

INFLUENCE OF HEAT TREATMENT ON MECHANICAL BEHAVIOR OF ALUMINIUM-7075/SILICON CARBIDE COMPOSITES MANUFACTURED BY SQUEEZE CASTING PROCESS

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Abstract: The effect of heat treatment on mechanical behavior of silicon carbide reinforced aluminum matrix composites has been investigated. Hardness values increased with the increase of silicon carbide addition in both as-cast and heat treated composites. Peak hardness values are about 20-25% higher than as-cast hardness values. The flexural strength increased with increasing reinforcement content up to 10wt% silicon carbide in both as-cast and heat treated composites. The difference between maximum tensile strength and flexural strength is 228 MPa in as-cast and 245 MPa in heat treated aluminum composites. Silicon carbide particulates have even distribution through the as-cast matrix. Agglomeration of silicon carbide particulates was observed in some of the tensile test specimens.

Keywords: 7075, heat treatment, silicon carbide, squeeze casting process

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1. INTRODUCTION

Composite materials are composed of a matrix phase and a reinforcement phase. Matrix and reinforcement phase work together to produce combination of material properties that cannot be met by the conventional materials [1-21]. In most of the composites, reinforcement is added to matrix to increase the strength and stiffness of the matrix. Reductions in material density, or increases in stiffness, yield strength, ultimate tensile strength can be directly translated to reductions in structural weight. This led the aerospace industry to develop new materials with combinations of low density, improved stiffness and high strength as attractive alternatives to existing high-strength aluminum alloys and titanium alloys. These high-strength metal matrix composites combine the high strength and hardness of reinforcing phase with ductility and toughness of light metals.

The most common particulate composite system is aluminum reinforced with silicon carbide. So far most of the alloys that have been employed as matrices in aluminum have been focused on the A356, 2xxx and 6xxx

series alloys. Although very few studies have been reported on the 7xxx series alloys reinforced with silicon carbide particles, much less attention has been paid to the 7xxx Al alloy matrix composites, which show the highest strength of all commercial Al alloys and widely used for structural applications. Stronger matrix alloys tend to produce stronger composites, but within these composite systems there are many variables such as ageing conditions, weight/volume fraction of particulate, particulate size, which can affect mechanical properties.

Hence, the objective of this paper is to investigate the effect of heat treatment on mechanical behavior of silicon carbide reinforced aluminum matrix composites.

2. MATERIALS

The selection of materials for matrix and reinforcement is discussed to prepare metal matrix composite.

2.1. Matrix Material

Al 7075 was used as matrix material. The main alloying element is zinc. The second is magnesium, which is predominantly added to increase the wetting between matrix and reinforcement. Table 1 gives the chemical composition of 7075 alloy. Al-Ti-B (Al-5wt% Ti-1wt%B) was used to refine and decrease grain size of the matrix.

Table 1: Chemical composition of Aluminium-7075 ally

Alloying element	Cu	Mg	Zn	Cr	Al-Ti-B	Si	Al
Wt%	1.49	2.75	5.91	0.27	0.41	0.02	89.15

2.2. Reinforcement Material

Silicon carbide particulates were used as reinforcement material. Density of silicon carbide is between 1.30 g/cm³ and the mesh size is 30 ± 1 μm.

3. CASTING OF METAL MATRIX COMPOSITE

The squeeze casting process was used to manufacture metal matrix composite. Die material is tool steel. Induction furnace was used to melt the aluminum 7075 alloy. The casting process was carried out through the following steps:

1. Chemical composition was calculated according to the composition of 7075.
2. Elements of aluminum alloy (except magnesium) were added into the induction furnace and temperature of the furnace was adjusted to about 800°C and waited until obtaining a liquid phase. Magnesium was added after the liquid phase was obtained.
3. After obtaining the melt, silicon carbide powder was added into the molten metal.

