FABRICATION OF HYBRID MMCS AND THEIR FUTURE SCOPE–A REVIEW

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Abstract - *The increasing demand of composites being used in aviation, defense and automotive industry, has enhanced the need of designing such type of fabrication techniques that are capable of economic and mass production of these composite materials. In recent times, hybrid composite fabrication has become an important issue especially with discontinuous reinforcements. Stir Casting is an important technique for fabrication of composites and hybrid composites over other fabrication techniques of such materials because it has capability of fabricating various sizes of composite and hybrid composite parts with simplicity of operation, as well as reasonably good mechanical properties of composites. This paper will review the fabrication techniques adopted by the industry people and researchers in context of hybrid composites. The study reveals that hybrid composites can be fabricated by melting metallurgy process as well as the powder metallurgical routes with little or no change in existing set up of fabrication of MMC. Hybrid composites such as* $Al/(SiC_p+Gr_{p)},$ $Al/(Al_2O_{3p}+SiC_p)$ *and* $Al/(ABO_w+ WO_{3p})$*, are found better in certain mechanical properties ,tribological behavior and also enabling the cutting down of cost of material as compared to their corosponding base matrix material alone. Indeed the addition ceramic particles/whiskers based reinforcements can improve mechanical properties while on the other end, addition of graphite particles can improve tribological behavior and machinability of the composite materials. However machining behavior of hybrid composites is tested to lesser extent as compared to other composites with single reinforcements*

Key Words: **hybrid composite, Stir Casting, machinability**

1.Introduction

Metal matrix composites (MMCs) offer high strength to weight ratio, high stiffness and good damage resistance over a wide range of operating conditions, making them an attractive option in replacing conventional materials for many engineering applications.[4,16] Typically the metal matrix materials of MMCs are aluminum alloys, titanium alloys, copper alloys and magnesium alloys, while the reinforcement materials are ceramics in general and added in the form of fibers, whiskers and particles [6,10] .Out of these Al based composites are more oftenly used in aerospace industry and they are usually reinforced by Al_2O_3, SiC, C but SiO_2, B, BN, B4C, AlN and Gr etc. [6,17].As proposed by the American Aluminum Association the AMCs should be designated by their constituents: accepted designation of the matrix / abbreviation of the reinforcement's designation / arrangement and volume fraction in % with symbol of type (shape) of reinforcement. For example, an aluminum alloy AA6061 reinforced by particulates of alumina, 22 % volume fraction, is designated as "AA6061/Al_2O_3/22p".

Particulate reinforced composites offer higher ductility and their isotropic nature as compared to fiber reinforced composites makes them an attractive alternative [10] .Some improvement was realized like in better wear behavior, better mechanical properties and low coefficient of thermal expansion in metal matrix composites [4,5,7]. So increasing number of reinforcements can improve certainly some of properties depending the nature of reinforcement or sometimes it reduces cost without altering the properties too much [1,7] .Such type of combination is called a hybrid composite. They have received considerable research and trials by Toyota Motor Inc., in the early1980s [23] .Composite materials with a metallic matrix are produced by two basic manufacturing techniques namely casting and powder metallurgy with little changes in these two.

2. Production and Processing of Composite Materials

A wide variety of fabrication techniques have been explored for metal matrix composites. These include liquid metallurgy methods, deposition of matrix from a semi-solid or vapor phase, and solid state consolidation [12]. Liquid phase processing has attractive economic aspects [10]. Chopped fibers, whiskers and particulates have been incorporated into molten matrix alloys. In some cases, pressure assistance has been used to infiltrate the reinforcement with the molten matrix. These methods result in microstructures dictated by the solidification of the molten metal. Powder Metallurgy is also extensively used to produce MMC.The important steps are : Blending of metallic powder with ceramic fibers or particulate, followed by cold compaction, canning, evacuation, degassing and a high temperature consolidation stage such as Hot Isostatic Pressing (HIP) or extrusion[22]. Achieving a homogeneous mixture can be difficult, particularly with fibers [4].

