Study And Analysis Of Fabrication Process In Metal Matrix Composites

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Abstract- *Inherently smart, metal matrix composites (MMCs) are lightweight and high-performance materials having ever expanding industrial applications. The structural and the functional properties of these materials can be altered as per the industrial demands. The process technologies indulged in fabrication of these materials attract the researchers and industrial community. It exhibits higher competence for machining complex shapes with greater accuracy. This paper presents an up-to-date review of progress and benefits of different routes for fabrication of composites. It reports certain practical analysis and research findings including various issues on fabrication of MMCs.*

Keywords- MMCs, Powder Metallurgy, Stir Casting, Diffusion Bonding.

I. INTRODUCTION

Metal matrix composites (MMCs) are the materials with less density and higher specific properties such as strength and stiffness. These materials are combinations of two or more materials, exhibiting properties that are hard to obtain from a single material otherwise. In these combinations, one material acts as a matrix and the other acts as reinforcement. The matrix material distributes the stress applied over it to the reinforcement constituents which also protects and gives shape to the matrix material. The reinforcement provides the desired mechanical strength to the composite material in a preferential direction. The reinforcement is in the form of wires, whiskers or particulates, that are distributed in different volume fraction percentages according to their properties. Except the reinforcements that are in the form of wires, others are provided of ceramics that are oxides, carbides, and nitrides having excellent properties like specific strength and stiffness at both high and ambient temperatures as described by Callister [1]. It is possible to tailor their properties as per the requirement of various industrial applications by suitable combinations of matrix, reinforcement, and fabrication method. These reinforcements are known for their lower coefficient of thermal expansion with higher strength and modulus. According to Marsh [2], the automotive industry is facing continuous pressures to develop fuel-efficient, less polluting vehicles. As a result, the industry has switched over to fiber reinforced composites from expensive alloy materials to make its products light in weight and environmentally friendly. The matrices like aluminum, magnesium, steel, etc. are mostly preferred as a potential material for composites. The brittleness in the form of reinforcement and the ductility in the form of a matrix are required in a good MMC. Titanium can also be used as a matrix where high-temperature applications are required. The conventional reinforcements used are SiC, Si_3N_4, AlN, Al_2O_3, TiB_2, ZrO_2, and Y_2O_3. Matthews and Rawlings [3], Surappa [4], and Waku and Nagasawa [5] found out that MMCs possess several advantages over monolithic materials. These include greater strength, higher stiffness, light weight, better high-temperature properties, low coefficient of thermal expansion, improved electrical performance, better abrasion, and wear resistance. However, on the other side, toughness of MMCs is inferior as compared to monolithic metals, and moreover the latter are comparatively more expensive. This paper reviews the conventional machining as well as the nonconventional machining of MMCs and various other methods to fabricate them.

II. FABRICATION METHODS

Development of fabrication processes for the production of high-performance composites has been reported in many research studies. Figure 1 illustrates various fabrication techniques that were in use for the last few years. The following methods are most common for fabrication of the MMCs at large-scale industrial level.