4. Then furnace was turned off, and mechanical agitation was started. While making the mechanical agitation, the mould was heated by a torch.
5. After 5 minutes of agitation, the furnace was turned on again to melt the alloy to maintain the loss of heat during agitation.
6. Silicon carbide reinforced aluminum 7075 was processed by squeeze casting process applying 80 MPa pressure. At each casting operation three specimens were prepared. The remaining part was re-melted and recycled.

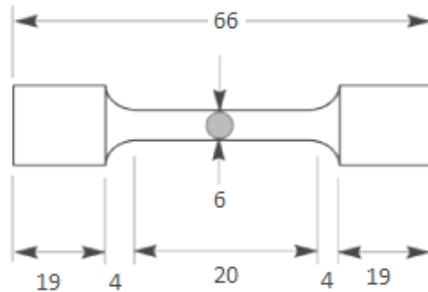


Figure 1: Tensile specimen, all dimensions are in mm.

4. EXPERIMENTAL TESTING

Five types (0-10-15-20-30 wt% SiC) of three point bending test and tensile testing specimens were obtained. The specimens were prepared for tensile testing and three point bending tests after casting. Only the burrs were cleaned before starting the tests. Dimensions and shape of tensile testing specimens are given in figure 1. Dimensions and shape of three point bending test specimens are given in figure 2.

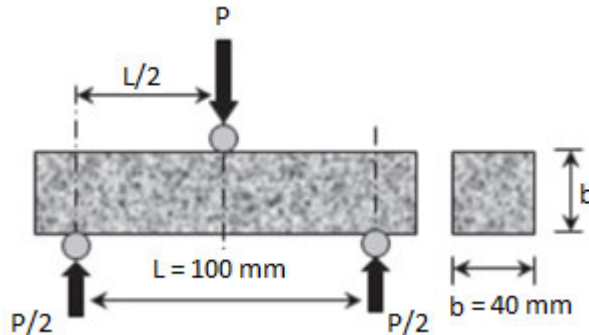


Figure 2: Three point bending specimen, all dimensions are in mm.

Two specimens of three point bending for each composition, as-cast and heat treated were tested. Also two specimens of tensile testing for each composition, as cast and heat treated were tested. Vickers 10 kg hardness values were acquired. Both sides of the specimens were tested for hardness.

Load (P) versus deflection (δ) data were recorded during tensile testing. Also the ultimate tensile strengths was evaluated. Recorded maximum loads are

in kilograms and they were converted to maximum stress values (MPa). Cross-sectional areas of tensile testing samples were measured and lengths are compared before and after fracture. All of the burrs were grinded in order to prevent notch effect. In three-point bending tests, the maximum fracture loads were evaluated. The load values were converted into flexural stress (MPa) values. The flexural stress formula is given as follows:

$$\sigma = \frac{M \times y}{I} \quad (1)$$

where σ flexural stress, M the bending moment, y the distance from the natural axis and I the moment of inertia respectively. The maximum flexural surface stress occurs in the mid-point of the specimen. Therefore:

$$M = \frac{P \times L}{4} \quad (2)$$

$$y = \frac{t}{2} \quad (3)$$

$$I = \frac{b \times t^3}{12} \quad (4)$$

$$\sigma_{\max} = \frac{3 \times P \times L}{2 \times b \times t^2} \quad (5)$$

$$\text{Since } b = t; \sigma_{\max} = \frac{3 \times P \times L}{2 \times b^3} \quad (6)$$

where p load applied, t thickness of the specimen, b width of the specimen, and L span length respectively.

4.1. Heat Treatment

All of the specimens were heat treated according to ASM T6 heat treatment procedures. All of the heat treated samples were also solution treated at 480°C for 60 minutes. Then they were quenched into water. Finally precipitation heat treatment was carried out for 24 hours at 120°C.