2.1 Melting Metallurgical Processing

This process can be distinguished further on the basis of the infiltration processes, where the reinforcements form a preform which is infiltrated by the alloy melt with pressure applied by a piston or by an inert gas and without pressure [4,7,10]. Composite materials can be prepared by following way under melting metallurgical approach :

- Stir casting
- Squeeze casting or pressure casting
- Gas pressure infiltration
- Reactive infiltration processes
- In deposition processes

2.1.1 Squeeze casting or pressure casting

This method is one of the common manufacturing variants for MMCs. After a slow mold filling the melt solidifies under very high pressure, which leads to a fine-grained structure. In comparison with die-casted parts the squeeze-casted parts do not contain gas inclusions, which permit thermal treatment of the produced parts [10]. In indirect squeeze casting, where the melt is pressed into the form via a gate system, the residues will remain in this gate. The flow rate of the melt through a gate is, due to its larger diameter, substantially less than with die casting, which results in a less turbulent mold filling and gas admission to the melt by turbulences is avoided. Both pressure casting processes make the production of composite materials possible, as prefabricated fiber or particle preforms are infiltrated with melt and solidify under pressure. Composite materials based on Aluminium,magnesium alloys reinforced by dispersion particles are produced by the mixing of dispersion particles in liquid magnesium alloy, or by the squeeze casting under pressure of porous preforms made of ceramic powders .[10,13] .

2.1.2 Stir Casting

In this method of production 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[13]. 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[10]. The vortex method [26] is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy. [10,26]

2.1.3 In gas pressure infiltration

The melt infiltrates the preform with a gas applied from the outside. A gas that is inert with respect to the matrix is used[15]. The melting of the matrix and the infiltration take place in a suitable pressure vessel. There are two procedure variants of gas pressure infiltration: in the first variant the warmed up preform is dipped into the melt and then the gas pressure is applied to the surface of the melt, leading to infiltration. The infiltration pressure can thereby be coordinated with the wettability of the preforms, which depends, among other things, on the volume percentage of the reinforcement[19]. The second variant of the gas pressure infiltration procedure reverses the order: the molten bath is pressed to the preform by the applied gas pressure using a standpipe and there upon infiltrates the bath [4,24]

2.1.4 Reactive Infiltration Processes

An alternative and simple manufacturing process is presented to produce high density composite materials of large dimensions [3]. The process avoids the use of high pressure apparatus, while wetting between reinforcement and melt obtained by reactive atmosphere, elevated temperature, alloy modification or reinforcement coating (reactive infiltration) [13,24].

2.1.5 In Deposition Processes

In this method**,** droplets of molten metal are sprayed together with the reinforcing phase and collected on a substrate where the metal solidification is completed. This technique has the main advantage that the matrix microstructure exhibits very fine grain sizes and low segregation, but has several drawbacks: the technique can only be used with discontinuous reinforcements, the costs are high, and the products are limited to the simple shapes that by obtained by extrusion, rolling or forging [19]. MMC material produced in this way often exhibits inhomogeneous distributions of ceramic particles [4].

2.2 Powder Metallurgy

The powder metallurgy processing technique is attractive for several reasons. This approach offers microstructural control of the phases that is absent from the liquid phase route. Powder metallury processing employs lower temperatures and, therefore, theoretically offers better control of interface kinetics[11]. The powder metallury processing approach also makes it possible to employ matrix alloy compositions and microstructural refinements that are only available via the use of rapidly solidified powders. Because of their basis as a powder, these composites must be metal worked to develop the best properties [5,11].

2.2.1 In Solid State Processes :

In solid-state processes, the most spread method is powder metallurgy PM; it is usually used for high melting point matrices and avoids segregation effects and brittle reaction product formation prone to occur in liquid state processes. This method permits to obtain discontinuously particle reinforced AMCs with the highest mechanical properties .Blending and Milling are important steps in this method [11]. They control the final distribution of reinforcement particles and porosity in green compacts which in turn, strongly affect the mechanical properties of the produced PM materials

2.2.2 Semi-Solid Powder Processing (SPP)

Semi-solid powder processing (SPP) combines the advantages of powder metallurgy and semi-solid forming [30]. In contrast to traditional bulk semi-solid forming, the process enables the mixing of various powders for improved properties and eliminates post-processing steps required for powder metallurgy routes. In general, four basic steps are involved in SPP: powder preparation, powder precompaction, heating and semi-solid forming. SPP has been applied to produce net-shaped metal matrix composites (MMCs) with low reinforcement loading (<30%). Previous work has demonstrated the potential to produce composites with high efficiency, low cost and good compositional control with promising microstructures [30].

