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Comprehensive Analysis of Stir Casting Process of Aluminum Based Composites with Silicon Carbide Reinforcements

Kiran Babu Nadikudi Bhanodaya*

Department of Mechanical Engineering, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana, India

***Correspondence to:**
Kiran Babu Nadikudi Bhanodaya
Department of Mechanical Engineering,
Sreenidhi Institute of Science and Technology,
Hyderabad, Telangana, India.
E-mail: uday.nadikudi@gmail.com

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Abstract

Aluminum matrix composites become great option choice for automobile and aerospace industries because of good strength and less weight. When strong reinforcement material grains are uniformly occupied all over the aluminum matrix material, a new composite is formed, these developed composites exhibit an enhanced properties like very high specific strength, high stiffness. Stir casting is one of the proper techniques to manufacture aluminum-based castings, this method is very flexible, less cost and appropriate for mass production. This study focuses on detailed analysis of stir casting method to produce aluminum-based composites blended with silicon carbide (SiC) reinforcement particulates. A comprehensive analysis of SiC particulates in aluminum matrix and influence on properties is analyzed from the previous works and also covers latest trends that are utilized to enhancement the properties. Base materials AA6061 and AA7075 alloys properties were studied and also composite mechanical properties and microstructural characteristics were examined.

Keywords

Aluminum alloy, Stir casting, Aluminum matrix composites, Silicon carbide, Tensile testing

Introduction

Metal matrix composites (MMCs) are made using base or matrix materials in bulk and in this some reinforcement materials such as abrasive ceramic materials are mixed with matrix to enhance strengthand stiffness [1, 2]. MMCs are categorized based on the base materials like in aluminum MMCs, the aluminum is matrix material mixed with some abrasive particles, like wise other matrix composites such as magnesium matrix composites, copper matrix composites. Due to favourable properties of composites, there is high demand in automobile and aerospace industries [3, 4]. It is not possible for a component made with a single metal to withstand with high strength, toughness, and specific weight. MMCs are acquired superior properties for the promising materials to meet industry requirements [5]. Some special dedicated properties like less moisture absorption, resistance to radiations is also advantage for composites. On the other side, composites are developed with lessweight and at low price [6]. Aluminum MMCs are holding a high specific weight and high stiffness properties [7]. Aluminum based composites are restoring the traditional materials, but these composites are facing some problems in manufacturing. Manufacturers and designers are working to overcome these problems with new processes and methods. The main intension of producing composite to acquire improved mechanical properties as well as other characteristics which mainly depends on suitable production method and selection and volume of both matrix and reinforcement materials. To develop a high strength aluminum-based composite, there is need of aluminum matrix material and a suitable reinforcement material. On other hand there is also need a suitable manufacturing method with optimised process parameters. A wide range of production techniques are being used for development of aluminum-based composites, which includes liquid and solid condition methods [8, 9]. Out of this, stir casting liquid state method is widely accepted method to produce aluminum-based composites. The features of stir casting method are more and commercially very popular manufacturing method [10]. Stir casting method is simple, very flexible and can be employed for mass production. On the otherside, this method can be used to develop the castings which are complex without damaging the reinforcement material [11]. But ensuring a correct blending of two materials by consistent spread of reinforcement material throughout the aluminum matrix [12]. Stir casting is proven casting method for development of aluminum-based composites and as well as hybrid composites due to its low-cost manufacturing.

The application of stir casting process is to develop metal composites which includes aluminum metal as matrix material and mixing one or more ceramic materials as blended material. Prior to addition of reinforcements to the molten metal, it should be degassing. Otherwise, it reacts with gases in the air and starts oxidation results in reduction in properties of base material. After proper mixing of matrix material with reinforcement materials, the pouring is done from bottom, so that enhance the association of reinforcement material and also reduction in pouring time. Stirring is carried out with the motor mounted at the top of the arrangement. The reinforcement materials are blended with molten aluminum and stir for some time. It is also ensuring the homogeneous dispersing of ceramic reinforcement material throughout the aluminum matrix, otherwise, the denser reinforcements gather at bottom of the crucible.

The foremost step-in stir casting is melting of aluminum matrix material, during melting, aluminum metal reacts with atmospheric gases and moisture in the air forms a surface layer of aluminum oxide (Al_2O_3), this formed surface layer shields the further reaction of aluminum with atmospheric gases [13]. Al_2O_3 is a stable compound and this not able to decrease and wettability remains stable [14]. To cease this oxidation, there is a necessity of making an inert environment and this is related to complicated procedure. But the alternate method for this is to add wetting agents like TiK_2F_6, borax, and magnesium materials to the melt [15]. Apart from oxidation, the stir casting process facing another problem that is not ensure ofsame kind spread of reinforcement material throughout the molten metal [16] and this can be controlled by process parameters. Selecting the right process parameters is main assignment for attaining a sound aluminum composite. The major stir casting process parameters are stirring speed, stirring time, impeller blade angle, size, and position of impeller.

