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A Review on the Processing Techniques for Magnesium Metal Matrix Composites with Emphasis on Friction Stir Processing

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ABSTRACT: In the last two decades, light-weight magnesium matrix composites have been the hot issue of material field due to their excellent mechanical and physical properties, e.g., high-specific strength and modulus, good wear resistance, and damping capacity. As compared with aluminium matrix composites, magnesium matrix composites have merit in their specific weight and have wide applications in aerospace and aeronautical fields. This paper presents an overview of different methods used for the processing of magnesium metal matrix composites such as stir casting, squeeze casting, powder metallurgy, and so on with emphasis on one of the newer methods known as friction stir processing (FSP) highlighting their merits and demerits. Friction Stir Processing (FSP) is a method for modifying the mechanical properties of surfaces by means of stirring action of the tool moving against the surface of the material whose properties need to be modified.

KEYWORDS: Composites, Magnesium matrix composites, Friction Stir Processing

I. INTRODUCTION

Metal matrix composites (MMCs) are those composites in which metals are taken as base or matrix materials and ceramics or organic compounds are used as reinforcements to enhance the properties of the composite as compared to the base metal. Aluminium matrix composites (AMCs), magnesium matrix composites, copper matrix composites are some examples of MMCs which are in demand these days in various applications such as automobile industries, aerospace industries, and electronics industries etc. due to their suitable properties with low cost availability Metal matrix composites (MMCs) have high mechanical properties and modified microstructures. The enormous hike in fuel prices has invoked and driven us to a never-ending emergency towards weight reduction, particularly in the automotive sector ^[1]. Composites always have great technical importance as they offer high flexibility to design materials by a composition of a large variety of reinforcements and matrices. Due to this, we can achieve hybrid properties in a single material which is unachievable in conventional materials ^[2].

Magnesium and its alloys are the highly structural metallic materials known till today. Owing to their higher specific strength, magnesium-based metal matrix composites (MMCs) have attracted the researchers. Apart from high specific strength, MMCs have low density, very high stiffness and higher wear resistance ^[3].

Today Magnesium based metal matrix composites are widely used in aerospace, structural, oceanic and automobile applications for its light weight, low density (two thirds that of aluminium), good high temperature mechanical properties and good to excellent corrosion resistance. The improvement of specific strength, stiffness, damping behaviour, wear behaviour, creep and fatigue properties are significantly influenced by the addition of reinforcing elements into the metallic matrix compared with the conventional engineering materials. But relatively very less work has been done related to the wear behaviour of these composites. Friction Stir Process is a modified technique to produce MMCs. The advantage of this technique is that it is used to join multiple pieces of metal without creating the heat affected zone typical of fusion welding. Friction stir processing also enhances the tensile strength and fatigue strength of the metal.

II. PROCESSING TECHNIQUES FOR MAGNESIUM MATRIX COMPOSITES

In order to optimize the microstructure and mechanical properties of magnesium matrix composites, a variety of processing methods have been developed over the last two decades. For the preparation of metal matrix composites, three well established processing methods have been widely recognized such as stir casting, squeeze casting, and powder metallurgy (PM), and they have been also adopted to prepare magnesium matrix composites.

i) Stir Casting

Stir casting is a type of casting process in which a mechanical stirrer is introduced to form vortex to mix reinforcement in the matrix material. It is a suitable process for production of metal matrix composites due to its cost effectiveness, applicability to mass production, simplicity, almost net shaping and easier control of composite structure^[14].

Stir casting setup as shown in Figure 1, consist of a furnace, reinforcement feeder and mechanical stirrer. The furnace is used to heating and melting of the materials. The bottom poring furnace is more suitable for the stir casting as after stirring of the mixed slurry instant poring is required to avoid the settling of the solid particles in the bottom the crucible. The mechanical stirrer is used to form the vortex which leads the mixing of the reinforcement material which are introduced in the melt. Stirrer consist of the stirring rod and the impeller blade. The impeller blade may be of, various geometry and various number of blades. Flat blade with three number are the preferred as it leads to axial flow pattern in the crucible with less power consumption. This stirrer is connected to the variable speed motors, the rotation speed of the stirrer is controlled by the regulator attached with the motor. Further, the feeder is attached with the furnace and used to feed the reinforcement powder in the melt. A permanent mold, sand mold or a lost-wax mold can be used for pouring the mixed slurry.

