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Comparative Study of Synthesis of Al6061-B_4C Metal Matrix Composites - A Review

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Abstract

Amongst the existing synthesis methods of composite materials, stir casting is a striking synthesis method for producing Al6061-B_4C (boron carbide) Metal matrix composites (MMCs). It is inexpensive and bids an extensive choice of materials and synthesis circumstances. The stir casting technique includes the introduction of preheated ceramic particulates into the vortex of melt created by the rotating stirrer. In this method, to attain the optimal properties of the metal matrix composite, the dispersal of the reinforcement material in the matrix should be unchanging and the wettability between the melt matrix and reinforcement particulates should be enhanced. An appropriate amalgamation can be produced by this technique by appropriate choice of the method parameters such as pouring temperature, stirring speed, preheating temperature of reinforcement, use of carrier gas etc. Grave to the accomplishment of stir casting is the control over normally disagreeable features such as porosity ensuing from gas entrapment during mixing, oxide inclusions. Present study involves a comparison between top, bottom pouring methods, and optical microstructure obtained after casting by both the methods.

Keywords: stir, pouring, cluster, porosity, interface

Introduction

A universal testing machine is usually used to test properties of metals [1] and properties composites are dependent on the method of making them. Metal matrix composites (MMCs) is an advanced material with a minimum of two essential components, with one as a metal and the other as a different material like ceramic. If there are three constituent parts with one being metal, then it is known as a hybrid composite. A MMC is like man made concrete used for construction of buildings or natural like bones in human beings. MMCs are made by dispersing reinforcement in a matrix of metals. The surface of reinforcement could be coated to maintain chemical stability. An instance is the coating of carbon fibre with titanium boride or nickel since carbon easily reacts with Aluminium (Al) to form water soluble and brittle Aluminium carbide (Al_4C_3) compound. Matrix is a base metal into which the reinforcement is dispersed, continuous and complete. The matrix material is usually light like Al and assists in giving a compatible support to reinforcement [2-5]. A ceramic material which can sustain high temperature can provide its attribute to the MMCs for high-temperature applications. Reinforcement material is dispersed into a matrix material and serves as supporting constituent to take up the load by modifying the physical, mechanical and tribological properties like density, hardness, tensile strength, wear resistance [6-10]. The reinforcement could be either continuous or discontinuous. Continuous reinforcements are used in applications where load is to be more aligned along one direction and discontinuous reinforcements are used where load is to be shared in more than one direction. There are three types of MMCs like particulate reinforced, short fibre/whisker reinforced and continuous fibre reinforced. The vital characteristics of MMCs are light weight, strength, wear resistance, fatigue resistance, good properties at elevated temperatures, low thermal expansion etc. The methods of manufacturing MMCs are solid and liquid state types. The solid-state methods include predominantly the powder metallurgy technique, and the liquid-state method includes stir casting [11-15]. Apart from these methods there are other methods like foil diffusion, squeeze casting, pressure infiltration, spray deposition, reactive processing, electroplating, electroforming etc. Advanced techniques like vapour deposition are also used [16-19]. Typical engineering structures containing MMCs include carbide drills, tank armor, automotive disc brakes, automotive engines, nuclear applications, and the F-16 Fighting Falcon. MMCs when fabricated at elevated temperatures evolve an essential requirement of bonding of reinforcement/matrix interface. After cooling to ambient temperature, residual stresses are induced in MMCs since there is a mismatch between the coefficients of thermal expansion (CTE) of matrix and reinforcement. Theses residual stresses are vital in determination of properties of MMCs at all loading conditions. Al-Gr MMCs are used in electronic modules due to adjustable thermal conductivity and low density.

Since MMCs are expensive they are used in applications where improvement in properties is essential at the expense of additional cost is justifiable. The scope of applications will increase when manufacturing costs are reduced. In contrast to polymer matrix composites (PMCs), MMCs are resistant to fire, operate at a range of temperatures, resistant to radiation, corrosion resistant and have better electrical and thermal conductivity. Diverse means have been approved for fabrication of MMCs [20-24]. The foundry processes that are conventional are finding importance since proper shape parts at higher rate of production with economy can be synthesized.

In stir casting, other methods like compocasting, rheocasting, disintegrated melt deposition are variations. Stir casting mixing particulates into melt and stirring by mechanical impeller. Composites of A536 and 6061 reinforced with 10% and 20% fraction volume of SiC particulates were manufactured by gravity casting and a new approach of two-step mixing was adopted to improve distribution and wettability of particulates. SiC particulates are observed in the inter-dendrite regions, due to a thermal lag. Nano particulates enhance hardness, yield, and ultimate tensile strength (UTS) when mixed in Al matrix, while ductility is retained. This is due to the refinement of grain, size of particulates, good distribution of particulates, less porosity, and thermal stress induced is multidirectional. All these enhancements lead to effective load transfer from matrix to particulate.