Melting metallurgy for the production of MMCs is at present of greater technical importance than powder metallurgy. It is more economical and has the advantage of being able to use well proven casting processes for the production of MMCs.

2.3 Vapor State Processing

In this type of processing ,Physical Vapour Deposition (PVD) is mainly under consideration. An evaporation process used for composite fabrication is usually completed by assembling the coated fibers into a bundle and consolidating this in a hot pressing or HIPing operation. A very uniform distribution of fibers is produced in this way [4].

2.4 Friction Stir Processing

FSP appears to offer another route to incorporate ceramic particles into the metal matrix to form bulk composites[2]. The severe plastic deformation and material flow in stirred zone (SZ) during FSP can be utilized to achieve bulk alloy modification via mixing of other elements or second phases into the stirred alloys. As a result, the stirred material becomes an MMC or an intermetallic alloy with much higher hardness and wear resistance.

3. Processing of Hybrid Composites

The hybrid composite materials can be produced by many different techniques and main focus is concerned with discontinuous reinforcements [5]. The focus of the selection of suitable process engineering is the desired kind, quantity and distribution of the reinforcement components (particles and fibers), the matrix alloy and the application [8].

The hybrid composite fabricated by squeeze casting can have more ultimate tensile strength and the yield strength than those of the metal-matrix composite . Feng et al. [7] has studied the mechanical behavior of Al-based hybrid composite reinforced with tungsten oxide particle and aluminum borate whisker by squeeze casting . For fabrication ,first stage is to form ABO_w and WO_3 particle hybrid preform and the second stage is to infiltrate the hybrid perform with pure aluminum by squeeze casting. The mixture of the particles, whiskers and the binder was heated in a water-bath while it was being stirred. Then the mixture was pressed into a desired size. The preform was subsequently baked and sintered. The molten pure aluminum was poured into the mold at 830ºC. Subsequently, 80 MPa pressure was applied on the mixture using a 200 tons pressure machine. The molten aluminum was infiltrated into the preheated preform and then solidified for 3 min under pressure. By improving the method of preform fabrication, the pure Al hybrid composite reinforced with WO3 and ABO_w can be fabricated successfully and having the application for the protection of semiconductor devices for X-ray.

Suresh Babu et al.[27] have studied A356 aluminum alloy reinforced by graphite nanofiber (GNF) and alumina short fiber hybrid perform by squeeze casting. The preform is preheated to 400 ºC and the die is at 300º C. The developed hybrid preform was placed into the die and molten aluminum alloy was poured into the preform. The pressure applied was 10MPa.Based on the microstructure observations, it was found that a good dispersion of the alumna short fiber and graphite nanofiber in the developed MMCs .

Mondal and Kumar [20] have studied the magnesium alloy (AE420)based composites. The alloy is reinforced with Saffil short fibres having various volume ratios with SiC particulates. The creep resistance of the hybrid composites is found to be comparable to that of the incocomposite reinforced with 20% Saffil short fibres at all the temperatures and stress levels investigated. The finding revealed that from the commercial point of view, the use of the hybrid composites, replacing a part of the expensive Saffil short fibres by cheap SiC particulates, is beneficial. Simillarily Mie –Juan et al.[18] investigated the the magnesium based composite reinforced by graphite particles and Al_2O_3 short fibers The addition of Ce refines the microstructures of the composites. The study conducted on the different specimens fabricated by squeeze casting shown that the increase of Ce content, the grain size becomes smaller and the wear resistance of the composite is improved.

