs are less expensive than continuous fiber reinforced composites
- Conventional casting technique or route with slight modifications can be used for the production of particle reinforced MMCs.
- Improved thermal stability
- Enhanced wear resistance
- Relatively isotropic nature in terms of physical and mechanical properties

The principal matrix materials are aluminium alloys, magnesium, titanium and its alloys. Maximum volume of MMCs is based upon aluminium and its alloy. In practical applications, the aluminium matrix composites have several advantages over conventional aluminium alloys. In recent years, inexpensive reinforcements such as SiC particles and SiC fibers have become available, making them as appropriate choice as reinforcement material. A majority of research effort has focused on development of aluminium based MMCs with SiC particle reinforcement. Aluminium alloy provides a good matrix for the development of these composites because of its low density, ease of fabrication, capacity to be strengthened by precipitation, good intrinsic properties, and higher thermal/electrical conductivity [2].

II COMPONENTS OF MMC

The matrix, reinforcement and interface between matrix and reinforcement are considered as three main components of MMCs. The detailed description of these components is presented in the subsequent sections.

2.1 Matrix

The main function of matrix is to transfer and distribute the load to the reinforcements. This transfer of load depends on the bonding interface between the matrix and reinforcement; however bonding depends upon the type of matrix and reinforcement and the fabrication technique.

Good corrosion resistance, low density and excellent mechanical properties of aluminium and its alloys makes them suitable candidate for matrix material. The 6XXX series of Al-Mg-Si alloys are widely used as medium strength structural alloys made by extrusion, which have the advantages of good weldability, corrosion resistance and immunity to stress corrosion cracking. A typical 6XXX type of aluminium alloy that could be used as a matrix for the composites is the Al 6063 alloy [2-3]. The 6XXX series provides excellent properties and thus they can be extensively used as a matrix material in various MMCs applications.

2.2 Reinforcement

Reinforcements are the second type of materials added to the matrix alloy. Reinforcement increases the strength, stiffness, and temperature resistance capacity of the MMCs. The choice of reinforcement depends upon the specific requirements of the composite to be fabricated. Certain dispersoids normally impart some special properties to the composites such as enhanced wear resistance and reduced density at the expense of strength. Generally, these dispersoids are refractory materials, such as, oxides, carbides and nitrides of different elements. Basically they are stable and non-reactive in most of the matrix alloys. In addition, they do not mostly undergo any change in phase or shape during composite synthesis or in use except those produced by in-situ methods. At present, there are wide ranges of reinforcement materials, which can provide varying combination of properties to the synthesized composites. SiC has been reported to be the most advantageous reinforcement for matrix of Al alloys because of its relatively high hardness, low density and availability in different size and shapes [2-4].

2.3 Interface

Interface is the region that lies between the matrix and the reinforcement. It plays an important role in determining the composite properties. It may contain a simple row of atomic bonds or reaction products between the matrix and the reinforcement or reinforcement coatings. In composites, (i) stiffening and strengthening rely on load transfer across the interface, (ii) toughness is influenced by crack deflection/ fiber pullout and (iii) ductility is affected by relaxation of peak stresses near the interface.

Bonding of interfaces is mechanical, physical and chemical in nature. Mechanical bonding is the simple mechanical keying or interlocking effect between two surfaces which could lead to a considerable degree of bonding. Any contraction of the matrix onto the fiber would results in a gripping of the fibers by the matrix. The physical bonding involves weak, secondary or Vander Waals forces, dipolar interaction and hydrogen bonding. Chemical bonding involves the atomic or molecular transport by diffusion process. Solid solution and compound formation may occur at the interface, resulting in a reinforcement/matrix interfacial reaction zone with a certain thickness. This encompasses all type of covalent, ionic and metallic bonding [1, 4].

III DEVELOPMENT OF METAL MATRIX COMPOSITES

Processing of MMCs can be classified according to whether the matrix is in solid, liquid, or vapor phase while it is being combined with the reinforcement. The comprehensive grouping of processing of MMCs is as under:

(1) Solid state: diffusion bonding, powder blending and consolidation.
(2) Liquid state: liquid metal infiltration, squeezes casting, stir casting, spray deposition etc.
(3) Vapor state: physical vapor deposition

Normally the liquid state production technique is more effective than the solid state and vapor state production techniques because solid state processing necessitates a longer time. The matrix metal is used in various forms in different production methods. Generally powder is used in powder metallurgy technique, and a liquid matrix is used in liquid metal infiltration, plasma spray, spray casting, squeeze casting, pressure casting and compo-casting. A molecular form of matrix is used in physical vapor deposition and chemical vapor deposition.

3.1Solid State Production Processes

There are numerous methods for the production of MMCs with solid state processing but commonly the diffusion bonding and powder metallurgy techniques are used. The principal of these processes is presented in the subsequent sections.

3.2Diffusion Bonding

The diffusion bonding technique is used to produce fiber reinforced metal matrix composites (MMCs) with sheets or foils as the matrix materials. The matrix in the form of sheets or foils and the fiber reinforcements are chemically surface treated to effectively inter-diffuse with each other. The fibres reinforcements are positioned on the matrix (metal foils) as per designed placement and press forming process is used to make bonding between the matrix and reinforcement.. Sometime fibres are coated with plasma spray or ion deposition to enhance the bonding strength before diffusion bonding [5].