Strength of MMCs is improved due to increase in dislocation density due to thermal mismatch between particulates ad matrix constituents. A 50% enhancement in yield of A356b alloy is due to 2% weight (wt.) fraction of nano sized SiC particles. A recent development in stir casting is two-step mixing process where matrix alloy is heated above its liquidus temperature for melting and further cooled between liquidus and solidus to keep in semi-solid state. At such a point, preheated particulates are added, mixed and then further slurry is reheated to liquidus to mix thoroughly [25-29]. The common stir casting synthesis equipment parts are shown in figure 1.1.

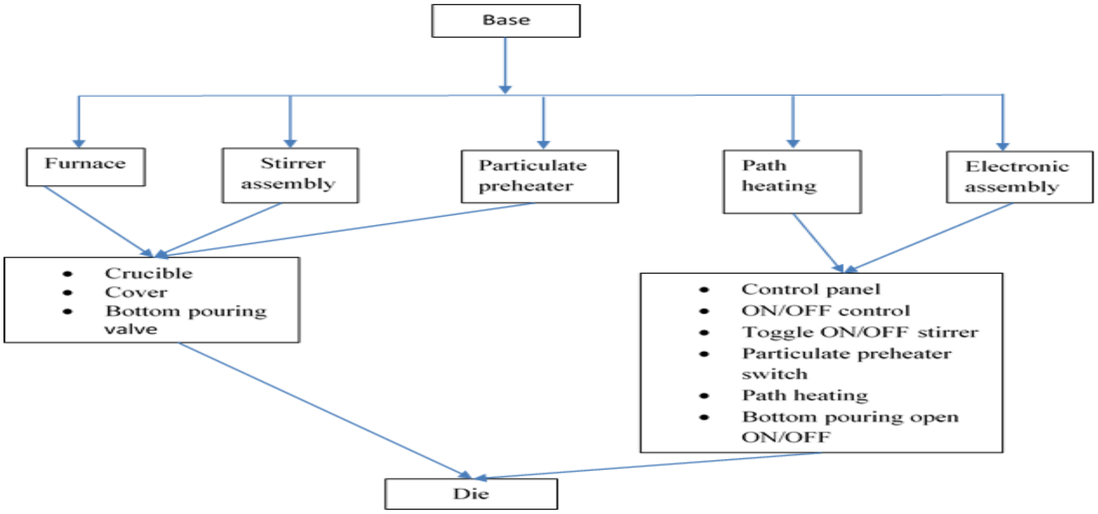

Fig1.1 Stir casting equipment block diagram for bottom pouring furnace.

Materials and Methods

In supplement to being lightweight, Al6061 alloy are resistant to corrosion, maintain strength at elevated temperatures offer elevated dimensional constancy while casting complex geometry and regions with narrow wall width. They retain elevated electrical and thermal conductivity. Machining Al6061 alloy is easy when related to other materials including iron, steel, and titanium. Al6061 is corrosion resistant under majority of service conditions, and no colored salts are formed to stain adjacent surfaces or discolor products with which it comes into contact.

The expansion purposes for low weight Al6061-B_4C MMC materials are:
Rise in yield and tensile strength at room and above temperature while preserving the lowest ductility/ toughness, rise in creep resistance at hot zones compared to that of orthodox alloys, rise in fatigue strength, particularly at hot zones, enhancement of resistance to thermal shock, enhancement of resistance to corrosion, rise in young's modulus, and decrease of thermal elongation.
Al6061 is a precipitation hardened Al alloy mainly consisting of Silicon (Si) and Magnesium (Mg). It is available in three grades like Al6061-O, Al6061-T4 and Al6061-T6. It has good mechanical properties and is easily weldable. It is used in aircraft structure construction, boats, automobile parts, bicycle frames, ultra-high vacuum chambers, radio antennas etc. The material was purchased from PMC corporation, Bengaluru. The purpose of the Al6061 alloy is to hold the particulates together by quality of its unified and adhesive features, to transference of load to and between B_4C, and to shield the B_4C from environment and handling. The Al6061 alloy also offers a solid system to the MMCs, which helps treatment through production and is classically essential in a complete component. This is predominantly essential in unevenly reinforced Al6061-B_4C MMCs, as the B_4C are not of adequate span to offer a holdable shape. Since B_4C are classically stronger and stiffer, the Al6061 alloy is weak region in MMC, from a structural standpoint. As a constant phase, Al6061 alloy controls the crosswise properties, and raised-temperature strength of Al6061-B_4C MMCs. However, Al6061 alloy allows the strength of the B_4C to be used to their full potential by providing effective load transfer from exterior forces to B_4C. The choice of