4.2. Metallographic Analysis

Microstructures of as-cast and heat treated aluminum composite samples were examined metallographically. Samples were firstly cut and mounted. Then they were grinded, polished and etched with Keller solution which contains 1.5% HCl, 2.5% HNO₃, 1% HF, 95% H₂O. At the end, representative photographs were taken by a digital camera. To find the volume fraction of SiC reinforced aluminum 7075 alloy composites, image analyzer study was performed. With the help of Clemex software, area percentages of SiC and aluminum matrix were calculated and this would give an approximate value about the volume percentages of reinforcement and the matrix.

4.3. SEM Study

In order to get interior structures of aluminum samples SEM studies were performed. In particular the precipitates that should form after heat treatment were examined. The percentages of alloying elements were analyzed and their graphs were obtained. SEM studies were done with JSM-6400 Electron Microscope (JEOL).

5. RESULTS AND DISCUSSION

Effects of silicon carbide addition on the fracture behavior of aluminum matrix alloy composites (both as-cast and heat treated) were examined. Hardness tests were also evaluated in order to find out the optimum heat treatment procedure.

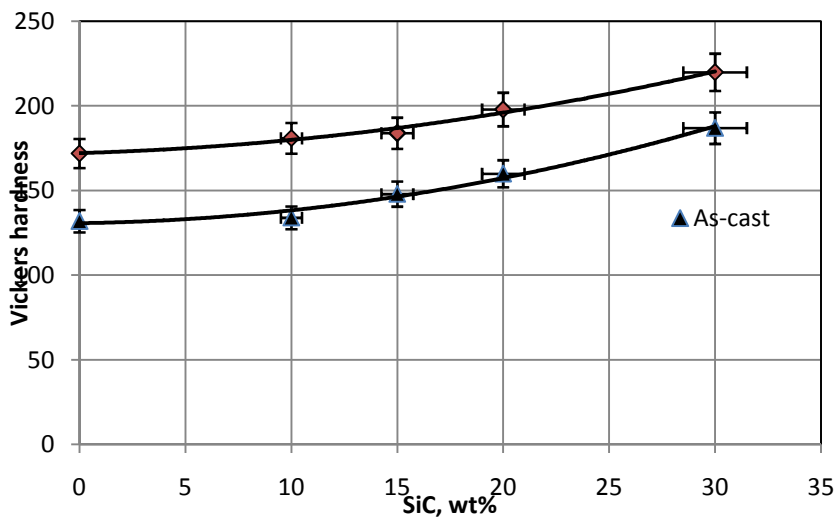


Figure 3: Variation of hardness with silicon carbide reinforcement

5.1. Effect of Silicon Carbide on Hardness

Hardness tests were carried out to observe the effects of heat treatment and effects of wt% addition of silicon carbide on aluminum alloy matrix since hardness is an indicator of a materials resistance to plastic deformation. Figure 3 shows the variation of hardness values with wt% silicon carbide. It is observed that the hardness values increase with the addition of silicon carbide. Silicon carbide particulates are ceramic materials that are harder than the aluminum matrix alloy. They fasten the dislocation motion and therefore an increase in strain hardening achieved. Heat treatment also has effects on the hardness values of aluminum matrix alloy. By precipitation heat treatment extra hardening was obtained. Precipitates act like silicon carbide particles and they form barricades to dislocation motion. The aluminum matrix composites were solution heat treated at 480°C for 60 minutes and precipitation heat treated at 120°C for twenty-four hours. In figure 3, a comparison between hardness values of as-cast and heat treated silicon carbide reinforced aluminum matrix composites can also be observed. It is seen that heat treatment increases the hardness values.

5.2. Effect of Heat Treatment Time on Hardness

Variation of Vickers hardness values with precipitation heat treatment time is shown figure 4. Peak hardness values are obtained after 24 hours precipitation heat treatment at 120 °C. From 4 hours to 24 hours usually hardness values increased gradually. Only in 15 wt% and 30 wt% SiC composite, a small decrease in hardness observed from 20 hours to 24 hours treatment. This decrease arises from the variation of hardness values in different regions of specimens. If the values were taken from the region where silicon carbide particles existed intensively, hardness values were measured higher than original values.