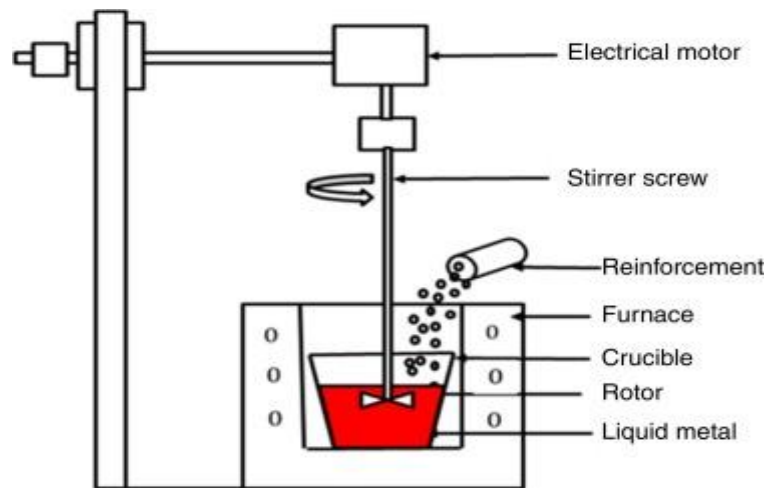


Fig 1 Stir Casting Setup

Stir casting refers to a process in which the reinforcements (usually in powder form) are introduced into molten magnesium through mechanical stirring, and mechanical stirring is the key element of this method. Stir casting process of fabricating metal matrix composites was initiated by Ray in 1968^[9]. Extensive researches about magnesium matrix composites fabricated by this method have been conducted during the past years.

Besides, stir casting was adopted in combination with other fabrication methods to fabricate magnesium matrix composites. For instance, stir casting and self-propagating high-temperature synthesis (SHS) reaction were combined to process magnesium matrix composites reinforced with in-situ reinforcements embedded in magnesium matrix^[12].

The major merit of stir casting is its applicability to mass production. Among the well-established processing methods, stir casting is the most economic. Stir casting also has some disadvantages: (1) a homogeneous distribution of reinforcements is requisite for achieving a high-strengthening effect, but a uniform distribution is relatively hard to obtain for stir casting; (2) reinforcing particles may be segregated caused by the surfacing of settling of the reinforcement in melting and casting process; and (3) gases and unwanted inclusions may be entrapped during stir casting.

ii) Squeeze Casting

Die casting is a metal casting process by which the molten forcing under high pressure into a mold cavity. The mold cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process. Most die castings are made from non-ferrous metals specifically copper, aluminium, magnesium-based alloys. It is especially suited for a large quantity of small- to medium-sized castings. Die castings are characterized by a very good surface finish (by casting standards) and dimensional consistency.

During squeeze casting, the reinforcement (either particles or fiber/whiskers) is usually made into a preform and placed into a casting mold. The molten magnesium alloy is then poured into the mold and solidified under high pressure. As a result, squeeze casting was also called pressure infiltration. Figure 2 illustrates the schematic diagram of squeeze casting.

Compared with stir casting, a unique feature of squeeze casting is that metal can be pressurized throughout solidification and this prevents the formation of gas and shrinkage porosity and produces a metallurgically sound casting ^[14]. The major shortcomings mainly lie in the constraints by the casting shape, its dimensions, and low suitability for large quantity automatic production ^[2]. In fabricating magnesium matrix composites by squeeze casting, the applied pressure must be properly controlled because an extensively high pressure may produce a turbulent flow of molten magnesium and then causes gas entrapment and magnesium oxidation.

