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Influence of SiC Particles Distribution and Their Weight Percentage on 7075 Al Alloy

Rajesh Kumar Bhushan and Sudhir Kumar

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The stir casting method was used for fabrication of 7075 aluminum alloy with 10 wt.% SiC particles of size 20-40 μm. The research objective of this paper are to achieve uniform distribution of SiC particles in the 7075 aluminum alloy matrix, characterization, and analysis of mechanical properties of composite formed. Experiments were carried out at stirring speeds of 500, 650, 750 rpm, and stirring period of 10 min. Microstructures of aluminum alloy and composites with 5, 10 wt.% SiC reinforcements were examined. The results reveal that composite produced at stirring speed of 650 rpm and stirring time of 10 min has uniform distribution of SiC particles. XRD and EDAX analysis were carried out for 7075 Al alloy and composite with 10 wt.% SiC reinforcement. No adverse reaction was observed in XRD and EDAX of composite with 10 wt.% SiC reinforcement. Tensile strength and hardness increased by 12.74% and 10.48%, respectively, with the increase in percentage of SiC reinforcement from 5 to 15 wt.%.

Keywords 7075 aluminum alloy, EDAX analysis, stir casting process, tensile strength and Hardness, XRD analysis

1. Introduction and Literature Review

Metal matrix composites (MMCs) are the combination of metal and reinforcement. Aluminum, magnesium, and titanium are the common matrix metals with characteristics such as light weight and high temperature resistance. The typical reinforcing ceramics are Al_2O_3, SiC, and B_4C. These can be used as long fibers, short whiskers, or particles in either an irregular or spherical shape (Ref 1). The properties of the resulting composites are generally controlled by three critical components: the matrix, the reinforcement, and the interface. Many of the considerations arising due to fabrication, processing, and service performance of composites are related to processes which take place in the interfacial region between the matrix and reinforcement.

Composites were formed by adding 15 wt.% of SiC dispersoid in the size range of 20-40 μm to Al-Zn-Mg-Cu alloy (corresponding to 7075 series) by stir casting process. The composite exhibits a uniform distribution of SiC particulates as well as good bonding between the matrix and particulates. Grain boundaries are clearly defined with some precipitates in the grains (Ref 2). Kalkani and Yilmaz investigated the squeeze casting of aluminum alloy 7075 reinforced with 10, 15, and 20 wt.% SiC reinforcements (Ref 3). Homogeneous distribution of the SiC particulates was obtained using vertical pressure/squeeze casting of the SiC composites. Some agglomeration was observed, but there was no evidence of porosity among the SiC particles when they were close to each other.

The hardness as well as toughness of a composite material depends significantly on the matrix microstructure, size, and distribution of the dispersoid and the interfacial bonding characteristics (Ref 4). The 7075 aluminum alloy and composites with 15 wt.% of SiC dispersoid (size 20-40 μm) fabricated by stir casting process were subjected to heat treatment in an attempt to optimize their properties. Result was that heat treatment definitely improves the properties of the 7075 aluminum alloy and SiC composite (Ref 2). Kalkani and Yilmaz investigated the squeeze casting of aluminum alloy 7075 reinforced with 10, 15, and 20 wt.% SiC reinforcements. In tensile tests, the composite containing 10 wt.% SiC reinforcement showed maximum strength in both the as cast and heat treated states as compared to the composites containing 15 and 20 wt.% SiC reinforcements (Ref 3).

The fabrication techniques vary considerably depending upon the choice of matrix and the reinforcement material. Among the variety of manufacturing processes available for discontinuous MMC production, stir casting is generally accepted (Ref 5). Stir casting of MMCs involves producing a melt of selected matrix material. This is followed by introduction of reinforcing material into the melt and stirring the melt to obtain a uniform distribution of reinforcement particles. Chemical interactions between the particles and molten matrix further proceed with time, and finally the particles are trapped in the composite slurry. Incorporation of the reinforcing particles with in a semi-solid alloy is advantageous; because the solid mechanically entraps the reinforcement hence it avoids particle agglomeration, and settling or flotation (Ref 6). This mechanical entrapment is promoted by a vigorous agitation, which also promotes wetting. As the reinforcement is forced into the matrix, it is essential to continue mixing, in order to ensure proper interface bonding between the matrix and particulates (Ref 7). This stir casting process is the most economical of all the available routes for production of MMCs. It is able to sustain high productivity rates and allow very large

