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Manufacturing and technological challenges in Stir casting of metal matrix composites– A Review

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Abstract

A "composite" is when two or more different materials are combined together to create a superior and unique material. This is an extremely broad definition that holds true for all composites, however, more recently the term "composite" describes reinforced plastics. This paper presents a study on the composites, production technologies related to metal matrix composites exclusively stir casting. Various processes of manufacturing metal matrix composites and how metal matrix composites are manufactured using stir casting process was discussed in this paper. Many processes like metal injection moulding ,friction stir process, mechanical alloying ,squeeze casting technology, continuous binder-powder coating etc. are used by the researchers for manufacturing metal matrix composites. Out of these processes stir casting process is very cost effective and simple. Researchers are doing lot of work in the field of production technologies of MMC which has brought down their cost to an acceptable level compared to those processed by powder metallurgy and spray casting process. Properties of these metal matrix composite materials depend upon many processing parameters of stir casting process like stirring temperature, stirring speed, stirring time, preheating time ,etc. and selection of matrix and reinforcements. This paper presents an overview of stir casting process, process parameter, & preparation of AMC material by using aluminium as matrix form and SiC, Al2O3 as reinforcement by varying proportion.
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Keywords: Composites, metal matrix composites (MMC), aluminium metal matrix(AMMC),stir casting processes, reinforcement

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1. INTRODUCTION

Composites

According to researchers a "composite" is [1] when two or more different materials are combined together to create a superior and unique material. This is an extremely broad definition that holds true for all composites, however, more recently the term "composite" describes reinforced plastics.

Benefits of Composites

Because of their advanced properties like high strength, light weight, non-corrosive, non-conductive, long life, design flexibility these are used in various applications like automobile components, sports goods, etc.

1.1 Classification of composites: three main categories:

The composites are classified as shown below in fig. 1 and discussed here [2].

- Particle-reinforced (large-particle and dispersion-strengthened)-These are composed of particle of one or more material is suspended in a matrix of another material to make the material stronger
- Fiber-reinforced (continuous (aligned) and short fibers (aligned or random)- these are the long fiber of one material is embedded in the matrix of other material which turns out to be extremely strong.
- Structural (laminates and sandwich panels)- these are layers of two or more different material are bonded together by sandwiching two layers of strong.

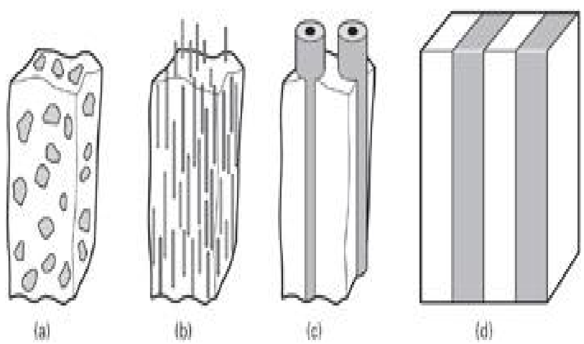

Fig. 1 – Types of metal matrix composites [2]

These types of composites cover a range of different material combinations. The most common type is polymer matrix composites, however, metal matrix composites, and ceramic matrix composites are also common, as are natural composites such as wood.

Metal matrix composites- Metal matrix composites (MMCs) are made of a continuous metallic matrix and one or more discontinuous reinforcing phases. The reinforcing phase may be in the form of fibers, whiskers or particles. The metal matrix composites have various advantages over other types of composites. Such as high strength, high modulus, high toughness and impact properties, Low sensitivity to changes in temperature or thermal shock, high surface durability and low sensitivity to surface flaws, high electrical conductivity.

2. Processing of metal matrix composites

These metal matrix composites have many advantages as compared to monolithic metals as discussed above so their applications are increasing day by day in various fields. Various processes are used to manufacture MMCs which are described here. These processes are classified [3] on the basis of temperature of the metallic matrix during processing. Accordingly, the processes can be classified into five categories: (1) liquid-phase processes, (2) solid–

liquid processes,(3) deposition techniques and (4) in situ processes. (5) two- phase (solid–liquid) processes. In this paper we have discussed only stir casting process and research work going on in the field of stir casting process.

