AA 6061 Metal Matrix Composites

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AA 6061 is an aluminium alloy that has extensive applications due to its superior material characteristics. It is a popular choice of matrix for aluminium matrix composite (AMC) fabrication. Stir casting method is widely for fabricating AA 6061 composites with reinforcements such as SiC, B4C, Al2O3, TiC, other inorganic, organic, hybrid and nanomaterials. An increase in reinforcement content enhances the mechanical and tribological properties of the composites. Hybrid composites show better material properties than single reinforcement composites.

Keywords: AA6061 alloy ; fabrication methods ; stir casing ; metal matrix composites

1. Introduction

Aluminium alloys are the predominant nonferrous metal used in various applications due to their plentiful desirable material properties. As a result of the extensive studies conducted, numerous alloys of aluminium have been created with an objective to improve the specific required material properties. Composites are multiphase materials that consist of matrix and reinforcement, which were developed to fulfil the ever-increasing demand for attractive engineering materials. Generally, composites exhibit excellent thermal properties and outstanding mechanical characteristics including higher strength, hardness, fracture toughness and better resistance to wear and corrosion [1]. Composites are classified according to the type of matrix material present in it. They are categorized into three major types as polymer matrix composites (PMCs), ceramic matrix composites (CMCs) and metal matrix composites (MMCs). In MMCs, matrix material will be a metal. It is the continuous phase of composite and functions as a binder that surrounds the reinforcement. The metal matrix transmits and distributes the load to the reinforcement, which is the dispersed phase [2]. Aluminium matrix composites (AMCs) are having pure aluminium or its alloy as the matrix, and are being increasingly utilized in industrial applications owing to their remarkable mechanical, material and tribological characteristics. AA 6XXX aluminium alloy series in which silicon and magnesium are the principal alloying elements are gaining particular interest in the aviation and automotive industries. The remarkable strength to weight ratio offered by this series of alloy along with their better formability, weldability, resistance to corrosion and wear, and low cost made it a potential material for the manufacturing of lightweight vehicles [3]. AA 6061 is one of the most popular alloys in the 6XXX series, being used as matrix material in numerous AMCs because of the possibility to alter the composite strength through suitable heat treatment. The AA 6061 alloy composition is shown in Table 1 below [4].

Table 1. Chemical composition of AA 6061 aluminium alloy.

Element	Composition (Mass Percentage)
Al	95.85–98.56
Mg	0.8–1.2
Si	0.4–0.8
Fe	0.0–0.7
Cu	0.15–0.40
Cr	0.04–0.35
Zn	0.0–0.25
Ti	0.0–0.25
Mn	0.0–0.15

The base alloy is having a tensile strength of 115 MPa, Rockwell hardness of 30 HRB, and elastic modulus of 70–80 MPa. AA 6061 alloys are primarily used in the automobile and aviation sectors for manufacturing lightweight parts. A wide variety of reinforcements have been used to fabricate the metal matrix composite (MMC) using AA 6061 matrix, which include the compounds such as SiC, B_4C, Al_2O_3, TiC, Si_3N_4, BN, ZrO_2 and so on. Several nanocomposites are also produced on a larger scale recently, with the AA 6061 alloy matrix [5].

2. Aluminium metal matrix composites

Composite materials developed with enhanced characteristics acknowledged a great deal of attention in multiple areas such as aviation, automotive, military and other manufacturing industries because of their distinct features and superior quality compared to their base materials [6]. The possibility of adding high strength particles as reinforcements also helps to overcome any disadvantages of matrix materials [7]. Reinforcement addition in aluminium matrix is reported to cause improvement in tensile strength, compressive strength, impact strength and hardness of the composite. Usually, wear resistance of AMCs are also higher than that of unreinforced aluminium or aluminium alloys [8][9]. Materials of various kinds are utilized as reinforcements in the manufacturing of AMCs. They can be used in the form of particles, whiskers, short fibres and continuous fibres. Compared to the other types, particle reinforcements have better isentropic properties that make them capable to distribute uniformly in the matrix phase [10]. Hence, they are preferred in AMC fabrication and are used mostly in automobile components manufacturing due to their superior tribological properties. Ceramic, synthetic, industrial waste and agro-waste reinforcement particles having micro or nano-size can be effectively blended with matrix material to produce AMCs [11].