Mechanical properties of a composites are mainlydependedon the spread of reinforcements in the aluminum matrix. Ramachandra and Radhakrishna developed castings using fly ash in the aluminum matrix at different temperatures like 720 ˚C and 800 ˚C [17]. Singla et al. [18] developed composites at mixing speed of 600 rpm at 1100 ˚C. Abdizadeh et al. [19] produced nano MgO composites with favours which includes less cost, flexibility in process. Dasgupta [20] have studied the composite wear properties of composites. In stir casting, the reinforcement particulates are first poured into molten aluminum matrix and secondly, the entire material was poured in to preheated molds. Amirkhanlou and Niroumand [21] explored the effect of reinforcement materialpre-treatment for the hardness improvement and achieved in the order of 60 - 68 HBN, which is much more than the base aluminum alloy. Few researchers reported that the design of impeller and other process parameters of stir casting impacts the mechanical properties. A groove-based impeller improves the toughness of the composite because of less porosity formed during stirring [22]. Goswami et al. [23] developed aluminum-based composites and analysed impact energy of composites. The improved properties are due to formation of new grain microstructure with eliminated porosity. Abd El-Azim et al. [24] reported hardness value improvement from 113 to 150 HBN with rise in weight percentage of blend material, which is also increases the brittleness of the composite. In some studies, Fono-Tamo and Tien-Chien [25] reported a more hardness obtained is due to pre heating the reinforcements. Saheb [26] reported the influence of graphite and SiC reinforcements on hardness and revealed that the SiC reinforcement composites achieved high hardness than the graphite reinforcement composites. Zhou and Xu [27] observed an enhancement in the wettability, dispersion of reinforcement material in interdendritic areas of the casting. Smeulders et al. [28] analyzed the thixotropic nature of MMCs. The distribution among the matrix material is decided by both cooling rate and stir parameters. Prakash et al. [29] reinforced various nano-silicon particle densities such as 0, 0.5, 1.0, 1.5, 2.0. and 2.5% with the adoption of stir casting method and observed that there is a notable enhancement in strength up to 1.5% weight. After that the strength was reduced with more than 1.5% insertion of nano-ceramic material is because of nanoparticle agglomeration. Madhukar et al. [30] and Dhaneswara et al. [31] developed silicon-based nanocomposite with aluminum alloys and achieved an enhancement in tensile strength. Bharat et al. [32] developed nanocomposites with AA7075 and reinforcement SiC particles and revealed the weight of nanoparticles are influencing the wear rate. The paper is aimed to analyse the stir casting method for fabrication of AA6061 and AA7075 alloy-based composites and the effect SiC reinforcement material on the mechanical properties and microstructure.

AA6061 and AA7075 Alloys

The materials selected for present review are AA6061 and AA7075 aluminum alloys and these alloys are categorised as heat treatable alloys. AA6061 material comprises magnesium and silicon as major components. The alloys properties are high specific strength, good weldability, castability, and machinability. The applications are finding in aerospace and automobile industries. AA7075 alloy made with zinc as major alloying component. It holds high mechanical properties and also have high fatigue resistance. Mechanical properties of base AA6061 and AA7075 are exhibited in table 1. The strength of AA6061 is 332 MPa, whereas for AA7075 is 687 MPa and elastic modulus for AA6061 is 70.1 GPa and for AA7075 is 72.4 GPa. These results are almost same as the standard

Table 1: Mechanical properties of AA6061 and AA7075 [36].

Aluminum alloy	Tensile strength (MPa)	Yield strength (MPa)	Elastic modulus (GPa)
AA6061 (Experimental)	332	305	70.1
AA6061 (Standard)	310	275	69.0
Differences (%)	7.1	10.9	1.6
AA7075 (Experimental)	687	607	72.4
AA7075 (Standard)	570	505	72.0
Differences (%)	20.5	20.2	1.9

properties of these two aluminum alloys [33]. From table 1, it can observe that the AA7075 exhibits a high tensile strength and elastic modulus compared to AA6061 alloy. AA7075 is categorized as a high strength alloy and AA6061 as a medium strength alloy [34]. Chemical composition of AA7075 alloy is with formation precipitation of Mg_2Al_3, Al_2Cu, and $Al_{32}Zn_{49}$ is the reason for higher strength [35]. It can note that the strain of AA6061 is more than AA7075 alloy before fracture and also the test specimen is elongated more with necking at the centre. On the other side, a small elongation and no neck formation can observe for AA7075 specimen [36].

AA6061 with SiC Composites

Aluminum alloy AA6061 is the very flexible silicon and magnesium alloy, and these composites are manufactured using stir casting method [37]. Although many researchers reported a numerous AA6061 based composites manufacturing, there is a limited comprehensive review on aluminum alloy with SiC reinforcement material. SiC particles are very hard material and holds superior mechanical properties. Due to their exceptional mechanical properties, these AA6061composites are ideal for applications in defence, structural, and production industries [38]. Kumar et al. [39] used to develop AA6061-SiC composites through stir casting process with 2 - 6% weight range. The SiC microstructurecomprisesspherical and angular shaped grains. Moses et al. [40] developed similar kind of composites with SiC weight of 5, 10, and 15% and revealed the distribution is homogenous and grain refinement takes place.