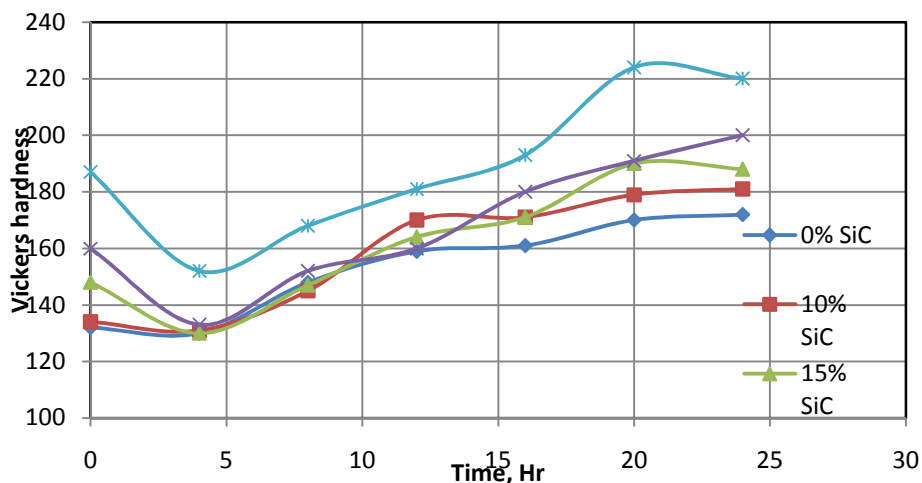


Figure 4: Variation of hardness with precipitation heat treatment time

5.3. Effect of Silicon Carbide on Flexural Strength

Three point bending tests were performed to observe the fracture behavior of aluminum matrix composite with different percentage additions of silicon carbide. Results are given graphically in figure 5. The flexural strength increased with increasing reinforcement content up to 10wt% silicon carbide. After 10 wt% SiC more additions of silicon carbide decreased the strength. In the 30wt% silicon carbide aluminum matrix composite the strength fell down to 302 MPa. Strength began to decrease as content approaches 15wt% silicon carbide. Composites failed at small strain values during the three point bending test for composites reinforced with 30wt% SiC. The matrixes probably did not have enough internal ductility and cannot overcome the localized internal stresses. All specimens showed brittle fracture at macro scale fracture surface examinations. The 10wt% SiC reinforced aluminum matrix composites have the maximum strength among the other composites. Silicon carbide particulates having particle size in the range of 10-30 μm form barricades and hinder dislocation motion. This supplies an increase in strain hardening and flexural strength. As in the as-cast composites the 10wt% silicon carbide reinforced aluminum matrix composites have maximum flexural strength. Small MgZn_2 , $\text{Mg}_{32}(\text{Al},\text{Zn})_{49}$ precipitates increased strength after T6 heat

treatment. They acted as barriers to dislocation motion. Size of precipitates is very small when compared with SiC particulates. Their sizes are between 0.5-1.5 μm . With the effect of precipitates and silicon carbide particulates, the 10%wt SiC reinforced composite reached to 579 MPa of maximum strength.