Rajesh Kumar Bhushan, Shri Mata Vaishno Devi University, Katra, Jammu, J&K, India and **Sudhir Kumar**, Noida Institute of Engineering and Technology, Greater Noida, UP, India. Contact e-mails: rkbrjit@yahoo.com and s_k_tomar02@yahoo.com.

size components to be fabricated. The fabrication cost of composites using a casting method is about one-third to one-half with that of other competing methods; and for high volume production it is projected that costs will fall to one-tenth (Ref 8).

There are technical challenges associated with producing homogeneous high density composites. To achieve optimum MMC properties, the distribution of the reinforcement material in the matrix alloy must be uniform and the bonding between these two substances should be optimized (Ref 9). The mechanical properties of MMCs are controlled to a large extent by the structure and properties of the reinforcement-metal interface. A stronger interface permits transfer and distribution of load from the matrix to the reinforcement, resulting in an increased elastic modulus and strength.

Particles distribution in the matrix material during the melt stage of casting process depend strongly on the stirring speed, heating temperature, stirring time, viscosity of slurry, particle wetting, effectiveness of mixing and minimizing of gas entrapment. The uniformity of particles dispersion in a melt before solidification is also controlled by the dynamics of particle movement in an agitated vessel. Continuous stirring of the melt with a motor driven agitator is essential to prevent settling of particles.

The above-mentioned literature review shows that no experimental work has been reported so far about effect of stirring speeds on the microstructures of aluminum alloy and composites with 5, 10 wt.% SiC reinforcements, fabricated by stir casting process. In addition, no work has been reported about XRD and EDAX analysis of 7075 Al alloy with 10 wt.% SiC reinforcement. The present investigation has been done to study the microstructure of 7075 Al alloy and composite with 10 wt.% SiC reinforcement at different stirring speeds, to carry out XRD, EDAX analysis of Al alloy, and composite with 10 wt.% SiC reinforcement and to find out the improvements in tensile strength and the hardness of composites due to the addition of 5, 10, and 15 wt.% SiC reinforcements, in 7075 Al alloy.

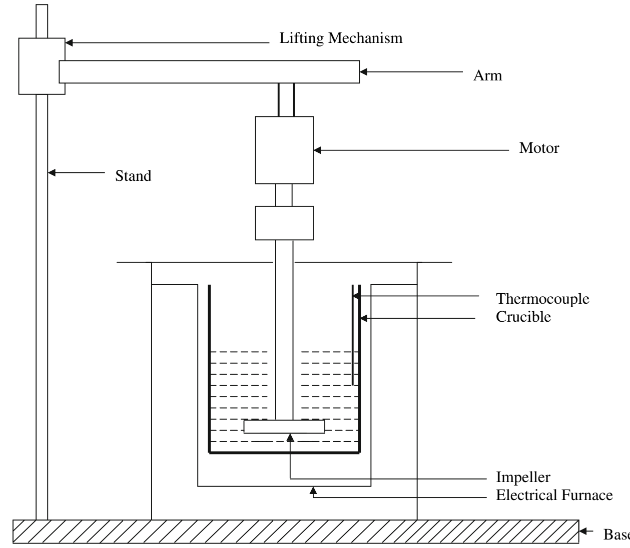


Fig. 1 Experimental setup of stir casting process

Table 1 Chemical composition (wt.%) of 7075 Al alloy

Material	Zn	Mg	Cu	Cr	Si	Fe	Al
Wt.%	5.62	2.52	1.63	0.22	0.06	0.18	Balance

2. Experimental Work

2.1 Heat Treatment of Reinforcement Particles

Most ceramic particles are visibly rejected by melt in the absence of heat treatment. Heat treatment conditions are important and must be optimized. Heat treatment removes absorbed surface contaminations and raises the surface energy of the solid thereby improving their wettability with the metal. Heat treatment of SiC particles may form surface oxides which also improves their wettability with molten metal (Ref 10). Hence, the silicon carbide particles were heated in an oven at 700 °C for 8 h to improve the wettability.

