Metal Matrix Alloy AA 6061 Produced by Stir Casting Method

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Abstract:
In compared to base alloy, aluminum composites made from the AA6061 alloy perform better and have better material properties. The current work provides a thorough analysis of the AA 6061 metal matrix composite (MMC) produced using a traditional stir casting technique. Process parameters and characterization techniques have both been discussed. Upon review, it was found that the most often employed reinforcements for the production of AA 6061 metal matrix nano composite (MMNC) were Al2O3, B4C, SiC, and TiC. Other acceptable reinforcements, such as hybrid, inorganic, nanomaterial, and organic reinforcements, are being considered in the current trend. The AA 6061 hybrid composites have comparable superior qualities to single component composites because they contain two or more reinforcements. There is a tonne of room for AA study. Research on the AA 6061 nanocomposite, which has significantly higher strength and wear resistance and is suitable for aerospace and defence applications, has a lot of potential
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Keywords: AA6061 alloy, stir casting process, reinforcement, nanocomposites

1 Introduction and Literature Review

Aluminum is the most popular nonferrous metal that has immense applications in industrial application [1]. The thermo-physical properties and durability of aluminum can be modified through alloying or using it in form of composites. The composites have comparatively higher fracture strength and are more resistant to wear or corrosion owing to multiphase nature. Aluminum composites are being used to manufacture aircraft and space vehicles due to larger strength to lower mass. The aluminum composites could be categorized into, (i)polymer matrix composites (PMC), (ii) metal matrix composites (MMC) and(iii) ceramic matrix composites (CMC). The reinforcements may be distributed in laminate, particulate, short fiber and whisker geometrical arrangement in A6061 matrix as shown in Fig. 1. The Aluminum metal matrix composites are usually used for different automotive applications owing to superior properties [2]. AA 6XXX aluminum alloys haves and Mg as main alloying elements and used for manufacturing IC engines and aircraft body parts. The AA 6061 composites can be developed efficiently and economically through stir casting process. The main alloying elements for AA 6061 alloy are Magnesium, Iron, Copper, Chromium, Zinc, Titanium and Manganese [3]. The elastic strength of AA 6061 is in range 70 – 80 MPa. The mechanical properties of AA 6061 matrix can be further improved with addition of compounds namedSi_3N_4, BN, ZrO_2, SiC, B_4C, Al_2O_3, TiC[4].

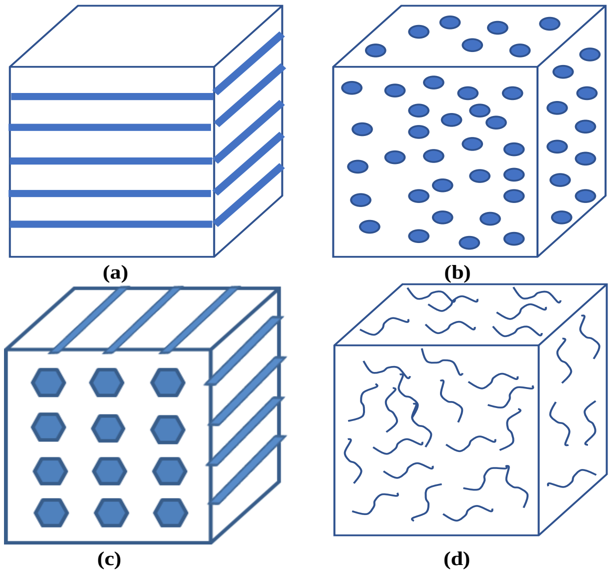

Fig. 1. The geometrical arrangement of reinforcements (a) Laminate, (b)Particulates, (c) Straight Fiber and (d) Whisker formin A6061 matrix.

A number of methods have been developed for manufacturing of A 6061 MMCs as shown in Fig. 2. The manufacturing methods of MMCs can be categorized on basis of solid state and liquid state processing methods [5]. Some manufacturing process like rheocasting and spray deposition use a mushy phase state during primary manufacturing treatment [5]. In case of solid state casting the fabrication is achieved at high temperature and pressure. Forthe case of liquid state processing the dispersion of metal matrix reinforcement is achieved by melting that is subsequently solidified [6].

