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PROCESSING OF ALUMINIUM BASED METAL MATRIX COMPOSITES

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Abstract

From the onset of the space era, both organic-matrix and metal-matrix composites (MMCs), with high specific stiffness and near-zero coefficient of thermal expansion (CTE), have been developed for space and other applications. Of the organic-matrix composites, graphite/epoxy (Gr/Ep) has been used in space for truss elements, bus panels, antennas, wave guides, and parabolic reflectors in the past 30 years. MMCs possess high-temperature capability, high thermal conductivity, low CTE, and high specific stiffness and strength. Those potential benefits generated optimism for aluminium based MMCs for critical space system applications in the late 1980s.1,2 The purpose of this article is to detail the history, status, and opportunities of MMCs for world wide applications.

Index Terms – MMC (Metal Matrix Composites), whiskers ,compocasting , Stir casting fracture toughness, volume fraction.

I. INTRODUCTION

Metal-matrix composites (MMCs) containing reinforcement particulates are well-known for their high specific strength when compared to their monolithic counterparts and more recently, for their excellent wear resistance. The suitability of MMCs as a viable replacement for conventional monolithic materials in engineering applications, however, depends on the ability of synthesizing them with a consistent reproducibility in microstructure and properties. With the continual development in fabrication techniques, more MMCs have been found to be suitable to replace some of the conventional metallic monolithic alloys such as the various grades of aluminium alloys in applications where light weight and energy saving (for example in the aerospace and automotive industry) are important design considerations. In these MMCs, the good ductility provided by the metallic matrix is retained, whilst the modulus and mechanical strength of the composites are increased, resulting from the addition of the reinforcement phase.

The presence of hard reinforcement phases, particulates, fibers or whiskers, has endowed these composites with good tribological (friction and wear) characteristics. This combined with their good specific strength makes them candidate materials for many engineering situations where sliding contact is expected.

In preparing metal matrix composites, there are several factors that need to be considered. They are

- Uniform distribution of the reinforcement material.
- Wettability between the two main substances.
- Porosity in the cast metal matrix composites.
- Chemical reaction between the reinforcement material and the matrix alloy.

In order to achieve the optimum properties of the MMCs, the distribution of the reinforcement material in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized. The porosity level need to be minimized, and chemical reaction between the reinforcement materials and the matrix alloy must be avoided.

II. PROCESSING AND MANUFACTURE

Of course the properties of real composites depend on how each is made. Processing is of paramount importance because whether or not the desired properties can be attained must depend on the processing procedure. If this is complicated or expensive the properties may not be achieved.

Fabrication methods can be divided into three types. These are solid phase processes, liquid phase process and semi-solid fabrication process. Solid-state processes are generally used to obtain the best mechanical properties in MMCs, particularly in discontinuous MMCs. This is because segregation effects and intermetallic phase formations are less for these processes, when compared with liquid state processes. Among the variety of manufacturing processes available for discontinuous MMC production, stir casting is generally accepted, and currently practiced commercially. Stir casting of MMCs generally involves producing a melt of the selected matrix material, followed by the introduction of a reinforcing material into the melt and obtaining a suitable dispersion through stirring. Vogel et al. gave the term 'stir-casting' to the production of metals with spheroid like microstructure by a shearing action induced by stirring. The term stir casting and compocasting are used interchangeably. Its advantages lie in its simplicity, flexibility and applicability to large scale production. It also, in principle, allows a conventional casting route to be used.

Relatively large-diameter monofilament fibers, such as boron and silicon carbide, have been incorporated into metal matrices by hot pressing a layer of parallel fibers between foils to create a monolayer tape. In this operation, the metal flows around the fibers and diffusion bonding occurs.

Monolayer tapes are also produced by spraying metal plasmas on collimated fibers, followed by hot pressing. Structural shapes can be fabricated by creep and super plastic forming of laminates in a die. An alternate process is to place fibers and unbonded foils in a die and hot press the assembly.

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Table I shows the comparative evaluation of different processes commonly used for production of discontinuously reinforced metal matrix composites (DRMMCs).