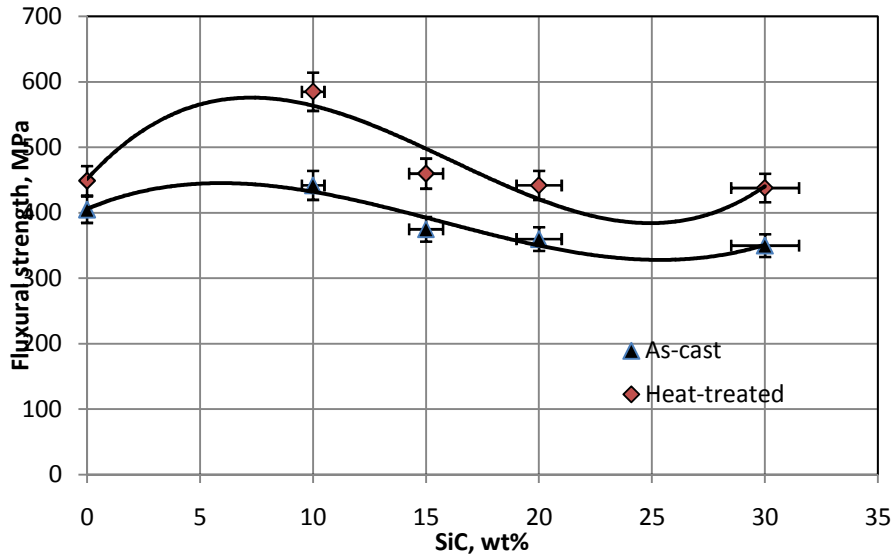


Figure 5: Variation of flexural strength with silicon carbide reinforcement

5.4. Effect of Silicon Carbide Reinforcement on Ultimate Tensile Strength

Variation of Vickers ultimate tensile strength with silicon carbide content and precipitation heat treatment time is shown figure 6. Almost all specimens were broken from the curved parts. Agglomeration of silicon carbide particulates was observed in some of the tensile test specimens. The ultimate tensile strength is found to be maximum for 10% silicon carbide reinforcement in the composite.

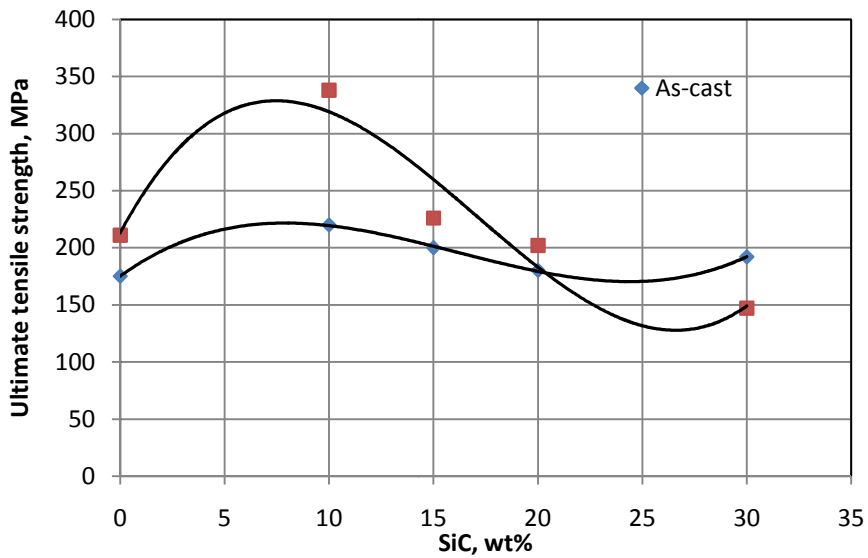


Figure 6: Variation of ultimate tensile strength with silicon carbide reinforcement