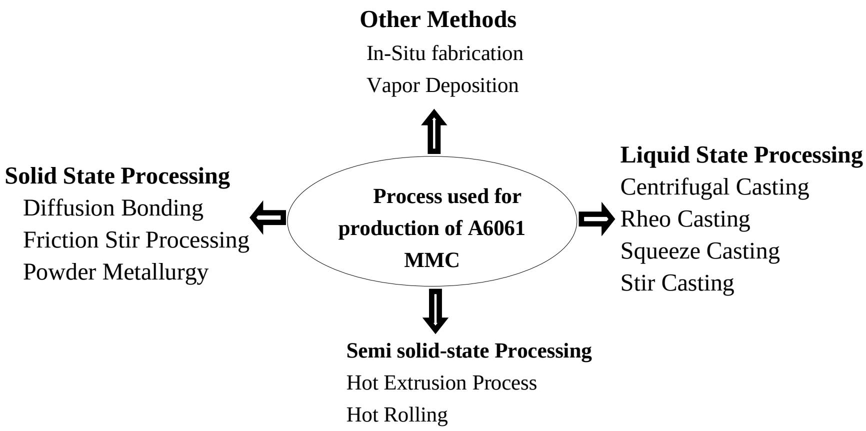

Fig. 2. Manufacturing processes used for synthesis of A6061 MMC.

The stir casting is one the techniques that uses liquid state material processing as homogenous dispersion is achieved with reduced porosity. Moreover, it is more economical as compared to other methods. Generally, an electric furnace is used for heat generation that melts the solid metal held in a crucible. The crucible is made up of refractory materials that are inert and non-reactive. The preheated reinforcement is poured in the crucible which is kept at an inert condition. An injection gun is used to place reinforcement in the molten crucible to further reduce the entrapment of reactive gases. The stirring is achieved using propeller blades which is rotated through an electric motor connected via a shaft. The rotational speed of the stirrer is controlled using stepper motor. The schematic of the setup which is generally used for the stir casting processfor AA 6061 MMC is given in Fig. 3.

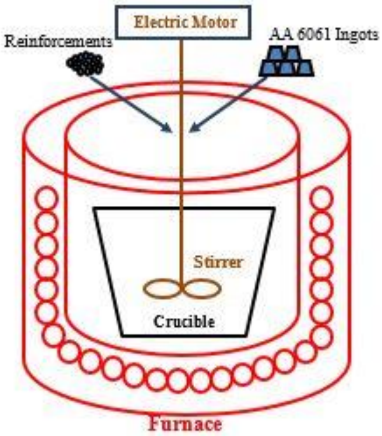

Fig. 3. The Schematic of the setup for manufacturing of AA 6061 composite.

There are many different parameters namely reinforcement shape and size, stirring time, stirring blade design, stirring speed, and operating range of temperature that determine the characteristics for theMMC produced. Thus, deciding optimum parameters for manufacturing is of prime importance considering tradeoff between the quality of the product and cost of manufacturing [7]. Each of the process parameters has been discussed in detail below.

Reinforcement Size: The reinforcement size affects the overall strength of the cast product. Generally, it is seen that smaller the reinforcement size more is the strength [8, 9].

Stirring speed and time: Predicting the optimum time and speed for stirring is very vital which is very much dependent on the different parameters like viscosity of fluid and inter-particle spacing. The larger viscosity of fluids resists smooth stirring of the reinforcement particles which is not desirable. If the viscosity of the fluid is small the distribution of reinforcement may not be uniform and there are chances of agglomeration. The homogeneity and inter-particle spacingin-between the reinforcement particles could be reduced by increasing the stirring time. The design of the propeller blade also determines the stirring time. Moses et al. [10] examined the variation of stirring frequency and rotational speed on the mechanical properties of MMC produced.

Melting Temperature: Maintaining optimum superheat temperature is very vital for manufacturing of metal matrix composites. If the temperature is higher the viscosity would be smaller and vice versa. Although the wettability of the melt is higher at larger superheat temperature.

Propeller Design: The stirrer design is very important as the propeller blades needs to create effective forced vortex flow in order to achieve even dispersion of reinforcement's particles in the molten fluid [5]. Generally stainless steel coated with refractory material like Zirconia is used as a stirrer.

Powder metallurgy is solid state manufacturing route that can be used for processing of AA 6061 metal matrix composites [11-14]. The major advantages of using powder metallurgy technique are that a homogenous distribution of reinforcements is achieved that has relatively better relative density, tensile strength and hardness. The main disadvantages of using PM method is that it is relatively costly and has slow rate of production. Thus, stir casting enjoys popularity asmanufacturing cost is comparatively smaller as compared to other processes. However, while distributing reinforcement in the liquid metal during stirring, homogeneity, wettability and chemical inertness must ensure [13, 14] an optimal level. The AA 6061 composites have been used with both organic and inorganic reinforcements. The reinforcement particles should be homogenously and effectively dispersedwithin the base alloy matrix. Quantity of reinforcement material typically ranges in between 5 to 30 wt%. The categorization for the AA 6061 MMC based on commonly used reinforcement materials has been listed and discussed in detail below.