2.2 Design of Stir Caster

In this work, a stir caster was used to fabricate 7075 aluminum alloy and composites with 5, 10, and 15 wt.% SiC reinforcements. Schematic diagram of stir caster is shown in Fig. 1. The stir casting furnace is mounted on ground. The temperature of furnace is to be precisely measured and accurately controlled (±2 °C) for fraction of solid in the semi-solid alloy. Two thermocouples and one PID controller are used for this purpose. Stainless steel material was selected for the stirrer rod and for the impeller because of its corrosion resistance and stability at high temperature. The stirrer was connected to 1 HP DC motor through flexible link. Stirrer was used to stir the molten matrix material in the semi-solid state. A screw operated lifting mechanism was used to bring the stirrer in contact with composite material.

2.3 Operation of Stir Caster

The chemical composition of 7075 Al alloy is shown in Table 1. These materials were placed in the furnace in the proportion as given in Table 1. Degassing of molten metal was carried out by passing nitrogen gas through the melt after covering the melt with a flux. The melt was cleaned by taking out the dross collected on the melt surface with a perforated flat spoon. The melt was maintained at a temperature between 750 and 800 °C for 1 h. Vortex was created in the melt using a mechanical stirrer. Preheated 10 wt.% SiC particles were added to the melt during stirring. Stirring was carried out for 10 min, at 500 rpm for sample number 1, at 650 rpm for sample number 2, and 750 rpm for sample number 3, both for 7075 Al alloy and composites with 5, 10, and 15 wt.% SiC reinforcements. Al alloy and composites were cast by pouring the liquid mixture in preheated cast iron die (diameter 55 mm and length 170 mm) for sample numbers 1, 2, and 3, respectively.

2.4 Metallographic Study

MMC ingots were cut to produce the samples for microscopic examination. Coolant was used during the cutting to avoid overheating of samples. Conventional grinding and polishing techniques were used for grinding and polishing the samples. Samples were etched to reveal the phase constituents using Keller's reagent.

2.5 XRD Analysis

X-ray diffraction (XRD) measurements were performed with a Bruker ASX D-8 x-ray diffractometer, which is equipped with a copper target operating at 1.8 kW and graphite-curved single crystal {0002} monochromator to select the CuK radiation at the goniometer receiving slit section. The divergence, anti-scattering, and receiving slits were chosen to be 0.5°, 0.5°, and 0.3 mm, respectively. The diffraction angle (2θ) was maintained between 10° and 100° during entire analysis.

2.6 EDAX Analysis

The chemical compositions of the different phases were investigated through spot and line-scan analyses on Energy Dispersive X-Ray (EDX) detector.

2.7 Tensile Test

Tensile tests were carried out on Universal Testing Machine (UTM) of 50 kN capacities. Load was increased in the steps of 5 kN. Sample dimensions were taken as 40 mm in gauge length, 50 mm in parallel length, and 10 mm in diameter. Results of the test are shown in Table 2.

Table 2 Tensile strength values of 7075 Al alloy and composite

Percentage of reinforcement	UTS, MPa	Standard deviation	Sensitivities
0	85.37	0.418	
5	94.28	0.679	1.785 MPa/%SiC
10	106.30	0.789	2.404 MPa/%SiC
15	99.45	0.570	−1.37 MPa/%SiC

Table 3 Hardness values of 7075 Al alloy and composite

Percentage of reinforcement	Brinell hardness	Standard deviation	Sensitivities
0	121 HB	0.707	
5	124 HB	0.816	0.6 HB/%SiC
10	128 HB	0.816	0.8 HB/%SiC
15	137 HB	0.816	1.8 HB/%SiC

2.8 Hardness Test

Hardness tests were carried out on Brinnell cum Rockwell Hardness testing machine. Samples for test were prepared metallographically and polished. Diamond cone indenter of 120° cone angle was used for Brinnell hardness test. Values of hardness are shown in Table 3.

3. Results and Discussions

The optical microstructure of 7075 Al alloy and composite with 10 wt.% SiCp are shown in Fig. 2(a-c) and 3(a-c), respectively, at magnification of 200×.