COMPARISON OF DIFFERENT PROCESSES

Method	Range of shape and use	Range of vol. fraction	Damage to reinforcement	Cost
Liquid metallurgy (Stir casting)	Wide range of shape	Up to 0.3	No Damage	Least expensive
Squeeze casting	Large size, up to 500kg limited by perform shapeup to 2cm height	Up to 0.45	Severe damage	Moderately expensive
Powder metallurgy	Wide range, restricted size	----	Reinforcement fracture	Expensive
Spray casting	Limited size, large	0.3 – 0.7	----	Expensive

III. STIR CASTING TECHNIQUE

Potentially, this is a way of making a broad range of MMCs whereby the dispersoid is added to the surface of the melt and then becomes entrained in the melt by agitation and/or mechanical work. This process can take the form of various semi-solid metal processing (SSP) routes e.g. compo casting/ rheocasting / thixocasting / thixoforging.

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. It is generally carried out in mushy zone with varying fraction of solid 10-60%. 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.

Various Aluminium based MMC were prepared by melting the constituent metals and master alloy in an electric resistant muffle furnace and incorporating the reinforcement in the solidifying metallic slurry of aluminium matrix alloy. A weighed amount consisting of pure aluminium alloy is charged in to plumbago crucible. This crucible was rigidly kept in electrical resistance heating muffle furnace. Before connecting the furnace to electrical power supply through control panel, the furnace mouth was closed tightly with an asbestos sheet cover specially fabricated for this purpose. There were suitable openings in the furnace cover for the thermocouple and mixing paddle. During heating and melting, the opening for mixer paddle was kept closed. One end of the thermocouple was connected to the temperature controller attached to the control panel and the other end was inserted in the furnace through the cover opening. The temperature of the melt was regulated continuously, with another thermocouple of which one end was sheathed in aluminium, touching the melt by passing through the cover opening and other end was connected to the furnace temperature indicator. The charge was melted with the help of electric power and super heat of nearly 200^{o} C was provided. Metallic melt was left at this temperature for about 5min for homogenization. Molten alloy temperature was lowered down and brought within its solidification range (540±5^{o} C) where some amount of melt was solid and some in liquid state. The stirring of solid-liquid phases was started mechanically (300 rpm) with the help of graphite paddle attached to the graphite rod, during which required amount of reinforcement material was introduced in to solid liquid slurry. The mixing period for each heat was 3 – 4 minutes. Temperature can be controlled by controlling the electric power supply. Plumbago crucible containing the composite slurry was taken out from furnace and placed on a sand bed. The composite slurry was allowed to solidify in the plumbago crucible itself. After solidification composite was removed for characterization.

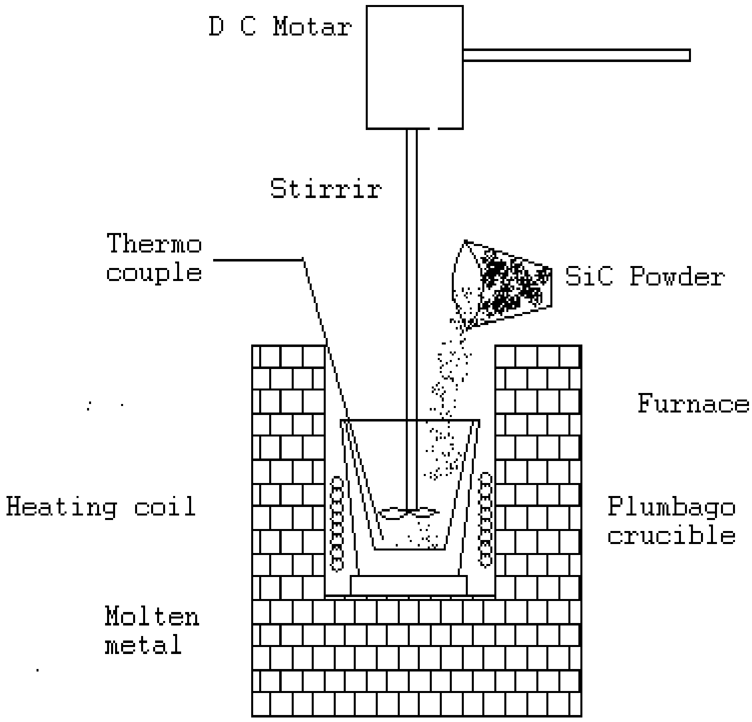

Fig 1: Schematic diagram of experimental setup

IV. RHEOCASTING TECHNIQUE

The steps involved in rheocasting process are shown schematically in fig.2. Rheocasting process involves super heating (950º C) the properly cleaned metal ingots in a graphite crucible followed by the addition of pre heated SiC particulate into the metallic melt. The melt is stirred (upto speed of 250 rpm) during the addition of reinforcement material and this continuous until the two phase region is reached in order to achieve a uniform distribution of reinforcement. The composite material thus obtained is allowed to solidify in the crucible. This is remelted (in the same crucible) to 950º C and then cast in to steel die. All of rheocast composite samples were solutionised at 540º C. The microstructure of the specimen prepared by rheocasting technique is shown in the Fig. 3.