1.1 AA 6061 SiC Composites

Silicon Carbide (SiC) is a very hard material next only to diamond and called carborundum. It has superior mechanical and tribological properties [15] and commonly used in defense and space industries. Density of SiC is quite comparable to Aluminium (Al) which assists in uniform dispersion of reinforcement particles during stirring of the melt. Kumar et al. [16] manufactured AA 6061 composites with varying weight percent 2 to 6 wt% of SiC reinforcements. Moses et al. [17] developed MMC composites with different concentration of SiC (5, 10 and 15wt %). On microstructural characterization it was found that nano SiC particulates were homogenously distributed in the melt. The hardness and strengthreported an increase with rise in concentration ofSiC reinforcement. Sivanantham et al. [18] produced AA 6061-SiC nanocomposite alloy with wt% of SiCranging from 0–4%. The strength(tensile and compression)increased with addition of SiCreinforcements. Mauraya et. al [19] used electromagnetic stir casting processformanufacturing AA 6061 SiC nanocomposites. The SiC nanoparticles were found to be homogenously distributed in the base matrix. A number other differentinvestigations have been done for AA 6061-SiC MMC [19-22].

1.2 AA 6061 B_4C Composites

Boron carbide (B_4C) is very hard and inert ceramic material and has a black solid metallic shining [23]. One of the major drawbacks of using B_4C is that it has lower density as compared to other oxides of Al_2O_3 and SiC, however the content of Boron Carbide can be very high [24]. The B_4C based MMC have immense applications [25, 26]. Kalaiselvan et al. [27] synthesized AA 6061-B_4C composites for different concentration of B_4C reinforcement. The wettability of B_4C was improved with the addition of K_2TiF_6 in the aluminum melt. The hardness was found to increase with rise in concentration of B_4C reinforcements. B. Ravi et al. [28] manufactured MMCwith 5 and 10 wt% of B_4C reinforcement using the stir casting process. It may be noted that B_4C reinforcement's particles also acts as nucleation sites from which the grain starts to grow. An increase in hardness for AA 6061 MMC was reportedonadding B_4C reinforcement particles during solidification. Bhujanga et al. [29] explored the wear characteristicsfor AA 6061 B_4C composites and reported better wear resistance on adding B_4C reinforcements. Manjunathaet al. [30] used extrusion process to enhance the B_4C reinforcement distribution and remove the defects for the AA 6061 MMC synthesized using stir casting process.

1.3 AA 6061 Al_2O_3 Composites

The aluminum oxides (Al_2O_3) is a hard material which is the oxide form of Aluminum [31]. The Aluminum oxide (Al_2O_3) has high thermal expansion coefficient and good interface compatibility [32]. Kanpal et al. [33] developed AA 6061- Al_2O_3 composite alloy with the different particle concentration of Al_2O_3 (5%, 10%, 15% and 20%). The hardness and strength increased with rise in concentration of Al_2O_3.

1.4 AA 6061-TiC composites

The Titanium Carbide (TiC) particles have high corrosion resistance and has good bonding characteristics [34]. Gopalkrishan and Murugan [35] manufactured Al 6061 TiC composites through stirring process. Improvement in wear and strength was reported on addingTiCreinforcement. Raviraj et al. [36] synthesized AA 6061-TiC MMNC with different weight percent of TiCreinforcement particles (3%, 5% and 7%). It was observed that TiC additionled to the formation of finer grain size which increasedthe strength.

1.5 AA 6061 Composites with Other Reinforcements

A number of other reinforcements have been used manufacturing of AA 6061 composites other than SiC, B_4C, Al_2O_3, and TiC as discussed above through the process of stir casting [37]. Marachakkanavar et al. [37] used iron ore as a reinforcement with varying weight fraction (2%, 4% and 6%) of reinforcement for synthesis of AA 6061 MMC. The microstructure characterization using SEM reportedhomogenous distribution of iron particulates in the base matrix. The tensile strength and hardnessimprovedwith rise in the concentration of iron ore particles. Phanibhushana et al. [38] manufactured AA 6061-Fe_2O_3MMC for different weight percent of Fe_2O_3 reinforcementthat rangedin between 0 to 8 wt%. A continuous increase in strength and wear hardness was obtained with the addition of Fe_2O_3 reinforcement material. Ycet al.[39]developed AA 6061 glass MMC where rise in tensile strength was observed with rise in weight percentage of glass particulate which can be attributed to increase in number of dislocations. Rao et al. [40] synthesized AA 6061 MoS_2 composite alloy with different wt% of MoS_2 (1%, 2%, 3%, 4% and 5%). The hardness was reported to be maximum for 4 % MoS_2-AA 6061 MMC. Prabhu et al. [41] synthesized AA 6061- TiO_2 composites with weight percent of TiO_2 reinforcements ranging from 1% to 4%. A continuous increase in the strength and hardness was observedwith rise in concentration of TiO_2 reinforcements. Panwar et al. [42] used red mud as reinforcement for synthesizing AA 6061 MMC using stir casting process. Rahman et al. [43] used steel machining chips with particle size varying from 40 to 60 microns as a reinforcement for manufacturing of AA 6601 MMC.The strength, wear resistance and hardness improved with addition of steel chips.