Ramesh et al. [28] investigated a latest development and performance analysis of novel cast copper–SiC–Gr hybrid composites. The stir casting routes were adopted to fabricate a Cu based hybrid composites. A batch of 4 kg of copper scrap was melted using a coke fired furnace. The metal was degassed using commercially available calciumborite tubes with a preparatory flux Cuprit (1 wt%). It was then agitated by a mechanical stirrer rotating at a speed of 75– 100 rpm to create a fine vortex. Preheated dispersoids (preheated to 500 ºC for 2 h) were added slowly into the vortex while continuing the stirring process. The stirring time adopted was 5–7 min. The composite melt maintained at a temperature of 1150ºc– 1175 ºC was then poured into a metallic mould. Silicon carbide was varied from 3 to 10 wt% while graphite content was 1 wt% in the prepared hybrid composites. Coated silicon carbide was varied from 3 to 5 wt% while coated graphite content was 1 wt%. Metallographic study, micro hardness, tensile strength, friction and wear tests have been conducted. The results show that the hybrid composites possess higher hardness, higher tensile strength, better wear resistance and lower coefficient of friction when compared to pure copper. The findings of Suresha and sridhara [29] suggested that, In tribological applications demanding similar strength requirement, Al–SiC–Gr hybrid composites are better substitutes to Al– Gr and Al–SiC composites owing to improved wear resistance as a result of combined reinforcement of SiC and Gr particulates and also having reduction in friction coefficient .Sasimurgan[23]adopted stir-casting method to produce cast composites with better wettability and particle distribution. The method was repeated for different wt.% of SiC and Al2O3 disperoids (3, 6, 9, 12 and 15 wt.%). Machining behavior revealed that Minimum surface roughness is achieved at a cutting speed of 60 m/min, feed rate of 0.20 mm/rev and a depth of cut of 0.50 mm.

Gupta et al [9] has chosen pure aluminum of 99.5% purity as the base material for producing DMMC. Titanium particulates of 99% purity and an average size of 20 μm were used as the discontinuous reinforcement. Galvanized iron wire mesh (0.4 vol.% zinc and 0.8-mm wire diameter) was used as the continuous/interconnected reinforcement phase. Disintegrated melt deposition technique was used for fabrication, the synthesis procedure involved superheating the aluminum pieces to 750 ◦C under inert atmosphere in a graphite crucible followed by stirring of the melt in the range of 450 rpm for about 3 min. Titanium particulates preheated to 400 ◦C were then added within a time period of 2 min . Following stirring, the composite melt was poured through a drilled hole in the graphite crucible and the resultant stream was disintegrated using two linear argon gas jets. The disintegrated composite melt slurry was subsequently deposited on a circular shaped metallic substrate containing wire mesh structure and located at 0.242m from the gas disintegration point. The manufacturing of the composite ends with secondary processing,in which Al and Al/Fe + Ti ingots obtained following disintegrated melt deposition were machined and hot extruded a reduction ratio of 13:1 on a 150 tonnes hydraulic press using colloidal graphite as the lubricant. Results of properties characterization revealed that the presence of hybrid reinforcement led to a reduction in coefficient of thermal expansion and an increase in hardness, elastic modulus,when compared to conventional Al/SiC composite formulations containing relatively higher weight percentages of SiC particulates.

Carreno-Morelli et al.[3] designed and built for unidirectional infiltration of ceramic preforms with a molten metal. Low gas pressure infiltration apparatus consisting of four major parts namely the melting chamber , the vacuum chamber , the injection chamber inside the vacuum chamber and the high pressure valve which allows one to isolate the melting and the injection chambers. It allows production of Al or Mg alloys reinforced with short or continuous ceramic fibres. This apparatus is composed of two parts: one melting chamber where the metallic alloy is melted under vacuum or protective atmosphere, and an injection chamber for preform preheating and gas pressure infiltration. In this configuration, infiltration needs a low volume of high pressure gas, and consequently, the infiltration time is reduced and the operational safety is increased. Al based alloy reinforced with Saffil fibres composites wer produced with variable process parameters and then characterised by microscopical and mechanical tests. This features that the infiltration apparatus is suitable for the production of both continuous reinforced and hybrid MMC.