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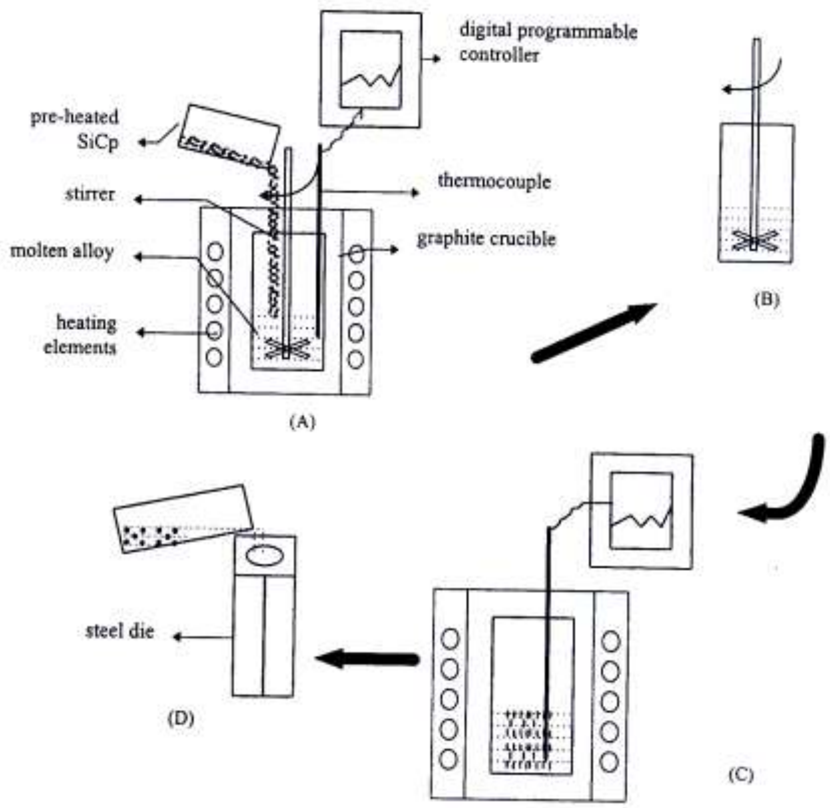

Fig.2. Rheocasting process.

a) A schematic representation of rheocasting process.
b) Addition of pre heated reinforcement in to Al alloy.
c) Stirring of composite melt near solidification.
d) Reheating to melt the composite.
e) Casting into the steel die.

V. POWDER METALLURGY

Powder metallurgy uses sintering process for making various parts out of metal powder. The metal powder is compacted by placing in a closed metal cavity (the die) under pressure. This compacted material is placed in an oven and sintered in a controlled atmosphere at high temperatures and the metal powders coalesce and form a solid. A second pressing operation, repressing, can be done prior to sintering to improve the compaction and the material properties.
The properties of this solid are similar to cast or wrought materials of similar composition. Porosity can be adjusted by the amount of compaction. Usually single pressed products have high tensile strength but low elongation.

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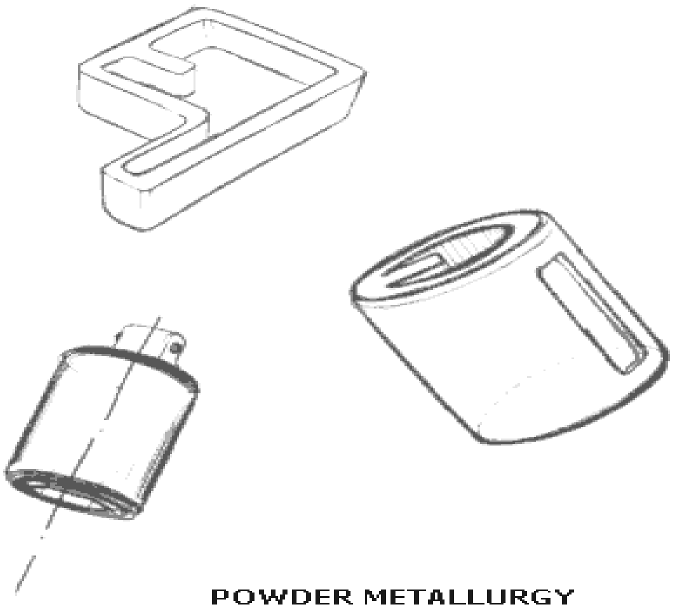