Figure 2(a) shows the microstructure of 7075 Al alloy formed at stirring speed of 500 rpm. In this structure, distribution of grains is uniform and grain boundaries are clearly defined. Aluminum grains are globular due to the stirring action and holding period. Figure 2(b) shows the microstructure of 7075 Al alloy formed at stirring speed of 650 rpm. In this structure, grains are distributed uniformly and grain distribution is dendritic at few places. Figure 2(c) shows the microstructure of 7075 Al alloy formed at stirring speed of 750 rpm. In this structure, grains are concentrated at few places and grain distribution is dendritic. Dendritic means tree-like structure. When the liquid is not inoculated and the nucleation is poor, the liquid has to be undercooled before the solid forms. Under these conditions, a small solid protuberance called a dendrite, which form at the interface, is encouraged to grow since the liquid ahead of the solidification front is under cooled. As the solid dendrite grows, the latent heat of fusion is conducted into the under cooled liquid, raising the temperature of liquid toward the freezing temperature. Secondary and tertiary dendrite arms also form on the primary stalks to speed the evolution of the latent heat. Stirring speed and stirring period affect the grain size. A higher stirring speed and shorter period during processing should produce smaller grains (Ref 11).

Comparison of these three figures indicates that grains formed at stirring speed of 500 rpm are globular and bigger in size. This is due to low stirring speed. Grains are smaller in

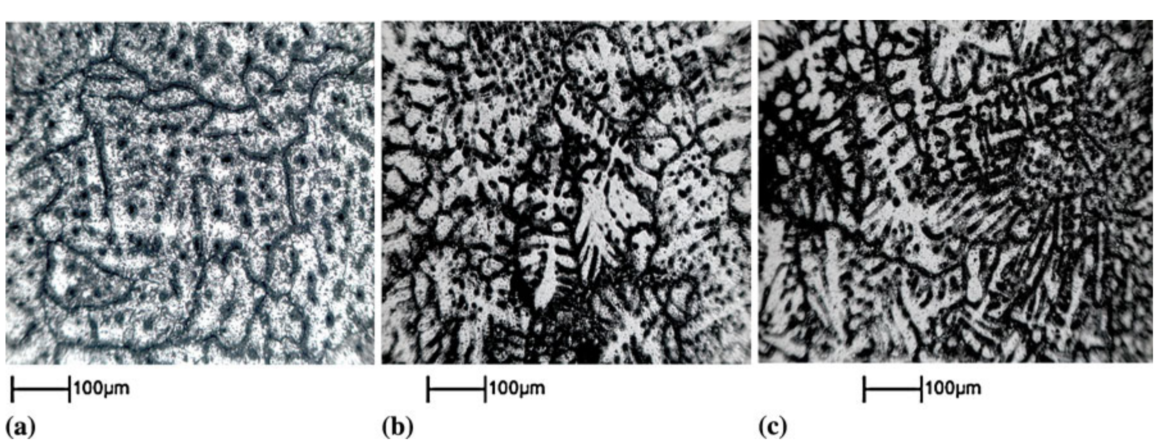


Fig. 2 (a-c) Microstructures of 7075 Al alloy at stirring speeds of 500, 650, and 750 rpm