B_4C as the reinforcement material is due to lower density, mechanical compatibility, chemical compatibility, thermal constancy, high young's modulus, elevated compression, and tensile strength, upright processability, monetary efficacy. Carbides have strength, stiffness though being brittle and are hard. There has been very little survey with B_4C as particulate due to its higher cost.

It is useful for bullet proof vests, neutron absorbing storage cases in nuclear plants and armour tanks. It has higher hardness and lower density as compared to silicon carbide (SiC) and alumina (Al_2O_3) which are the two commonly used and analysed particulates with much extensive study. The material was purchased from Quesst International, Bengaluru who is a distributor for Sigma Aldrich. The particulate size is -200 mesh (74µm). A unit cell of B_4C is shown in Figure 2.1. The green sphere and icosohedra are boron atoms and carbon atoms are black [30-36].

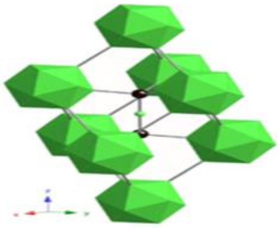

Fig 2.1 Image of crystal structure of B_4C [32]

Though cumulative expansion activities have directed to system solutions using metal composite materials, the usage of particularly pioneering systems, predominantly in light metals, is not understood. The motive for this is inadequate method constancy and dependability, united with manufacture and processing difficulties and insufficient monetary efficacy. The chief aspects behind the extensive acceptability of Al-B_4C MMCs are (a) accessibility of a range of B_4C reinforcement sizes at rational costs, (b) recognized engineering methods that can yield reproducible microstructures and properties, and (c) accessibility of metal working methods to form these resources. Stir casting method parameters are described as follows.

The selection of stir casting as synthesis method is by considering the restraining parameters of particulate content (up to 30% by volume), particulate alignment which is random, price of the method is less and production proportion is high due to conventional way of manufacturing, the synthesis technique has the limitation of part size. For manufacturing of Al6061-MMCs liquid metallurgy route via stir casting the working process parameters are important for success of synthesis. If these process parameters are properly administered adequately, it can enhance the properties of the MMCs. Stirring speed is the important method variable since stirring is vital in increasing wettability and influence the flow pattern of the melt. Turbulent flow is preferred over laminar flow since good mixing is possible with matrix. The turbulent flow pattern from inside to periphery is preferred. In this study, the speeds were kept at 400 & 500 revolutions per minute (rpm) for synthesis of Al6061-2wt.%B_4C MMCs. Two castings were synthesized of composition Al6061-2wt.%B_4C by top pouring and Al6061-2wt.%B_4C by bottom pouring technique with

500rpm and 400rpm stirring speed, respectively. Since, the solidifying rate is high it will increase the wettability.

Stirring temperature is a vital process parameter since it is related to melting temperature of base metal alloy used in making the MMCs. Al has a melting point of around 650°C and it influences the viscosity since alteration of viscosity dominates the distribution of particulate in matrix alloy. When the temperature and stirring time were increased the viscosity reduced accelerating the reaction between particulate and matrix alloy. In the present study, the pouring temperature was kept at 710°C. The particulate preheat temperature was 300°C for a duration of 25 minutes to eliminate moisture and to improve wettability. Mg was added to increase wettability however higher addition leads to increase in viscosity, thus leading to bad distribution of particulates in matrix alloy. The stirring time is also vital in determination of distribution and hence the properties of the MMCs since it leads to a good bonding and interface. In the present study, it was kept for 10 minutes for better melt flow from inside to periphery. The particulates were added to vortex of the stirred melt at a uniform rate through a feeding pipe. The stirrer plays a vital role in synthesis due to the following mentioned reasons: i. transfer particulates into melt. ii. maintain the particulates in suspension in melt. iii. increase surface energies of the solid. iv. decrease surface tension of the liquid melt. v. decrease solid-liquid interface energy at the particulate-matrix interface. Six basic factors involved in both top and bottom pouring techniques casting process are mold cavity preparation, melting process, pouring technique, solidification process, part removal process, post processing. In the present study, a permanent mold has been used. Permanent molds have a life which varies depending on maintenance after which they require refinishing or replacement. Cast parts from a permanent mold generally show 20% increase in tensile strength and 30% increase in elongation as compared to the products of sand casting. The only necessary input is the coating applied regularly. Typically, permanent mold casting is used in forming iron, aluminum, magnesium, and copper-based alloys. Mold is reusable and Control of mold temperatures is possible.