1.6 AA 6061 Matrix Nanocomposites

Generally, most of the reinforcements used are micro level based but with passage of time the goal has been set for using nano level reinforcements that have homogenous distribution, smaller particle size and spacing and larger thermal stability which leads to improvement in the NMMC properties [44]. Thus, nano sized reinforcement have better mechanical properties as compared to micro size particles which is useful in many scientific and industrial applications [45]. The major disadvantages associated with using nano sized reinforcements is the cost associated with its production which makes it uneconomical for large scale production. Ezarpor et al. [46] developed nano AA 6061 Al_2O_3 composites by mixing nano Al_2O_3 particulates in the molten alloy for different weight percent of Al_2O_3. An increase in the hardness and strength upto 1 wt% has been reported with the addition of Al_2O_3 and subsequently a decrease beyond 1 wt% which can be attributed to large porosity and heterogeneous distribution of the nanoparticles. To achieve homogeneity and decrease the level of porosity hot extrusion could be carried out. Rana et al. [47] manufactured AA 6061 Al_2O_3 nano composites with wt% ranging between 1 to 3 using ultrasonic stir casting which has been followed by squeeze casting. The strength (compressive andtensile) and hardness increasedon adding nano Al_2O_3reinforcement in the base matrix. Sozhamannan [48] developed AA 6061-Graphite-TiC nano hybrid composites using stir casting process. A significant improvement in wear strength was reported on addingGraphite and TiCreinforcement particles. Pitchayyapillai et al. [49] used silver nano particles to manufacture AA 6061 nanocomposites that had finer microstructure and lower porosity which resultsin higher strength and wear resistance.

1.7 AA 6061 Matrix Hybrid Composites

These composites are one which contains two or more reinforcements that may be organic or inorganic in nature. It has been observed that using secondary reinforcements over primary reinforcement leads to superior properties. The hybrid composites have reasonablybetter thermal and mechanical properties. The characteristics of the developed composites could be optimized using different composition and concentration of hybrid reinforcement concentration [50]. The increase in concentration of hybrid MMC leads to increase in agglomeration and porosity, which has adverse effect on fatigue, creep and impact strength [51]. Thus, an optimum concentration hybrid reinforcement would lead to enhance properties for case of AA 6061 composite.Sharma etal. [52, 53] synthesized AA 6061 composites using different hybrid combinations of Al_2O_3 and SiC reinforcements. The improvement in the mechanical properties (porosity, strength, hardness and wear) was observed with addition of CeO_2 rare earth oxides. Sarkar et al. [54] synthesized hybrid composite using rice husk ash (RHA) as secondary reinforcement and SiC as primary reinforcement. The hardness and strength of the of RHA reinforced hybrid composite was found to be higher and may be potentially used as lightweight material due to lower density of the rice husk. Kumar et al. [55] synthesizedAluminium nitride (AlN) and Zirconium boride (ZrB_2) based AA 6061 hybrid composites. Pitchayyapillai et al. [56] used Al_2O_3 and MoS_2 hybrid additives in different proportions to synthesize AA 6061 matrix hybrid composites. The wear and friction resistance was found to rise with increase in concentration of MoS_2but on other hand tensile strength and hardness was found to decrease. Jawalkaret al. [57] used hybrid mixture of bagasse ash (8%) and Al_2O_3 (5%) for synthesizing AA 6061 MMC.Thestrength and hardness of the AA 6061 MMCimproved with decrease in size of reinforcement particle distribution in matrix. Nathan et al. [58] used ZrO_2 and SiC as reinforcement additives for manufacturing MMC whichled to significant increase strength (tensile and compressive) and hardness.Devanathan et al. [59] used SiC primary reinforcement along with coconut shell ash and fly ash as secondary reinforcements in different weight concentrations for developing A6061 MMC. An increase in strength and hardness was reported with rise in coconut shell ash and fly ash reinforcement concentrations. Kumar et al. [60] synthesizedAA 6061 hybrid MMC using SiC and fly reinforcement particulates that were homogenously distributed in the base matrix. The highest strength (UTS) and hardness was reported for an optimum concentration of fly ash content (7.5 wt%). James et al. [61] used hybrid combination of ZrO_2 and Al_2O_3reinforcements in the AA 6061 base alloy which led to increase in strength, wear resistance, hardness and corrosion resistance.