3. Stir casting of AMC

In the past decade, an extensive range of methods have been developed for producing MMCs. Mechanical properties and production cost of the composite significantly depend upon the type of fabrication method involved. These fabrication methods can be classified based on the state of the metal matrix in primary process treatment, into solid and liquid state processing. In solid-state fabrication, bonding of matrix with reinforcements occurs as a result of the mutual diffusion arising between them in solid state at higher levels of temperature and pressure. Liquid state fabrication involves dispersion of reinforcements in the molten matrix, followed by its solidification, either through infiltration or casting methods [12]. These methods are cost-effective compared to solid-state methods. Stir casting is the most popular and commercially used technique in liquid state processing since it is economical compared to other manufacturing techniques. It also provides fairly homogenous dispersion of reinforcements in matrix, better wettability and reduced porosity [13]. Stir casting primarily involves the mixing of dispersed phase in matrix phase, which is facilitated using a stirring mechanism. Electrical energy is often used to energize the stir casting furnace and electrical resistance heating is the commonly used method of heat generation. The process comprises of heating the matrix placed in the crucible, up to its melting point. Crucible is made as chemically inert to the matrix and reinforcements. Preheating of the reinforcements is often carried out to improve the mixing between the materials. Mixing takes place in molten condition and an inert condition may be kept while stirring and pouring of charge, so as to reduce the chances of casting defects. Particulate reinforcements are usually fed through an injection gun in order to reduce the possibility of gas entrapment. Propeller blades of the stirrer are attached to a shaft, connected with output of the electrical motor, which imparts rotational motion. The vertical motion of the stirrer can be effectively controlled through a lead screw arrangement powered by another electrical motor. Stepper motors are commonly used for varying the rotational speed of stirrer [14]. For achieving a homogenous mixture through this process, wettability between the matrix and reinforcement should be proper [15]. Schematic diagram of the stir casting process of AA 6061 composites is shown in Figure 1.

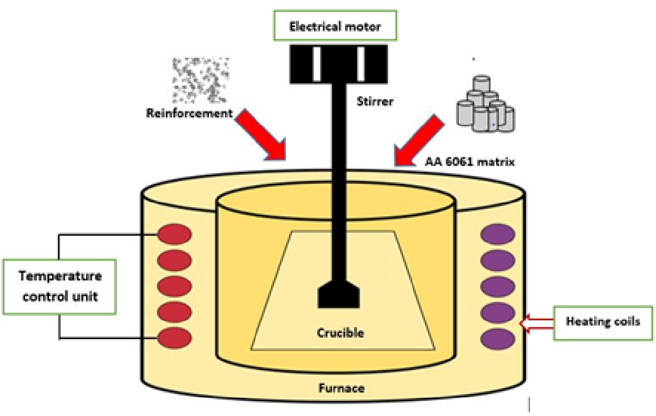

Figure 1. Schematic diagram of stir casting method of AA 6061 composites

4. AA 6061 composites developed through stir casting route

Researchers have developed an extensive set of AA 6061 composites using organic as well as inorganic reinforcements. Generally, reinforcement weight composition in the composite ranges from 5 wt% to 30 wt% as that of AA 6061 alloy. Several types of reinforcements are made to mix together and used in composite production as hybrid reinforcement, which further improves the properties. Nano AA 6061 composites are also gaining popularity among researchers, in which nano-sized particles are used as reinforcements. SiC, Al_2O_3, B_4C and TiC particulate reinforcements are very popular reinforcements owing to their excellent ability of composite characteristics improvement. Many other reinforcements such as molybdenum disulfide, glass, iron ore, red-mud, hematite, rutile, steel machining chips, bamboo charcoal were also used to form AA 6061 AMCs. Uniform distribution of reinforcements in matrix could be observed in microstructural evaluations of AA 6061 composites fabricated by stir casting. Excellent bonding exists between matrix and reinforcement in the composites with uniform distribution. The mechanical characterization of the several AA 6061 composites revealed that tensile strength, compressive strength, and hardness were improved as the weight fraction of reinforcement increased. Wear properties also showed considerable improvement because of the presence of reinforcement particles in composites. Grain size was reduced as a result of reinforcement addition. But increasing the weight fraction beyond a limit may deteriorate the properties, due to increased porosity, agglomeration and non-homogeneous particle distribution at higher reinforcement content.