(a) (b)

Fig 2(a-b). Top and bottom pouring furnaces used in the study.

These facts assisted in deciding this technique of casting suitable for synthesis of Al6061-B_4C MMCs. In case of top pouring, the melt flows directly from the top into the mold cavity whereas with bottom pouring the melt flows into the lowest mold cavity area filling it from the bottom to the top.

The top pouring method has the following characteristics :
a. The Al6061melt mixed with B_4C has a great impact on the bottom of the mold and has a lot of contact with the air, which is easy to cause casting defects such as porosity, cold beans, oxide inclusions, etc.
b. The solidification mode of casting is from bottom to top, which improves the feeding capacity of riser.
c. The spatter is large during pouring, which requires high side wall strength of the mold.
d. Quick filling and convenient operation.
In bottom pouring type, it is usually the following characteristics :
a. The Al6061 melt mixed with B_4C has less impact on the mold and will not cause splashing.
b. The Al6061 melt mixed with B_4C rises slowly from the bottom to the top, the cavity is easy to vent, and the Al6061 melt mixed with B_4C is not easy to oxidize; however, the rising direction is just opposite to the feeding direction of the riser, which reduces the feeding capacity of the riser.
c. The temperature distribution of the casting is even, and the metallographic structure is even [37].

Results and Discussions

Microstructure is the structure on a small scale by preparing surface of a material, by sectioning the material, polishing, etching, and viewing under a light microscope at different magnifications. The microstructure determines the properties of the material like resistance to wear, hardness and strength. The process of taking the image of the surface of the material after subsequent sectioning, polishing, etching helps in determining the voids/porosity, inclusions, and crystal orientation. In the present study, micrograph was taken under a light microscope with Nikon make with clemex image analyser. Micrograph of Al6061 alloy is shown in figure 3(a).

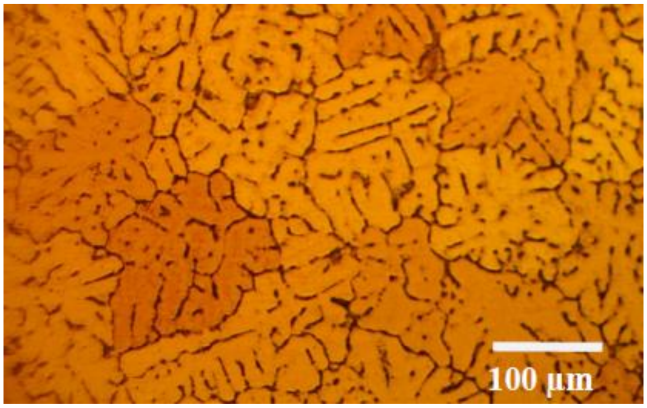

Figure 3(a) Microstructure of Al6061 alloy

The micrographs revealed under the microscope by top and bottom pouring methods are shown in figure 4(a-b). It is observed in figure 4(a) that are dark dispersion in Al6061 matrix alloy which are particulates of B_4C. There is good distribution and bonding of the particulates with the Al6061 alloy. No porosity or cracking is observed in the micrograph of Al6061-2wt.%B_4C MMC synthesized by top pouring method. It is observed in figure 4(b) that are dark dispersion in Al6061 matrix alloy which are particulates of B_4C.