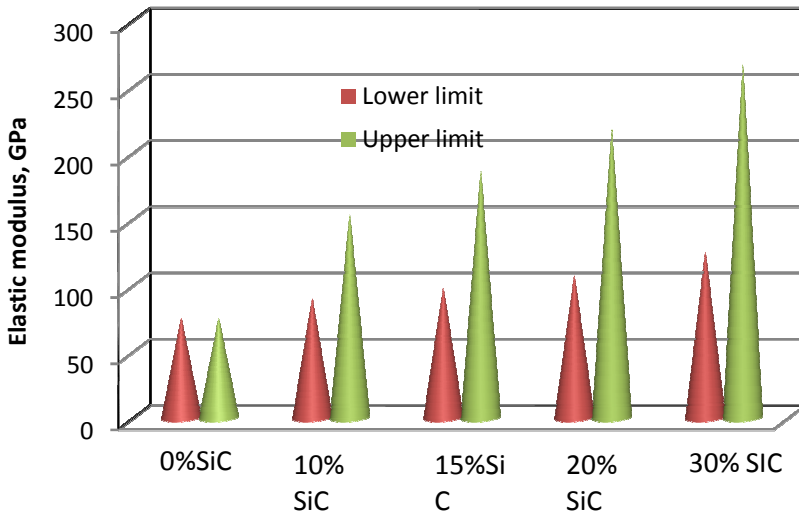


Figure 7: Variation of elastic modulus with silicon carbide reinforcement

5.5. Effect of Silicon Carbide Reinforcement on Elastic Modulus

Elastic modulus values were calculated theoretically with the **rule of mixtures** formula since proper strength-strain values could not be obtained. According to the formula, range of elastic modulus of composites can be found with the following formulae.

For upper limit: $E_{comp} = E_p \times V_p + E_m \times V_m$ (7)

$$\text{For lower limit: } E_{\text{comp}} = \frac{E_p \times E_m}{E_p \times V_m + E_m \times V_p} \quad (8)$$

where V_p and V_m are volume percentages of silicon carbide particulate and matrix respectively. From the literature, elastic modulus of aluminum 7075 alloy was found between 70-80 GPa and the manufacturer firm states the elastic modulus of SiC as 480 GPa. So, with the calculation according to the rule of mixtures the upper and lower limits of elastic modulus are shown in figure 7. The elastic modulus of the matrix was taken as 75 GPa, which is the average value. Theoretically the elastic modulus increases with increasing vol% of silicon carbide. This increase is valid up to 10 vol% silicon carbide addition where a uniform composite can be produced.

5.6. Microstructural Analysis

Metallographic examinations were carried out to see the distribution of silicon carbide particulates in aluminum matrix and investigate condition of grains. Both as-cast and heat treated aluminum composites were investigated. In figure 8, optical microscopy photographs of as-cast aluminum composites are shown. Silicon carbide reinforced aluminum composites have even distribution of reinforcement and this distribution can be seen in X200 magnified optical microscopy photographs. Aluminum matrices have grains with different sizes. This is due to the result of fast cooling during casting process.

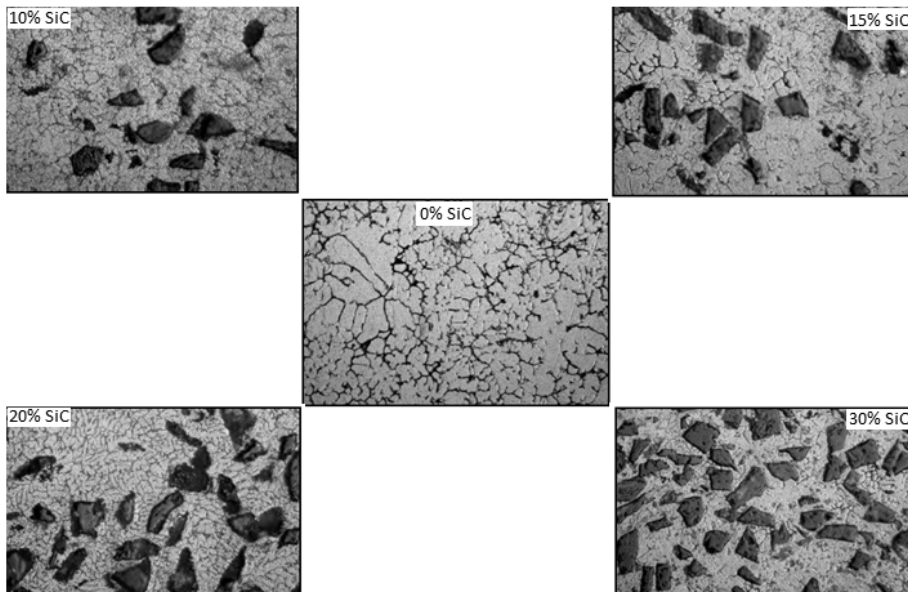


Figure 8: Micrographs of as-cast SiC reinforced 7075 composites, X500

Since the precipitates are very small and it is very hard to observe with optical microscopy, the only reliable way to observe them is scanning