1. Solid-phase processes.
2. Liquid-phase processes.

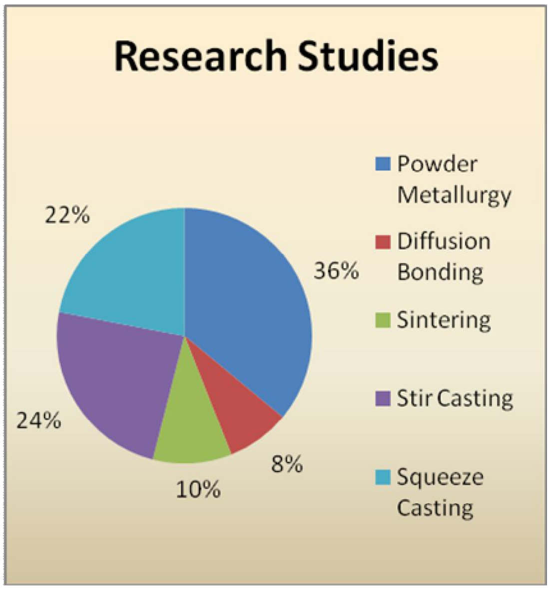

Fig 1. Research studies of different MMCs fabrication methods

The adoption of the route for the synthesis of MMCs depended on many factors including the matrix temperature during processing, extent and reinforcement loading, and desired degree of microstructural integrity. Well-established methods in solid-state processes include blending of powder followed by isostatic pressing (powder metallurgy (PM) processing), spray deposition techniques, and diffusion bonding. Melt stir casting, melt infiltration, spray casting, and in situ (reactive) processing come from liquid-state processing. In the PM technique, dry or liquid suspended powder is blended that is followed by hot isostatic pressing (HIP), cold compaction, canning, degassing, etc. There are a few composites that can be fabricated by the PM technique alone, as quoted by Hehmann and Froes [6]. In the PM method, the constituents are mixed into solid-state diffusion, and sintering gives desired shape to the composite. In spray deposition technique for composite fabrication, each individual fiber providing reinforcement is coated along with the matrix material followed by diffusion bonding. The MMC thus fabricated possesses more homogeneous microstructure compared to those fabricated by the cast technique. In conferences held in the UK, Willis et al. [7] and Miller et al. [8] had already supported it as the best suitable technique for fabrication of reinforced and un-reinforced alloys. It provides even distribution of the reinforcement in a matrix that is 95–98% dense. Melt stir casting method or the vortex technique involves incorporation of a reinforcing agent (particulate=whisker) into liquid matrix melt, stirring it with rotating impeller and allowing the mixture to solidify. In infiltration process, preform of fibers=whisker is made and is infiltrated by melt thus allowing mixing of liquid metal (partial or full) with reinforcement.

III. SOLID-PHASE PROCESSES

Solid phase processes involve the fabrication of particulate reinforced MMCs from blended mixture of elemental powders and particulates. A number of steps prior to final consolidation are involved in these processes. Powder metallurgy, sintering and diffusion bonding fall in this category[9].

Powder Metallurgy

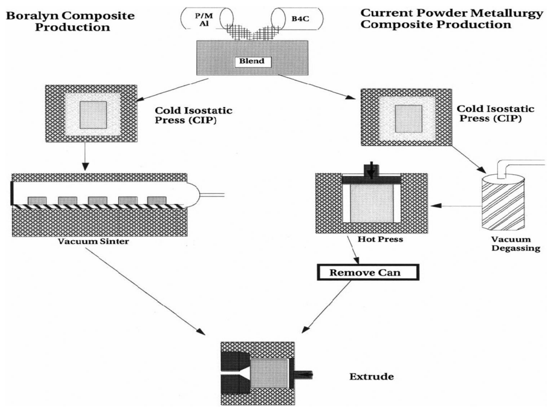

Fig 2.Schematic diagram of processing steps for the manufacture of powder metallurgy composites [10].

Powder metallurgy is defined as mixing different metal powders to form finished and semifinished components by compressing it After compressing subsequent heating at elevated temperature in a furnace under a progressive atmosphere is done so as to obtain satisfactory strength, density without losing essential shape. The powder metallurgy process generally consists of four basic steps: powder manufacture, powder blending, compacting, and sintering.

Diffusion Bonding

Diffusion Bonding is a solid state fabrication method, in which a matrix in form of foils and a dispersed phase in form of long fibers are stacked in a particular order and then pressed at elevated temperature. The finished laminate composite material has a multilayer structure. Diffusion Bonding is used for fabrication of simple shape parts (plates, tubes).

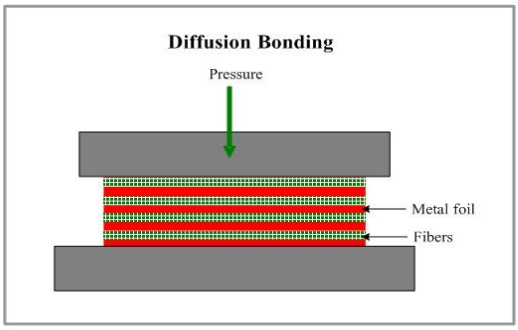

Fig 3. Diffusion Bonding

Variants of diffusion bonding are roll bonding and wire/fiber winding:

Roll Bonding is a process of combined Rolling (hot or cold) strips of two different metals (e.g. steel and aluminum alloy) resulted in formation of a laminated composite material with a metallurgical bonding between the two layers.
Wire/fiber Winding is a process of combined winding continuous ceramic fibers and metallic wires followed by pressing at elevated temperature.

Sintering

Sintering fabrication of Metal Matrix Composites is a process, in which a powder of a matrix metal is mixed with a powder of dispersed phase in form of particles or short fibers for subsequent compacting and sintering in solid state (sometimes with some presence of liquid). Sintering is the method involving consolidation of powder grains by heating the "green" compact part to a high temperature below the melting point, when the material of the separate particles diffuse to the neighboring powder particles.