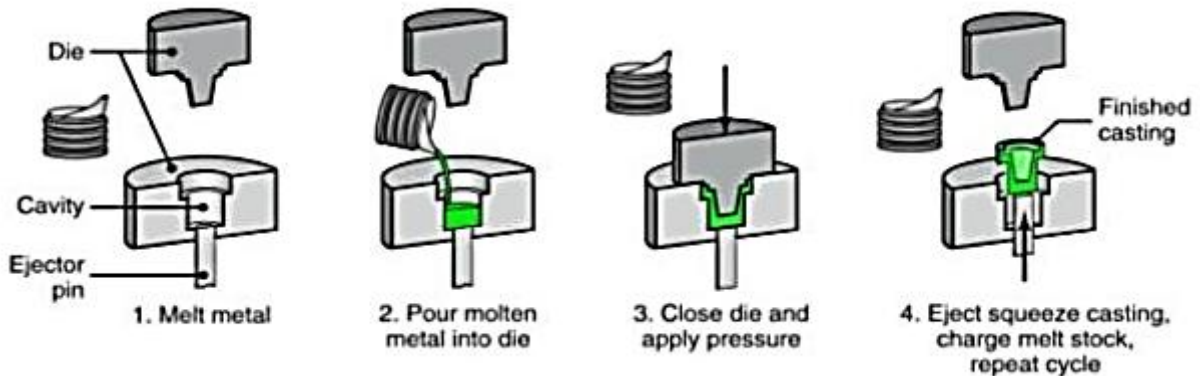


Fig 2 Squeeze Casting Process

iii) Powder Metallurgy

In PM process, magnesium and reinforcement powders are mixed and pressed, degassed, and sintered at a certain temperature under a controlled atmosphere or in a vacuum. PM manufacturing method is usually used to fabricate magnesium matrix composites reinforced with boron carbide particulates, and the schematic of this method is shown in Fig.3. PM method has several attractive features for preparing magnesium matrix composites: (1) it allows any alloy to be used as the matrix and any kind of reinforcements to be used because the reaction between the matrix and reinforcement can be minimized by this method ^[17]; (2) it need not have too high manufacturing temperature but can gain a uniform distribution of reinforcement; and (3) compared with stir casting, PM technique can gain a larger volume fraction of ceramic reinforcements ^[15]. However, this method requires alloy powders that are generally more expensive than bulk material and involves some complicated processes during the fabrication of material. Thus, PM process is costlier than other processes for the magnesium matrix composites.

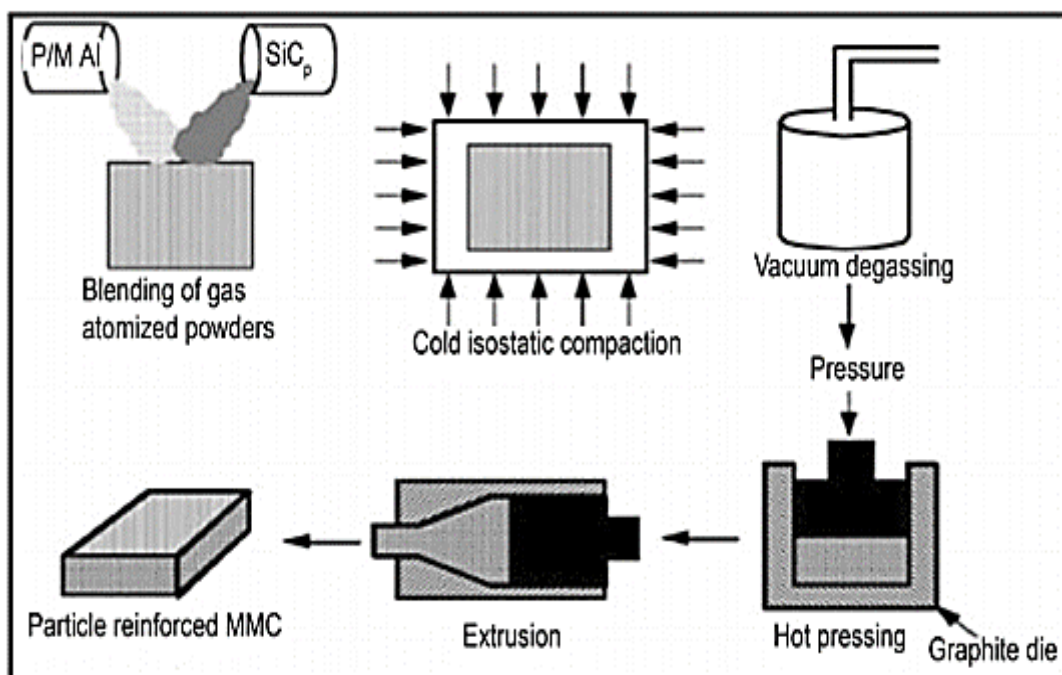


Fig 3 Powder Metallurgy Process

iv) Friction stir processing (FSP)

Friction stir processing (FSP) has evolved from the basic principles of friction stir welding (FSW) and emerged as a promising tool to alter the surface microstructure of metallic sheets and plates^[29]. During FSP, the material surface is modified by inserting a cylindrical rotating tool that contains a small pin at the end and plunged along a desired length in traverse direction by applying a suitable load. Therefore, the material at the stir zone undergoes intense plastic deformation and dynamic recrystallization is initiated^[34], which lead to refinement of the microstructure.