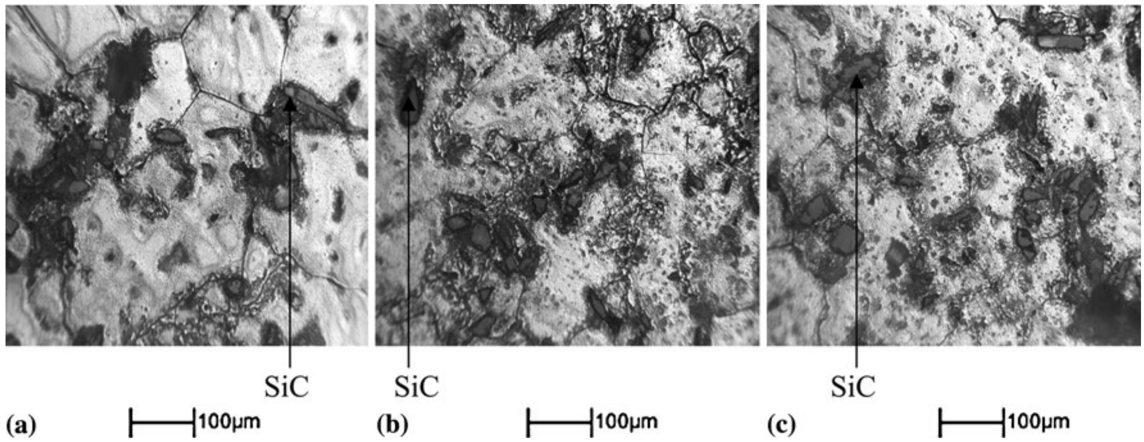


Fig. 3 (a-c) Microstructures of 7075 Al alloy 10 wt.% SiCp composite at stirring speeds of 500, 650, and 750 rpm