2.1 Liquid state fabrication of Metal Matrix Composites – It involves incorporation of dispersed phase into a molten matrix metal, followed by its solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix.
The methods of liquid state fabrication of Metal Matrix Composites: Stir casting, Infiltration like gas pressure infiltration , Squeeze casting infiltration or Pressure die infiltration.
2.1.1 Stir Casting- It is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir casting as shown in figure 2 is the simplest and the most cost effective method of liquid state fabrication. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

2.1.2 Process parameters of stir casting process

This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production [3], and allows very large sized components to be fabricated. Also the cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth. In preparing metal matrix composites [4] by the stir casting method, there are several factors that need considerable attention, including (a) The difficulty of achieving a uniform distribution of the reinforcement material ;(b) Wettability between the two main substances;(c)Porosity in the cast metal matrix composites; and (d) Chemical reactions between the reinforcement material and the matrix alloy.

Proper distribution of reinforcement materials in matrix[4]

In the stir casting process it is important that the reinforcement particles should be properly distributed in the molten matrix phase during casting. During this phase sometimes problem arises because of density difference between the reinforcement particles and the matrix alloy melt. It can be avoided by vortex method in stir casting process. In this method, after the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The stirring is continued for a few minutes before the slurry is cast.

Proper wettability between reinforcement material and matrix alloy [4]

There is proper wetting between the reinforcement particles and matrix alloy to achieve the quality in cast samples of MMC. Wettability can be defined as the ability of a liquid to spread on a solid surface. Successful incorporation of solid ceramic particles into casting requires that the melt should wet the solid ceramic phase.

Porosity in cast metal matrix composites [4]

There is problem of porosity in the samples of stir casting samples of MMC. It can be minimised by proper stirring like use of mechanical stirring. It also decreases the corrosion resistance of castings. In general, porosity arises from three causes: (a) gas entrapment during mixing, (b) hydrogen evolution, and (c) shrinkage during solidification. The process parameters [5] of holding times, stirring speed, and the size and position of the impeller will influence the development of porosity.
The quality of samples which are casted in stir casting process depends on various process parameters of stir casting like stirring speed, stirring time, holding time , pouring temperature and the size and position of impeller. By controlling these parameters the porosity, wettability in cast metal matrix composites can be improved.

3. Research developments in stir casting process

According to some researchers [4] combining high specific strength with good corrosion resistance, metal matrix composites (MMCs) are materials that are attractive for a large range of engineering applications. In this paper, the relatively low cost stir casting technique was evaluated for use in the production of silicon carbide/aluminium alloy MMCs. The technical difficulties associated with attaining a uniform distribution of reinforcement, good wettability between one of the simplest ways of producing aluminum matrix composites (AMCs). Their work focused on the fabrication of AMCs reinforced with various weight percentages of SiC particulates and a constant weight percentage of Fly Ash by modified stir casting route. The wettability of SiC and Fly ash particles in the matrix was improved by adding magnesium into the melt. The SEM micrographs revealed that the addition of Fly Ash helped to prevent SiCp dissolution and the formation of Al4C3. The mechanical properties like hardness and tensile strength were improved with the increase in weight percentage of SiC particulates with constant weight percentage of Fly Ash in the aluminum matrix. They discussed [7] about Al–nano MgO composites using A356 aluminum alloy and MgO nanoparticles (1.5, 2.5, and 5 vol.%) which were fabricated via stir casting and powder metallurgy (PM) methods. Different processing temperatures of 800, 850, and 950°C for stir casting and 575, 600, and 625°C for powder metallurgy were considered. Powder metallurgy samples showed more porosity portions compare to the casting samples which results in higher density values of casting composites (close to the theoretical density) compare to the sintering samples. Introduction of MgO nanoparticles to the Al matrix caused increasing of the hardness values which was more considerable in casting samples. The highest hardness value for casting and sintering samples have been obtained at 850 and 625°C respectively, in 5 vol. % of MgO. Compressive strength values of casting composites were higher than sintered samples which were majorly due to the more homogeneity of Al matrix, less porosity portions, and better wettability of MgO nanoparticles in casting method. The highest compressive strength values for casting and sintered composites have been obtained at 850 and 625 °C, respectively. In their study [8] aluminum (Al-6063)/SiC Silicon carbide reinforced particles metal-matrix composites (MMCs) fabricated by melt-stirring technique. The MMCs bars and circular plates were prepared with varying the reinforced particles by weight fraction ranging from 5%, 10%, 15%, and 20%. The average reinforced particles size of SiC are 220 mesh, 300 mesh, 400 mesh respectively. The stirring process was carried out at 200 rev/min rotating speed by graphite impeller for 15 min. It was observed that the hardness of the composite is increased with increasing of reinforced particle weight fraction. The tensile strength and impact strength both are increased with rising of reinforced weight fraction. They discussed[9] about Elemental Mg and Mg-alloy (AZ91D) based composites reinforced with 15 vol.% silicon carbide (SiC) particulates (average particle size 15 μm and 150 μm) which were synthesized by stir casting technique. They investigated the particle distribution, particle–matrix interfacial reaction, hardness and mechanical properties in the as cast as well as T4 heat-treated conditions. The composite materials show uniform distribution of SiC particulates. The average grain size decreased with the presence of SiC particulates and the grain size further decreased as the particle size decreased. The AZ91D alloy composite shows an increase in hardness and elastic modulus compared to monolithic alloys. The improvement in elastic modulus of composite containing 15μm size SiC particles was significantly higher than the composite with 150 μm size particles.