electron microscopy. Their size can be predicted from SEM photographs and their sizes are between 0.5-1.5 μm . Figure 9 show SEM photographs of heat treated silicon carbide reinforced aluminum composites. Silicon carbide particulates and precipitates can be observed. Precipitates formed during heat treatment are also observed within each grain. Grain boundaries and precipitates of heat treated aluminum matrix can be observed in matrix alloy (0% SiC). Small black points seen in each grain are the precipitates formed during heat treatment.

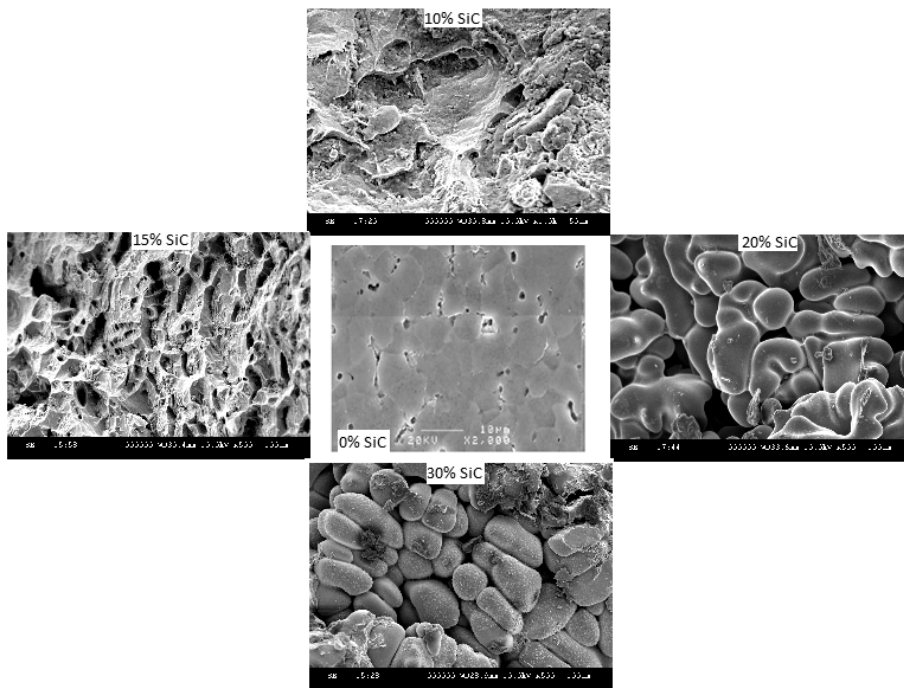


Figure 9: SEM photographs of heat treated SiC reinforced 7075 composites, X5000

CONCLUSIONS

The following results were concluded form the study presented in this paper:

1. Hardness values increased with the increase of silicon carbide addition in both as-cast and heat treated composites.
2. During heat treatment from 4 to 24 hours hardness values increased gradually. Peak hardness values are about 20-25% higher than as-cast hardness values. By precipitation heat treatment extra hardening was obtained.
3. The flexural strength increased with increasing reinforcement content up to 10wt% silicon carbide in both as-cast and heat treated composites.
4. The maximum flexural strength increased about 40 MPa in as-cast, 180 MPa in heat treated composites.
5. Tensile strength values of all as-cast and heat treated samples were lower than flexural strength as expected. The difference between

- maximum tensile strength and flexural strength is 232 MPa in as-cast and 240 MPa in heat treated aluminum composites.
6. Silicon carbide particulates have even distribution through the as-cast matrix. As-cast aluminum matrices have grains with different sizes as a result of fast cooling during casting and the efficiency of grain refiner addition, Al-Ti-B.
 7. Agglomeration of silicon carbide particulates was observed in some of the tensile test specimens.

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