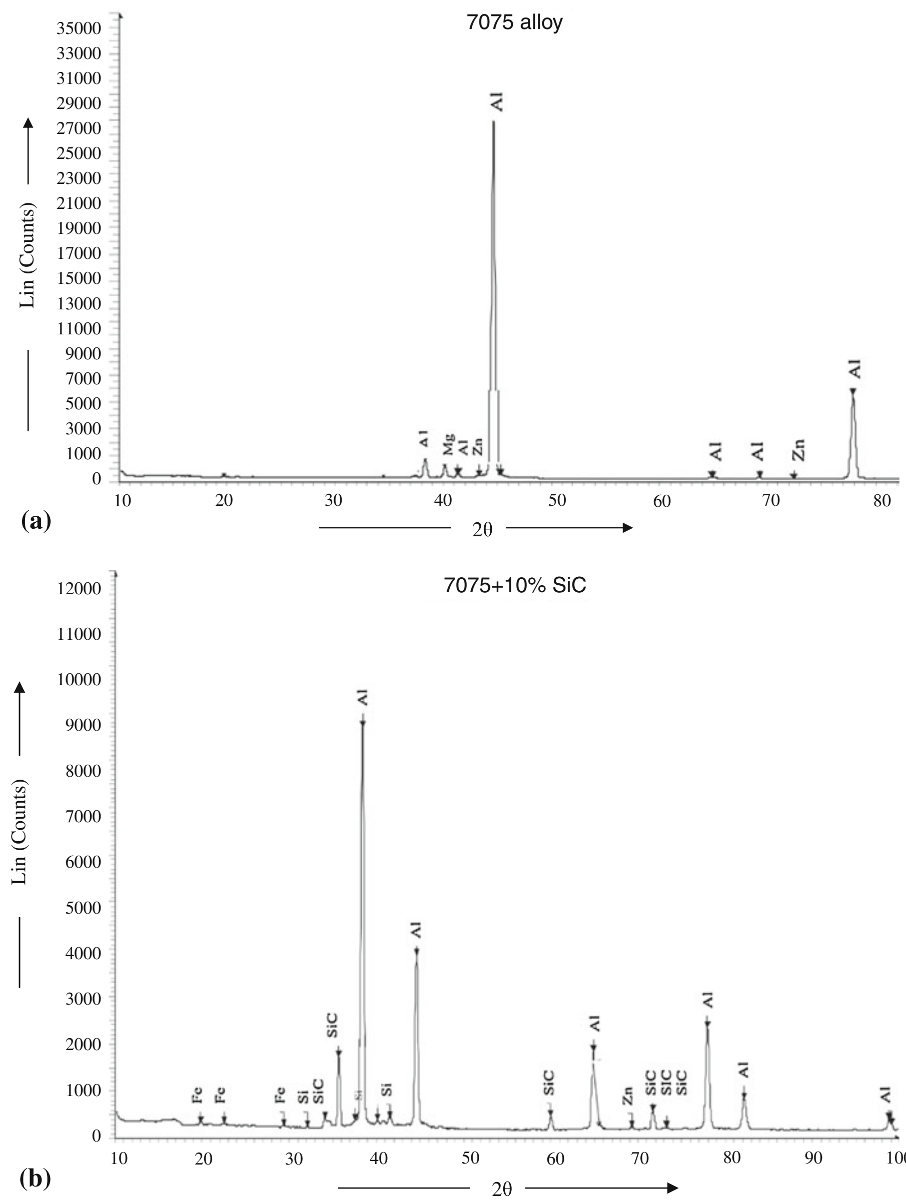
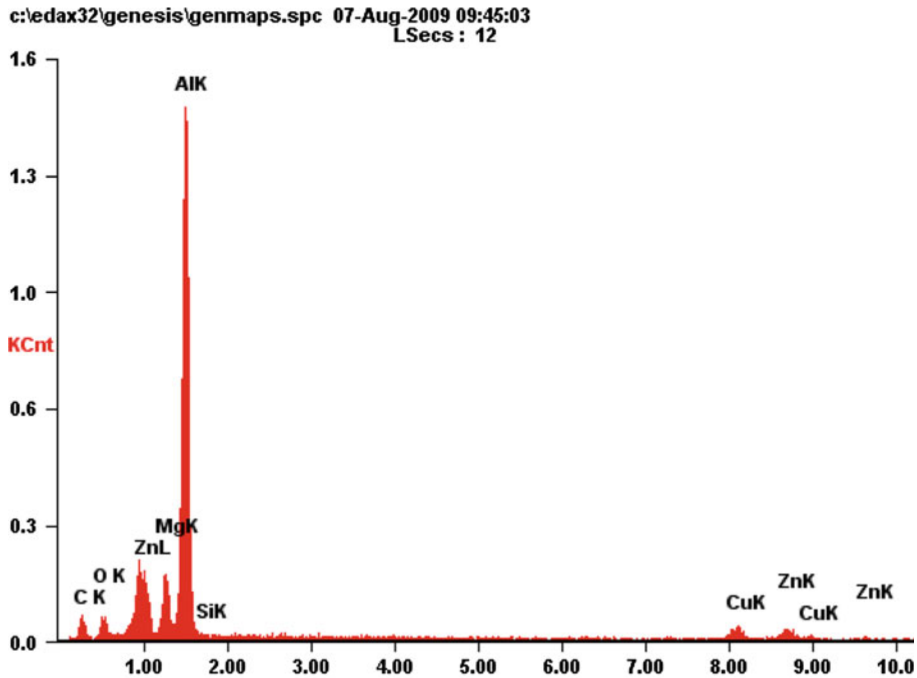
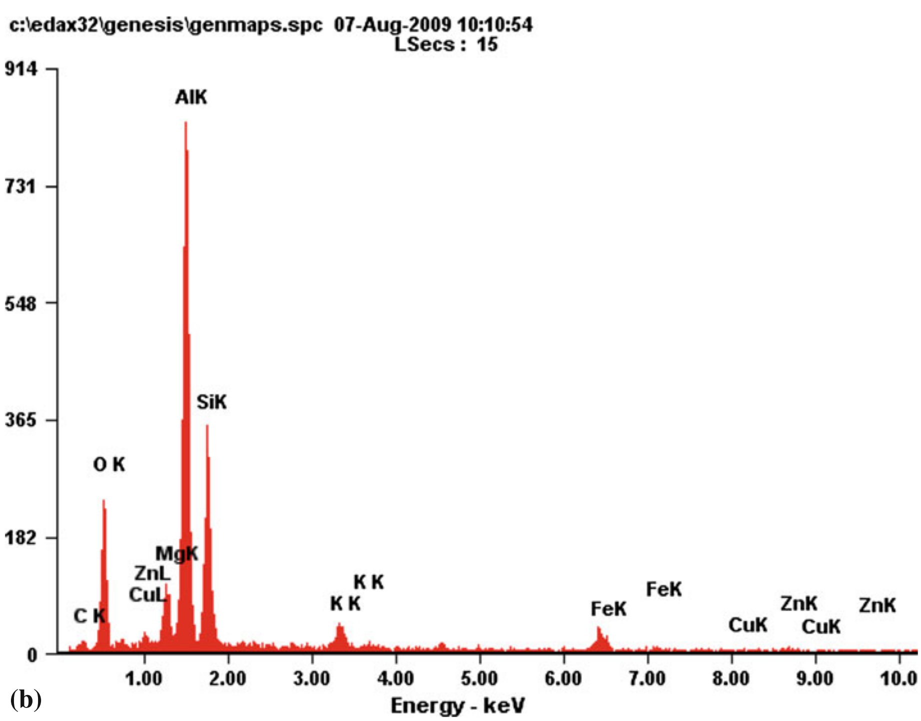