It was [10] found that stir casting process is mainly used for manufacturing of particulate reinforced metal matrix composite (PMMC). Manufacturing of aluminum alloy based casting composite by stir casting is one of the most economical methods of processing MMC. Properties of these materials depend upon many processing parameters and selection of matrix and reinforcements. In their work they discussed about stir casting process, process parameter, & preparation of AMC material by using aluminium as matrix form and SiC, Al2O3, graphite as reinforcement by varying proportion. In their work [11] nano and micro-composites (A356/Al2O3) with different weight percent of particles were fabricated by two melt techniques such as stir-casting and compo-casting. The mechanical results showed that the addition of alumina (micro and nano) led to the improvement in yield strength, ultimate tensile strength, compression strength and hardness. It was indicated that type of fabrication process and particle size were the effective factors influencing on the mechanical properties. Decreasing alumina particle size and using compo-casting process obtained the best mechanical properties. They discussed[12] about the influence of material processing conditions for preparing aluminium based metal matrix nanocomposites through stir casting route. The role of particle size with respect to Brownian motion, Stoke's settling velocity and strengthening mechanism was assessed from theoretical understandings. Variation of microstructural features and mechanical properties of the nano composites were predicted from theoretical concepts and related mathematical models. Experiments conducted to validate the theoretical predictions showed that grain refinement strengthening mechanism remain operative which was the key to the improved strength property of the nanocomposites. Some experiments [13] were conducted by varying weight fraction of TiB2 (0%, 4%, 8% and 12%), while keeping all other parameters constant. The wear mechanism was studied through worn surface and wear analysis as well as microscopic examination of the wear tracks. This study revealed that the addition of TiB2 improves the wear resistance of aluminium composites. The results showed that increasing the mechanical properties, such as tensile strength, wear resistance and hardness caused by the percentage of TiB2 present in the samples. It was found [14] that the mechanical properties of metal matrix composites were deeply influenced by the distribution of reinforcement particulates in the matrix and the morphology of secondary matrix. They investigated the distribution of SiC particulates in a stepped (3-step) cast LM6-SiCp metal matrix composites, which were reinforced by SiCp at different weight fraction i.e. 5, 7.5,10 & 12.5wt%. The experimental results showed that the mechanical properties and forgeability of cast MMCs were different at different step of castings. The morphology of cast MMCs indicated that the distribution of SiCp is not uniform throughout the casting and it changed on changing the thickness of the casting. They studied[15] about Al–TiCp castings with different volume fraction of TiC which were produced in an argon atmosphere by an enhanced stir casting method. Specific strength of the composite has increased with higher % of TiC addition. Dry sliding wear behaviour of AMC was analysed with the help of a pin on disc wear and friction monitor. The present analyses revealed the improved specific strength as well as wear resistance. They [16] fabricated aluminium base metal matrix composites as shown in fig.2 using stir casting process and evaluated their mechanical properties. They found that as the percentage of reinforcement material which was alumina was increased from 5 to 10 % there was increase in tensile strength and hardness but % elongation was decreased.

Fig.2- Sample of impact and fatigue test(Ajay singh, et. al, 2013)

They fabricated[17]6061Al alloy / Al2O3 aluminum based metal matrix composite by an indigenously developed stir casting process as shown in Fig. 3. The fabricated sample was shown in Fig.4. They have tested mechanical properties also.

Fig. 3 – Stir casting set up

Fig.4 - Sample of aluminium based metal matrix composite

Conclusion

Now metal matrix composites applications are increasing day by day. So our focus is on developing new and economical methods for manufacturing metal matrix composites. In this paper we have discussed briefly various processes e.g. Liquid-phase processes, solid–liquid processes, deposition techniques and in situ processes which were used by the researchers for manufacturing metal matrix composites. Out of these processes stir casting process is very cost effective and simple. By controlling various parameters of stir casting process like stirring temperature, stirring speed, stirring time, preheating time ,etc. and selection of matrix and reinforcements the quality of components can be improved. Now there is lot of work going on enhancing the capability of stir casting process to make it more efficient.

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