Two or more reinforcement particles were used in hybrid AA 6061 composites, which resulted in better properties. Reinforcements can be selected based on the specific properties desired. Since more than one type of materials are reinforced in hybrid composites, each type could contribute particularly to the enhancement of mechanical properties of composite. Hybrid AA 6061 composites can be effectively engineered depending on the applications and required properties. There has been an increasing trend in the usage of industrial as well as agricultural waste products as dispersed phase. Materials like fly ash, bamboo charcoal, rice husk and other industrial as well as agricultural residues are being used. Reinforcement addition should be limited to the optimum weight fraction in order to avoid material defects. Nano composites of AA 6061 produced by stir casting exhibited enhanced mechanical properties. But porosity formation is a major drawback reported in the fabrication. The nano sized reinforcement particulates have higher surface to volume ratio and poor wettability. Thus, dispersion of particles in matrix phase become non-uniform. Heterogeneous distribution of reinforcement particles in the matrix also affects the properties of composites. When the reinforcement weight fraction is increased beyond a limit, the composite shows decline in characteristics. Usually at higher reinforcement content, clustering and agglomeration of nano particles takes place which affects the properties. Volume of porosity will also increase as the amount of nano particulates increases. Hence addition of reinforcement should be properly controlled. Ultrasonic assisted stir casting followed by squeeze casting can effectively reduce the porosity and increase the homogenous distribution of nanoparticles. Ultrasonic vibration will be very effective in dispersing the nano particles uniformly in the matrix. Vigorous vibration generated by the ultrasonic vibrator could be able to inhibit the formation of clusters and agglomeration in composite. High power ultrasonic vibrations generated by the ultrasonic probe could lead to acoustic streaming and strong cavitation effects. Transient cavitation triggers the breakdown of gas microbubbles near the reinforcement particle clusters, to shatter the clustered particles and disperse them uniformly in the molten pool. In addition, acoustic flow, which is the flow of liquid due to the acoustic pressure gradient, causes the stirring to be extremely effective [17]. Squeeze casting of the composite is also greatly recommended for reducing the material defects and to improve the mechanical properties. Solidification under pressure would results in fine grained microstructure with homogenous dispersion. Future studies could focus on the fabrication of metal matrix nano composites (MMNCs) through stir casting combined with squeeze casting, since it proven as an economical as well as effective method of MMNC fabrication.

The properties of AA 6061 alloy were significantly improved by the addition of reinforcements. Generally, as the weight fraction of reinforcement in composite increases, mechanical properties such as hardness, tensile strength, impact strength show improvement. Wear resistance was also improved as the content of reinforcement increases. But addition of reinforcement beyond a certain limit may cause reduction in properties. This was mainly due to the formation of porosity, clusters and agglomeration at higher level of reinforcement content. Excellent mixing of matrix and reinforcement phases are necessary to achieve homogenous distribution of particulates. Ultrasonic assisted stir casting and squeeze casting can be employed for fabricating composites with better properties and fewer defects.

5. Conclusion

- AA 6061 is one of the most popular aluminium alloy used in various applications. Numerous AA 6061 composites were produced by reinforcing various organic and inorganic materials by stir casting method The composites fabricated showed superior properties than the base alloy.

- Stir casting process parameters like speed of stirrer, stirring time, stirrer blade design, reinforcement size and melt temperature have great effect on AA 6061 composite characteristics. Optimization can be done to achieve suitable parameters.
- The properties of the AA 6061 composites had a strong dependence on the weight fraction of the reinforcement particles. Increasing the weight fraction of reinforcement could improve the mechanical and tribological properties of the composite. However, reinforcement addition beyond a limit would lead to formation of pores and agglomeration, and affects the properties.
- Hybrid and nano AA 6061 composites having enhanced properties can be developed by stir casting techniques. The combination of proper reinforcements improved mechanical, tribological and corrosion properties of composites.
- Ultrasonic assisted stir casting and squeeze casting were found to be effective in reducing the formation of pores, clusters, and agglomeration. It can lead to homogenous distribution of reinforcement particulates and improve the mechanical properties.

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