Ravindran et al.[22] compared the tribological behavior of Al hybrid composite with Al based MMC.The composites were fabricated by the P/M process route. The mixing of the powder was performed in a planetary tumbler mixer using stainless steel balls with a diameter of 8 mm and a ball to powder weight ratio of 10:1. The mixed powders were pressed in a uniaxial press at 845 MPa to form green compacts . Before each run, die wall lubrication was performed manually using zinc stearate. The green compacts were sintered at a closely regulated temperature The sintered composites were solution treated at 540 C in a muffle furnace for 120 min and water quenched; then, they were naturally aged for 72 h. The addition of increased wt.% of graphite decreased the hardness, wear, and friction coefficient of the Al/SiC/Gr composites, as hybrid reinforcements can effectively improve the tribological properties of the sliding system produced by the powder metallurgy route, setting a new guideline for the design of materials for application to self-lubricated sliding wear conditions.

Ted Guo and Tsao [30] adopted a new process known as semi-solid powder densification (SSPD) in which the PM and the semi-solid synthesizing (SSS) are combined. In the study mixtures of 6061 aluminium powder (average powder size: 30 mm), SiC powder (average powder size: 45 mm) of 10 vol% (v/o), and graphite powder (average powder size: 8 mm) of 2, 5 and 8 v/o, were mixed in a V-shape mixer. The mixtures were then put into a graphite container of 10 mm in diameter & 20 mm in length and semi-solid-deformed directly. Semi-solid powder densification was carried out with a 10 ton Instron machine. The mixtures were heated to 630 ºC for semi-solid powder densification, and held for 10 min. to equalize the temperatures within the mixtures before the onset of semi-solid densification. The mixtures were then held at 40 MPa densification pressure for 10 min to form composite compacts. After semi-solid powder densification, the composite compacts were given a T6 heat treatment, in which the solution treatment was done at 530º C for 2 hr, followed by direct quenching into water. The measured behavior shown that wear rate of the composite increases as the amount of graphite addition increases up to 5% Gr addition, then drops to a lower value for 8% Gr addition. Also friction coefficient decreases as the amount of graphite increases.

Soleymani et al. [25] fabricated Al5083 based surface hybrid composite produced by *friction stir processing for* this Commercially Al5083 rolled plates of 3 mm thickness with a nominal composition of 4.3Mg–0.68Mn–0.15Si–bal. Al (in wt pct) were used as the base material. A mixture of SiC and MoS2 powders at weight ratio of 2 to 1 were used as the reinforcement. MoS2 particulates .A tool made of H-13 steel with a shoulder of 20 mm diameter and a pin of 6 mm diagonal length and 2.8 mm height with a tilt angle of 3◦ was used to perform the FSP. The reinforcing powder was packed in a groove of 2 mm depth and 0.65 mm width machined out on the Al plate. A rotating tool with 20 mm diameter and without pin was applied in order to close the groove and prevent the sputtering of mixed powder during FSP. A single pass friction stir process with rotation speed of 1250 rpm and travel speed of 50 mm/min was subjected in room temperature to all samples. Identification of the various wear mechanisms was achieved through. The tribological studies showed that surface hybrid composite has the highest wear resistance in comparison to other samples

4. Conclusion

The possibility of bulk size, simplicity of operation and reasonably good mechanical properties of composites; stir casting is having an edge over other composite fabrication techniques. Some improvement has realized like better wear behavior, better mechanical properties and low coefficient of thermal expansion in composite material that can be fulfilled by increasing the number of reinforcements .The study reveals that hybrid composites can be fabricated by melting metallurgy process as well as the powder metallurgical routes with little or no change in existing set up of fabrication of metal matrix composites. Hybrid composites such as Al/(SiC_p+$Gr_{p)}$, ,Al/(Al_2O_{3p}+SiC_p), and Al/(ABO_w+ WO_{3p}), etc.are found better in certain mechanical properties ,tribological behavior and also enabling the cutting down of cost of material. Indeed the addition ceramic particles/whiskers based reinforcements can improve mechanical properties while on the other end, addition of graphite and ferrous particles can improve tribological behavior and machinability of the composite materials. However machining behavior of hybrid composites is tested to lesser extent as compared to other composites with single reinforcements

Presently, melt infiltration techniques are used to produce components for automotive engine and electronic substrate applications and powder processes are employed for aerospace applications. It is likely that, as composite and hybrid composite applications continue to expand, the spectrum of materials and processes employed will remain relatively wide.

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