There is good distribution and bonding of the particulates with the Al6061 alloy. The debonding of B_4C from Al6061 alloy suggestively decreases the strength, toughness, and ductility of the Al6061-B_4C MMCs. Cracks originated when stress exceeds strength of the Al6061-B_4C interface, frequently at the positions where extreme stresses are produced like, at the ends of spherical particulates and at corners of triangular/rectangular B_4C particulates. The impairment proliferates as the crack raises beside the Al6061-B_4C interface and reduces the degree of load that spread to B_4C from Al6061 alloy. Finally, voids mature from the cracks in interface and rupture takes place by union of interfacial voids. This mechanism is broadly accepted for MMCs. Nevertheless, this evidence has been acknowledged qualitatively. Exact assessable statistics on the self-determining effect of Al6061-B_4C interface properties on macroscopical behaviour and miniscule rupture method are not accessible in literature. The complications linked to the Al6061-B_4C interface are organic reactions, particulate deprivation, deficit in wettability with matrix etc. Hence, Al6061-B_4C interfaces are suggestively affected sections at the time of production as well as under service conditions. It is also observed in aqueous environments that corrosion begins in the form pitting at the interface if the bonding is not proper. The common temperature domains of corrosion in water are: <70°C – pitting corrosion dominates, 60-100°C – tendency to pitting decreases, 100-150°C – general corrosion, 50-250°C general corrosion and inter-crystalline corrosion, 250°C – change to linear rate law, highly destructive inter-crystalline corrosion with rapid destruction of the metal. In the present study, no porosity or cracking is observed in the micrograph of Al6061-2wt.%B_4C MMC synthesized by bottom pouring method. In general, porosity arises from three causes like gas entrapment during blend, evolution of hydrogen, shrinking during solidification. In some claims, Al6061-B_4C MMCs bid greater performance; for example, in elevated-temperature applications like diesel engine pistons, connecting rods, and in turbomachinery SiC reinforced Al-MMCs are used. Though, in some elevated-temperature claims, fiber reinforced ceramics perform to be a possibly strong contestant. Al6061-B_4C MMCs may find abundant claims in proposals where weightiness, diminished life cycle expenses, wear resistance, and thermal constancy are irresistible deliberations. Part of the resistance to enlargement of claims of Al6061-B_4C MMCs is related to naivety and inadequacy of consistent proposal data, chiefly for safety serious claims. Accordingly, the choice to use Al6061-B_4C MMCs must not be based on price deliberations only, but on practical and working criteria also.

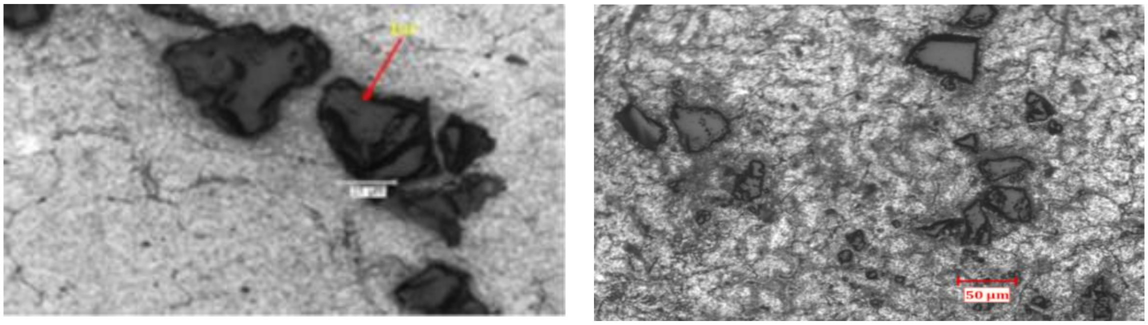

Figure 4(a) Microstructure of Al6061-2 wt.%B_4C alloy by top pouring technique

Figure 4(b) Microstructure of Al6061-2 wt.% B_4C alloy by bottom pouring technique

FIGURE 4(a-b) Microstructure of Al6061-2wt.%B_4C by top and bottom pouring method.

Conclusions

Synthesis of Al6061-2wt.%B_4C MMCs by liquid metallurgy route via stir casting method of particulate size 74µm respectively was obtained successfully. Good wetting leads to a strong bond between reinforcement particles and matrix, adding surface-active elements such as Mg has enhanced the wettability. Preheating of particulates improves the wettability of reinforcement particulates in the matrix material which is to be concluded from the observation of optical micrographs. The optical studies carried out by using optical microscope indicated the presence of reinforcement particulates, with homogeneity, decent distribution and good bonding between the matrix and reinforcement material. Use of stirrer for mixing of reinforcement particles helps in better distribution of particles in the matrix material and breaking up of agglomerates which further enhances the strength of the composites. B_4C can seize Helium that is generated by neutron absorption of boron nuclide because of its specific crystal structure. Consequently, B_4C is appropriate to be a neutron captivating material in the basket. In adjunct, heat degeneracy is a critical reason to select the basket material. Aluminum has a high thermal conductivity therefore, B_4C/Al MMC is extensively utilized as a basket material in nuclear applications provided low humidity for longer duration and microstructural changes at temperature near to 300°C tests are done on the material. The temperature usually is around 300°C in used nuclear fuel placing baskets. The synthesized Al6061-B_4C MMC could be tested for such an application. Al6061-B_4C MMCs could also be use in wear resistant applications since the particulate is very hard and it provides its attributes to the MMCs which is the main objective of making any composite.

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