Friction Stir Processing (FSP) is a solid-state material processing technique which is a clone of Friction Stir Welding (FSW), invented by The Welding Institute in 1991^[3]. FSP has become a novel technique to produce Surface MMCs^[4]. Although, stir casting method is widely used for producing MMCs, because of its ability to produce complex shaped components at relatively lower costs. However, its performance is limited by many metallurgical features such as dendritic porosity, particulate oxide inclusions, Secondary Dendritic Arm Spacing, Iron phase inter-metallics, etc. FSP provides unique opportunity to embed 'wrought' micro-structure in 'cast' components by a localized modification^[4]. FSP locally refines microstructure and it also eliminates inherent defects in the starting material, thus improving its ductility, corrosion resistance, fatigue resistance, formability and a host of other properties to a great extent. A fine grain size even in the range of 30-180 nm has also been demonstrated by the researchers^[5]. FSP is used to produce Surface Metal Matrix composites (SMMCs) by mixing the reinforcement particles in the stir zone during the process^[6]. To Friction stir process a location within a plate or sheet, a specially designed cylindrical tool is rotated and plunged into the selected area. The tool has a small diameter pin with a concentric larger diameter shoulder. The rotating pin contacts the surface and as it descends to the part, friction heats the surface. When the shoulder contacts the surface, it causes additional frictional heat and plasticize a larger cylindrical column of metal around the inserted pin. The area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the entire selected area is processed and a fine grain size and the material is transported from the leading to the trailing face of the pin. As the processed zone cools without solidification due to absence of any liquid, it forms a defect constrained recrystallized surface composite with fine grained microstructure^[7]. The mechanical properties of so fabricated Surface MMCs are better in-terms of ductility, wear resistance, fatigue and creep resistance etc.

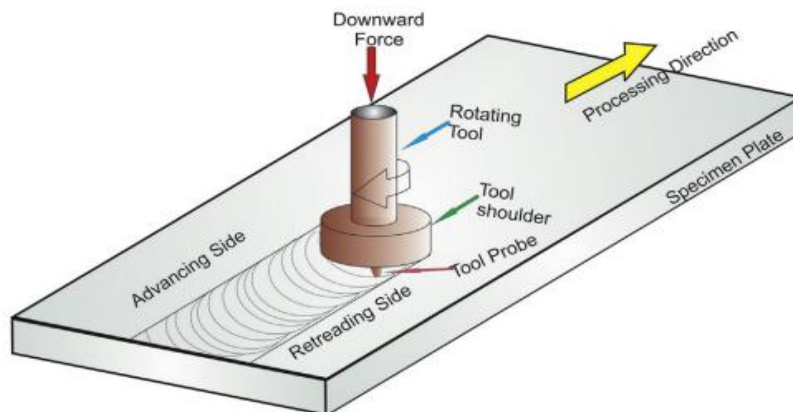


Fig 4. Friction stir processing (FSP)

The advantages of FSP include: Simple equipment with easy process parameters such as tool rotation, traversing, tool geometry and downward load etc. These process parameters are easily controlled to tailor the mechanical and technological properties of the substrate material. The problems such as wettability, unrestrained chemical reactions, sintering temperatures and the cooling rates during the classical production methods of MMCs are easily overcome in FSP.

Zones in Friction Stir Processing:

The different zones of Friction Stir processing are listed below:

- Stir Zone (SZ) or Nugget Zone
- Thermomechanically affected Zone (TMAZ)
- Heat Affected Zone (HAZ)
- Unaffected or Parental Material

Advancing and retreating sides:

The side of the processing tool where surface motion (attained due to spinning) is in the same direction as the travel direction is referred to as the advancing side. The opposite side, where surface motion opposes the travel direction, is referred to as the retreating side.

III. SUMMARY AND DISCUSSION

FSP is a very successful process to produce Metal Matrix Composites. The selection of FSP parameters is a great challenge to produce sound composite zone means uniform distribution of reinforcement particles in the matrix. Very fine particles used for reinforcement improve the grain structure and improve the overall properties of the material in the form of increased young's modulus, microhardness and Tensile strength. The large amount of plastic strain produced by FSP can shear the metal powders and break the oxide film surrounding reinforcement particles, which causes contact between the matrix and the reinforcement particles and promotes the reaction. The tendency of particle agglomeration can be significantly reduced by appropriate selection of an FSP tool shoulder diameter, which is responsible for the generation of frictional and shear forces.

IV. CONCLUSION

It has been clearly demonstrated from the study that the FSP technique can be used as a potential method to fabricate surface MMCs in solid state itself. Being difficult to process materials, magnesium and its alloys can also be easily processed using FSP to produce surface composites of different composition. Several routes such as groove filling, holes filling, sandwich method and direct methods were successfully developed to introduce secondary phase particles into the matrix metal in developing surface MMCs by FSP. However, there are some limitations associated with each method and need to be addressed by developing optimum methods in the future. The enhancement of FSP with the Mg MMC obviously increases the micro hardness. Friction stir process has been found effective to improve mechanical properties, refined grain size and homogeneous grain mixture^[6,7]. FSP is a better method for surface composite and surface modification^[8-10].

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