Fig. 4 (a, b) XRD Analysis of 7075 Al alloy and composite with 10 wt.% SiCp



(a)

Element	*Wt%*	*At%*
CK	20.43	38.71
OK	04.73	06.72
MgK	05.69	05.32
AlK	50.67	42.73
SiK	00.00	00.00
CuK	09.05	03.24
ZnK	09.43	03.28
Matrix	Correction	ZAF



(b)

Fig. 5 (a, b) Energy dispersive x-ray analyses (EDAX) of 7075 Al alloy and composite with 10 wt.% SiC reinforcement size, and their distribution is dendritic in the case of Al alloy formed at stirring speed of 650 and 750 rpm. This is due to higher stirring speed. The microstructure formed at stirring speed of 650 rpm is better than structure at 750 rpm due to less number of dendrites.

Figure 3(a) indicates the microstructure of SiC composite formed at stirring speed of 500 rpm. In this structure, some SiC particles are accumulated at few places. Pores enclosed by these SiC particles can be seen in the microstructure. The SiC particles in the agglomeration are partially bonded by aluminum matrix. This results in low density of the composite ingot.

Figure 3(b) shows the microstructure SiC composite formed at stirring speed of 650 rpm. In this structure, SiC particles are uniformly distributed in the aluminum matrix. No pores are seen. On measurement density of composite with 10 wt.% SiC reinforcement was found as 2.75 g/cm^3. Figure 3(c) represents the microstructure of SiC composite formed at stirring speed of 750 rpm. In this structure, some porosity has been observed as vigorously stirred melt tends to entrap gas and draw it into the melt. It has been found that presence of vortex inhibits wetting. The pouring distance from the crucible to the mold should be as short as possible in all the three cases. This avoids contact of liquid metal with atmospheric gases, when liquid metal is being poured in the mold.

Comparison of all the three structures indicates that distribution of grains is uniform in the microstructure of composite with 10 wt.% SiC reinforcement formed at stirring speed of 650 rpm and stirring period of 10 min. The macroscopic distribution of the reinforcement particles is more uniform and particle clustering limited in composites formed in a semi-solid state compared to composites fully remelted above their liquidus temperatures. The reinforcing phase resides in the interglobular spaces where the eutectic is associated with the reinforcement. Also, no gravity segregation of particles is observed in partially remelted composites after prolonged holding, which also contributes to homogeneous distribution of SiC particles in Al alloy matrix. There is no porosity in this structure. Hence, mechanical properties of this structure will be better than other two structures. Figure 4(a, b) indicates the XRD analysis of 7075 Al alloy and composite with 10 wt.% SiC reinforcement. From Fig. 4(a), it can be seen that besides Al reflections, there appeared a broad peak at about $2\theta = 45°$ and some other weak peaks. The broad peak at about 45° corresponds to G-P zones, and other weak peaks whose positions are little lower than those of hexagonal η phase are from the metastable hexagonal ή phase whose lattice parameters are little larger than those of η phase (Ref 12). Judging from the relative peak intensities in the XRD pattern, we conclude that a uniform structure was formed in 7075 Al alloy.

In Al-SiC composites, a direct reaction between Al and SiC can occur during the fabrication stage forming Al_4C_3 and Si.

$$4Al + 3SiC = Al_4C_3 + 3Si$$

This reaction is known to have undesirable effects on the overall Al-SiC composite properties such as: degradation of mechanical properties due to formation of Al_4C_3, reduction in corrosion resistance in water, methanol, HCl, etc. because of unstable nature of reaction product (Al_4C_3) in such environment and changing the matrix alloy composition by Si released during interfacial reaction. As a result, composite interface plays an important role in determining the resultant composite properties (Ref 13).