Fig.3.Examples of Powder metallurgy

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VI. CHARACTERISTICS AND DESIGN CONSIDERATIONS:

The superior mechanical properties of MMCs drive their use. An important characteristic of MMCs, however, and one they share with other composites, is that by appropriate selection of matrix materials, reinforcements, and layer orientations, it is possible to tailor the properties of a component to meet the needs of a specific design.
Monolithic metals tend to be isotropic, that is, to have the same properties in all directions. Some processes such as rolling, however, can impart anisotropy, so that properties vary with direction. The stress-strain behavior of monolithic metals is typically elastic-plastic. Most structural metals have considerable ductility and fracture toughness.
The wide variety of MMCs has properties that differ dramatically. Factors influencing their characteristics include:

- ►Reinforcement properties, form, and geometric arrangement.
- ► Reinforcement volume fraction.
- ► Matrix properties including effects of porosity.
- ► Reinforcement-matrix interface properties.
- ► Residual stresses arising from the thermal and mechanical history of the composite.

► Possible degradation of the reinforcement resulting from chemical reactions at high temperatures, and mechanical damage from processing, impact, etc.

Particulate-reinforced MMCs, like monolithic metals, tend to be isotropic. The presence of brittle reinforcements and perhaps of metal oxides, however, tends to reduce their ductility and fracture toughness. Continuing development may reduce some of these deficiencies.

The properties of materials reinforced with whiskers depend strongly on their orientation. Randomly oriented whiskers produce an isotropic material. Processes such as extrusion can orient whiskers, however, resulting in anisotropic properties. Whiskers also reduce ductility and fracture toughness.

MMCs reinforced with aligned fibers have anisotropic properties. They are stronger and stiffer in the direction of the fibers than perpendicular to them. The transverse strength and stiffness of unidirectional MMCs (materials having all fibers oriented parallel to one axis), however, are frequently great enough for use in components such as stiffeners and struts..

Because the modulus and strength of metal matrices are significant with respect to those of most reinforcing fibers, their contribution to composite behavior is important. The stress-strain curves of MMCs often show significant nonlinearity resulting from yielding of the matrix.

Another factor that has a significant effect on the behavior of fiber-reinforced metals is the frequently large difference in coefficient of expansion between the two constituents. This can cause large residual stresses in composites when they are subjected to significant temperature changes. In fact, during cool down from processing temperatures, matrix thermal stresses are often severe enough to cause yielding. Large residual stresses can also be produced by mechanical loading.

Although fibrous MMCs may have stress-strain curves displaying some nonlinearity, they are essentially brittle materials, as are PMCs. In the absence of ductility to reduce stress concentrations, joint design becomes a critical design consideration. Numerous methods of joining MMCs have been developed, including metallurgical and polymeric bonding and mechanical fasteners.

VII. APPLICATIONS OF ALUMINIUM BASED METAL MATRIX COMPOSITES

▪ **Space applications**

The extreme environment in space presents both a challenge and opportunity for material scientists. Re-entry vehicles for Earth and Mars missions may encounter temperatures that exceed 1,500°C. Critical spacecraft missions, therefore, demand lightweight space structures with high pointing accuracy and dimensional stability in the presence of dynamic and thermal disturbances. Composite materials, with their high specific stiffness and low coefficient of thermal expansion (CTE), provide the necessary characteristics to produce lightweight and dimensionally stable structures. Therefore, aluminium based (MMCs) have been developed for space applications.

Organic-matrix composites continued to successfully address the system-level concerns related to microcracking during thermal cycling and radiation exposure, and electromagnetic interference (EMI) shielding; MMCs are inherently resistant to those factors. Concurrently, discontinuously reinforced MMCs such as silicon-carbide particulate (p) reinforced aluminum (SiC_p/Al) and G_p/Al composites were developed cost effectively both for aerospace applications (e.g., electronic packaging) and commercial applications.

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- **Other applications**

Aluminium based metal matrix composites plays important role in world wide applications .Some of them are

- MMC are used in manufacturing composite gears.
- Widely used in making ship bodies.
- MMC are used in making blades of wind turbine.
- Used in automobiles and for military applications,
- One of the latest application is "First Refraction Enhanced 3D Computed Tomography ".

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