3.3Powder Metallurgy

The powder metallurgy process is a most common production technique used to produce particulate or whisker reinforced metal matrix composites. In this technique, the powder of matrix and reinforcement is first blended to form a mixture of desired proportion and placed in the mold of required shape. Pressure is applied to further compress the mixture (cold pressing). The combined mixture is heated below the melting temperature (sintering) to assist the bonding between the constituents of the mixture. Alternatively, after sintering hot pressing is used to further compact the mixture. The merged product is formerly used as MMC after certain secondary processing steps [6].

3.4Liquid State Production Processes

Liquid state production processes are more efficient and economical as compared to the solid state production processes, since they require more time for fabrication. Majority of the MMCs are fabricated by liquid metallurgy route to take the cost advantage.

3.4.1Liquid Metal Infiltration

Liquid metal infiltration comprises of penetration of reinforcement into the liquid matrix. The various complication of the process like wetting of the ceramic reinforcement makes this production technique a challenging task. The reaction between the molten matrix and fibers substantially degrade the properties of the reinforcement. Sometimes coating on the reinforcement applied before infiltration to increase the wettability and better control on interfacial reactions. Such coatings have been developed and are generating inspiring outcomes. [7].

3.4.2Squeeze Casting

Mostly the ceramic reinforcements such as graphite, SiC, Al_2O_3 do not wet optimally in the liquid matrix and hence it is problematic to produce the MMCs with liquid infiltration process. In the squeeze casting the reinforcement is forcefully infiltrated into the liquid matrix and, ejecting all absorbed as well as entrapped gases.

Squeeze casting is defined as "the capability to forcibly charge liquid metal into a pre-heated ceramic fiber or any reinforcement preform that is set in a metal die and then to allow the liquid metal to solidify whist applying a high pressure, thereby squeezing the molten metal" [5].

Composites produced through this process have the benefit of negligible reaction amid the reinforcement and the matrix because of shorter processing time. These types of MMCs are naturally free from common casting flaws such as porosity and shrinkage cavities.

3.4.3Stir Casting

Stir casting comprises of addition of reinforcement into the molten melt and letting the constituents to solidify. The wettability among the matrix and reinforcement is the main challenge for the production of MMCs by stir (vortex) casting route. The vortex method includes addition of pre-treated reinforcement into the vortex of melt formed by rotary impeller. Inhomogeneity in the dispersal of reinforcement in the developed MMCs might be a problem because of interaction between the reinforcement and the moving solid-liquid interface during solidification. With the help of vortex casting route the incorporation of reinforcement upto 30% is possible for a variety of reinforcement size (5 to 100 μm). The vortex method is not suitable for incorporation of particles having sub-micron size. Compo-casting is other variant of vortex casting process. In compo-casting the reinforcement are incorporated into the melt in the mushy (semi solid) state [5].

3.4.4 Spray Deposition

The Spray deposition technique can be divided into two categories; whether the droplet stream is produced from a molten bath or by continuous feeding of cold metal into a zone of rapid heat injection. This method has been comprehensively discovered for the production of MMCs by inserting reinforcement particles into the spray. The MMCs manufactured by this method frequently exhibit homogeneous dispersal of reinforcement. Normally a porosity level of 5-10% is observed in the sprayed deposition technique. This technique can be used for the production of fiber reinforced MMCs.

3.5Vapor Deposition Process

The physical vapor deposition method is a vapor state processing technique for MMCs. The evaporation route is used for production of titanium reinforced by monofilament. It involves passing the fiber through a section having high vapor pressure of the metal to be deposited, where the condensation takes place to produce a thick surface coating. There is little or no mechanical disturbance of the interfacial region and very uniform distribution of fibers is produced. The fabrication of composites is usually completed by assembling the coated fibers into a bundle and the bundle is consolidated at high pressure. [5, 7]

IV CONCLUSIONS

The following conclusions can be drawn from the present investigation on various production techniques for the development of metal matrix composites:-

1. A number of casting routes have been developed by the researches over a period of time and most common casting method is liquid state production process.

2. Conventional casting techniques or routes with slight modifications can be used for the production of particles reinforced MMCs.
3. Stir and Squeeze casting routes of liquid state production processes are commonly used for production of metal matrix composites.
4. Diffusion bonding and powder metallurgy are commonly used for solid state production process of MMCs.

REFERENCES

1. Chawla N., Chawla K.K., 2006, "Metal matrix composites" *Springer publication, USA.*
2. DvivediAkshay., 2008, "Electric discharge machining of Al6063-SiC MMC produced by stir casting process", *Ph.D. thesis, Indian Institute of Technology Roorkee, India.*
3. Huda D., El Baradie M.A., Hashmi M.S.J., 1993, "Metal-matrix composites: Materials aspects. Part II", *Journal of Materials Processing Technology, Vol. 37, Issues 1-4, pp.529-541.*
4. Gupta M., Srivatsan T.S., Lin C.Y.H., Varin R.A., 2008, "Proceedings of the XVII International Conference on Processing and Fabrication of Advanced Materials*" Indian Institute of Technology Delhi, INDIA.*
5. Huda D., El Baradie M.A., Hashmi M.S.J., 1993, "Metal-matrix composites: Manufacturing aspects. Part I", *Journal of Materials Processing Technology, Vol. 37, Issues 1-4, pp.513-528.*
6. Miracle D.B., 2005, "Metal matrix composites - From science to technological significance" *Composites Science and Technology, Vol. 65, pp. 2526-2540.*
7. Surappa M. K., 2003, "Aluminium matrix composites: Challenges and Opportunities"*Sadhana, Vol. 28, Parts 1 & 2, pp. 319-334.*