From Fig. 4(b), it can be seen that broadening of Al-peak is only marginal. If an amorphous state had been existed, it would have broadened the peak to a greater extent than observed in the present case. One of the main observations of XRD analysis is the absence of peak corresponding to Al_4C_3. This peak is undesirable due to low strength and brittleness.

Figure 5(a) and (b) shows the energy dispersive x-ray analysis (EDAX) of 7075 Al alloy and composite with 10 wt.% SiC reinforcement, respectively. EDX analysis of 7075 Al alloy revealed that these precipitates contained magnesium, zinc, copper, representative of the equilibrium precipitate. No adverse reaction has been observed in EDX analysis of composite with 10 wt.% SiC reinforcement.

Analysis of Fig. 6 and 7 indicates that tensile strength increases by 12.74% with increase of percentage of SiC reinforcement from 5 to 10 wt.%. Tensile strength decreased when percentage of reinforcement reached 15 wt.%.

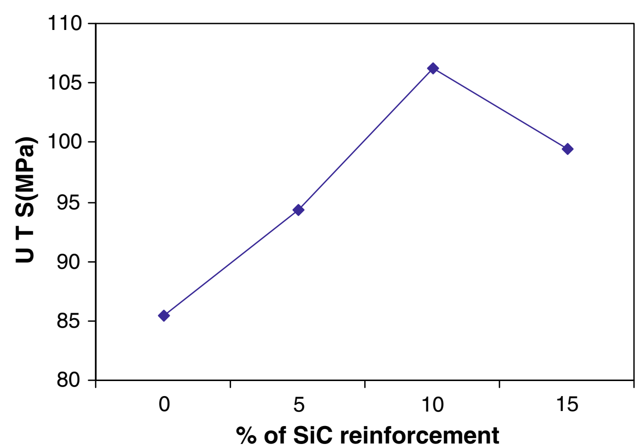


Fig. 6 Variation of tensile strength of composites with percentage of SiC reinforcement

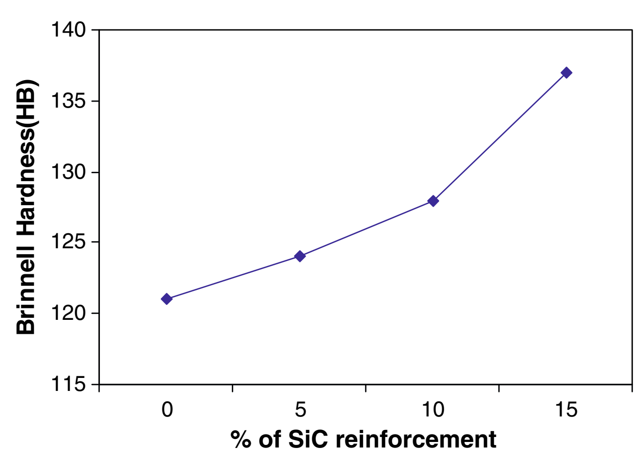


Fig. 7 Variation of hardness of composites with percentage of SiC reinforcement

Hardness increases by 10.48% with increase of percentage of SiC reinforcement from 5 to 15 wt.%. Silicon carbide particles of 20-40 μm size form barricades that hinder dislocation motion. This contributes to increase in the tensile strength and hardness. Decrease in tensile strength with addition of 15 wt.% SiC reinforcement is due to sharp edge of particulates, which acts as nucleation site. Stress will concentrate at these nucleation sites which will lead to fracture.

4. Conclusions

The following conclusions have been made:

1. The stir caster method was found to be successful to fabricate 7075 Al alloy and composites with 5, 10, and 15 wt.% SiC reinforcements. Heat treatment of SiC particles has improved their wettability with molten 7075Al alloy.
2. The 7075Al/10 wt.% SiCp cast at stirring speed of 650 rpm exhibits a uniform distribution of the particles as compared to the other two composites. A good bonding between the Al alloy matrix and 10 wt.% SiC reinforcements is also observed in the micrograph.
3. Full incorporation of 10 wt.% SiC reinforcement into aluminum matrix was obtained without addition of any wetting agent.
4. In tensile test composite containing 10 wt.% SiC reinforcement showed the maximum strength.
5. Hardness increased by 10.48% when percentage of SiC reinforcement was increased from 5 to 15 wt.%.

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