From the analysis, it can note the dispersal of SiC material is uniform in aluminum matrix and also noted that the separation of particles at grain boundaries. Due to this homogeneous distribution, the properties of composites are increased, and this is achieved by proper mixing of SiC reinforcements in molten metal through stirring action. The strong SiC particles resist the aluminum grain development, which results in finer grains through growth in nucleation sites [37]. For AA6061 alloy with 15% SiC material exhibited an enhancement of 133.33% hardness and 65.2% of strength when differentiated with base alloy. SiC particles are consistently dispersed all over the aluminum matrix was disclosed through micrographs, which shows that the manufacturing process of making these composites was successful to disperse reinforcement particles. Due to this dispersion of SiC particles is consistent which leads to enhancement of the properties.

Sivananthan et al. [41] investigated the influence of reinforcements on AA6061 alloy with addition of 0 to 4% of SiC materials with use of stir casting. Mechanical properties were evaluated for composites and observed an enhancement of mechanical properties than base alloy. For 4% SiC composites, hardness and strength are enhanced by 25% and 25.6%, respectively [42]. Similar kind of dispersal of SiC particles throughout the molten metaland no agglomeration was recorded in micrographs. In this technique, an induction motor was employed to develop an electromagnetic field that assists the stirring of aluminum molten metal after mixing SiC particles.This continues in molten metal until solidification takes place. This stirring action led to consistent dispersion of SiC particles throughout the aluminum matrix results in enhancement in mechanical properties [43].

AA7075 with SiC Composites

AA7075 alloys is made with aluminum and zinc. It holds superior strength, toughness, and adequate resistance to fatigue. Many reports are available for AA7075 alloy composites and there is limited review is available with addition of SiC reinforcements. Some studies outlined 7xxx series alloys with SiC reinforcements and revealed the higher mechanical properties as compared to base aluminum materials [44]. These stronger matrix alloys are tended to manufacture a very high strength composites with some reinforcement materials. However, there are some variables to control, like ageing condition, weight of reinforcements and size, these are directly influencing the composite properties [45]. From the microstructures, it can be analysed that the dispersion of SiC particles are almost same throughout AA7075 matrix [46], which enhances the tensile properties. Bhushan et al. [47] introduced micrographs of AA7075 with SiC reinforcement material of 0, 10, and 15%, it contains more uniform spread of SiC reinforcements all over the aluminum matrix.

Composites of AA7075 with SiC exhibit an enhanced strength compared to base alloys. Existence of SiC particles in composite enhances the strength because of high hardness [48]. In composite, SiC particles are dispersed all over the aluminum alloy matrix which blocks the dislocations movement leads an enhancement of properties [49]. Fractions of SiC particles are increases the strength through stress transfer from matrix material to the added material as per Orowan mechanism [50], it avoids serious obstacles where dislocation is confined all over the reinforcement material. During casting of aluminum-based composites, various sizes of SiC particles were used. Aluminum based composite with 5 wt.% of SiC exhibited a 16.36% increase in hardness and tensile strength [51]. Aluminum alloy AA7075 with 5 and 10% weight of SiC disclosed an enhancement of 69.23% and 84.61% in hardness and strength, respectively [52]. On the other side, AA7075 with 6% SiC showed a 58.33% and 77.77% improvement in hardness and tensile strength, respectively [53]. Composite with 10% of 75 μm SiC particles shown improved propertiesand there is an improvement of 22.58% and 8.25% in hardness and tensile strength, respectively [54].

Conclusions

The review has discussed the tensile strength and other properties of base AA6061 and AA7075 alloys. Review also discussed usage of stir casting technique to manufacture of AA6061 and AA7075 alloys including SiC reinforcement materials.

- In tensile tests, AA6061 alloy obtained the tensile strength of 332 MPa which is categorised as moderate strength alloy and AA7075 alloy obtained the tensile strength of 687 MPa which is categorised as high strength alloy. The obtained experimental results are almost same as the results of standard alloy of AA6061 and AA7075 materials.
- The composites fabricated using AA6061 and AA7075 alloys with SiC reinforcement particles exhibited better properties as compared to as received materials and it also revealed that the SiC reinforcement material played a crucial part in casting solidification.
- The review discloses the addition of SiC particles improves the prosperities of composite as well as microstructural developments as compared to base alloys.
- A homogeneous scattered SiC material completely throughout the AA6061 matrix without agglomeration was recorded in micrographs.
- In case of AA7075 + SiC composites, the SiC particles are dispersed throughout aluminum matric consistently results in blocking the dislocation movement, this led to increase in mechanical properties.

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None.

Conflict of Interest

None.

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