In contrast to the liquid state fabrication of Metal Matrix Composites, sintering method allows obtaining materials containing up to 50% of dispersed phase.

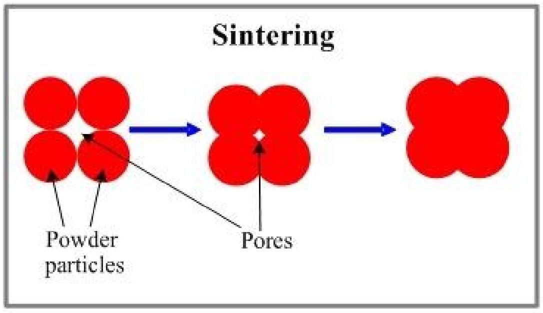

Fig 4. Sintering

IV. LIQUID-PHASE PROCESSES

In liquid phase processing, ceramic particulates are incorporated into a molten metallic matrix using various proprietary techniques. This is followed by mixing and eventual casting of the resulting composite mixture into shaped components or billets for further fabrication[11]. There are three different types of liquid phase fabrication methods: Stir casting and squeeze casting [12].

Stir Casting

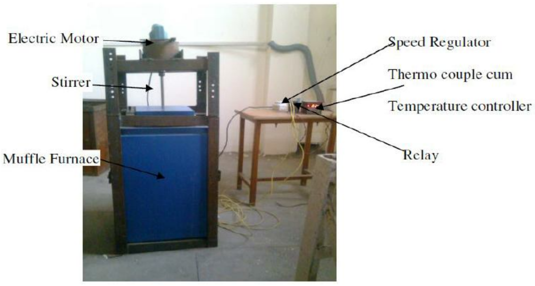

Fig 5. Stir Casting

Stir casting method was applied for the manufacturing and fabrication of the composite due to its expenditure effectiveness. The primary matrix material was encumbered into a graphite crucible and liquefied in an electric resistance furnace. The dissolving of the alloy occurred in an inert gas atmosphere, which avoids chemical reaction and produces a sound casting. Upon melting the preheated reinforcements were added at regular intervals and stimulated constantly at 350 rpm for 6 minutes to ensure consistent distribution of the reinforcement particles. The molten metal was then poured at a temperature of 760°C into preheated (300°C) steel moulds with dimensions and allowed to solidify.

Squeeze casting

Squeeze casting is a method combining casting and forging technologies.

In contrast to other casting techniques (sand casting, die casting), in which a molten metal is poured (injected) into the mold cavity after the two parts ofthe mold are assembled, squeeze casting mold is closed after a portion of molten metal has been poured into the preheated bottom die.

The upper die lowers towards the bottom die causing the melt to fill the mold cavity.

The squeezing pressure is applied until full solidification of the casting.

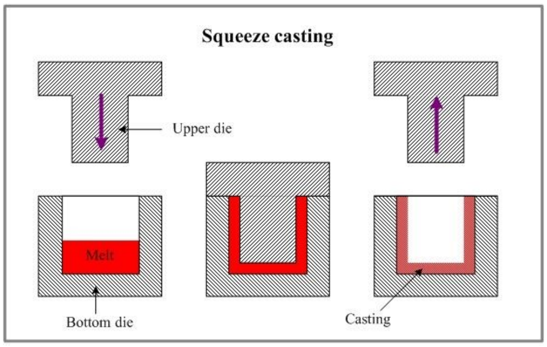

Fig 6. Squeeze Casting

V. CONCLUSION

MMCs are the material exhibiting properties that are hard to be obtained from a single material otherwise. These can be tailored and used as per the demands of various industrial applications by suitable fusion of their constituent materials. Aluminum is preferred as matrix component due to its ductility and low density.PM is one of the most promising and versatile routes for the fabrication of composites as compared to other manufacturing methods. This method ensures more homogeneous microstructure of the fabricated MMC as compared to other techniques. However, the existence of a new phase in addition to impurities in the form of carbon could be witnesses in XRD results due to partial reaction between matrix and reinforcement. Al2O3, reinforcement of the brittle nature, reduces the impact strength and increases the hardness of composite while fabrication with melt stirring technique. The interface between matrix and reinforcement in an MMC has an effect on the amount of martensitic transformation. The toughness of composite deteriorates with weak interface, but no effect on the wear resistance and hardness were noticed.

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