2. Discussion

The SiC, Al_2O_3, B_4C and TiC are the commonly used reinforcements for manufacturing of AA 6061 matrix composites. Other reinforcements like glass, MoS_2, iron ore and bamboo are also used for making AA 6061 MMC. The percentage of research investigation carried out using different type of reinforcement is shown in Fig. 4. The stir casting process methodhas beenextensively used for distributing reinforcements within the base matrix. On investigationimprovement in the strength and wear resistanceis noticed with increase in concentration of reinforcement particulates up to a certain level. After that decrease in mechanical strength was observed which can be attributed to agglomeration which leads to inhomogeneous distribution in the base matrix.

The AA 6061 nanocomposites manufacturing has gained a new trend. The nanoparticles generally exhibit large surface to volume ratio which leads to poor wettability and higher chances of agglomeration andmay alsolead to inhomogeneous distribution. The increase in number of reinforcement particles may also lead to higher porosity which may adversely affect the porosity. On basis of literature available it has been observed that ultrasonic assisted stir casting is very efficient in distributing nanoparticles homogenously in the base matrix. This could be attributed to high frequency generated by ultrasonic vibration which leads to more homogenousmixing. In addition, the vigorous vibration leads to cavitation which leads to collapse of small bubbles which trigger breaking of cluster particles leading to more effective distribution. The squeeze casting process is helpful in reduction of the porosity and improving mechanical properties for manufacturing of MMNC.

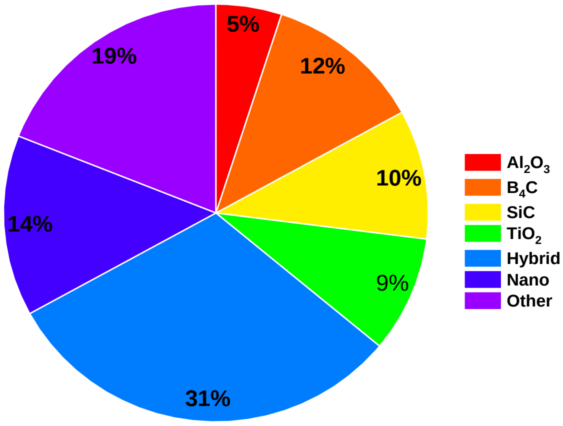

Fig. 4. The percentage research investigation carried using different reinforcements on A6061 metal matrix composite (MMC).

Lastly a detailed discussion was carried on hybrid AA 6061 composites which contains two or more reinforcements for the stir casting process. The addition of secondary reinforcement over primary reinforcements may further improve mechanical property of the AA 6061 composite. For example, addition of MoS_2 as a secondary reinforcement for Al_2O_3 AA 6061 composite would lead to increase in wear resistance. The potential use secondary organic reinforcement materials (fly ash, bamboo and rice husk)which have lighter weight and commonly used for manufacturing of hybrid AA 6061 MMC has been discussed in detail.

Generally,the concentration of reinforcement theparticulates within the base matrix determines the mechanical properties of synthesized MMC. An increase in reinforcement concentration upto a certain level may increasehardness, strength and wear resistance. The stir casting process method isbroadly used for the synthesis of MMC. The hybrid composites have gained a new trend where organic and inorganic materials are used as reinforcement material for MMNC production.

3. Conclusion

AA 6061 alloy is commonly used material in several industries. Stir casting process is generally used for synthesizing AA 6061 MMC, where it has been observed that blade design, stirrer rotational speed, stirring frequencyand melt temperatureaffect the properties of manufactured composites. The addition of reinforcement in the molten composite leads to grain refinement. The mechanical properties (hardness, strengthand wear resistance)improveon the addition of the reinforcement particulates. The hybrid AA 6061 composites are manufactured using two or more reinforcements and havebetter corrosive, mechanical and tribological properties. AA 6061 nanocomposite hold a future potential as they are advanced materials that have superior strength and wear resistance. However higher porosity and inhomogeneous distribution of the reinforcements nanoparticles in matrix has been reportedthat are synthesized using stir casting method. The distribution can be moved towards homogeneous using ultrasonic mixing followed on by squeeze casting which can minimize the agglomeration and porosity formation.

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