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Microstructure Characterization and Mechanical Properties of Al-SiC_p Composites

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Abstract: In recent years the aluminum matrix composites are gaining wide spread applications in automotive, aerospace, defense, sport and other industries. The reason for this is their exciting properties like high specific strength, stiffness, hardness, wear resistance, dimensional stability and designer flexibility. The present work reports on mechanical properties and microstructure analysis of Al-SiC particulate composites with different wt. % of SiC_p. Al-SiC_p composite specimens with different weight % of SiC (viz. 5, 10, 15, 20, 25 and 30 wt. % of SiC) were fabricated through casting process. The induction furnace and open furnace were used for melting of Al-SiC particulate composites. The induction furnace gives the advantage of self-stirring action on the introduction of SiC particles. Grinding and fine polishing was done using diamond paste to prepare different samples for microscopic study. The microstructure examination of the polished and carefully etched Al-SiC_p composite specimens showed that the structure consists of a network of silicon particles, which were formed in inter-dendritic aluminum silicon eutectic composition. These SEM micrographs clearly indicate that the SiC particulates are dispersed uniformly in the Al matrix even at higher percentage such as 20 weight % SiC_p. The SiC particulates were observed to be in irregular shape.

Keywords: Al-SiC_p Composites, Induction Furnace Melting, Wear Debris and Microstructure

1. Introduction

The Aluminum-Silicon carbide particulate (Al-SiC_p) composites are now emerging as an important engineering material. Its potentially high tensile strength and elastic modulus at room or elevated temperatures have stimulated the interest in this material. Unlike composites with continuous fiber reinforcement, the properties of particle reinforced composites are often isotropic. Particle reinforced metal matrix composites are commonly produced by means of powder metallurgy or liquid metallurgy routes. Both routes have the potential to produce a near net shape product that minimizes further machining operations. When aluminum-silicon carbide composites are produced by melt processes, SiC particles often react with molten aluminum to form aluminum carbide (Al_4C_3) which may result in degradation of the reinforcement strength and the interfacial strength. To control the behaviour of the resulting interface and the wetting behavior of the melt, unusual alloys high in silicon and magnesium are necessary [1].

The discontinuously reinforced metal matrix composites, (SiC particulate reinforced aluminum matrix composites) have received much attention for their good properties with low cost. The widely used commercial SiC particulates generally have a size ranging from a few micrometers to several hundred micrometers [2]. Mechanical strength of the almost all the structural materials including Metal Matrix Composites (MMCs) is decreased with an increase of use time. Such a phenomenon is called degradation. There exist many environmental factors to degrade the structural materials such as temperature, corrosion, radiation, and so forth [3]. So, it is necessary to understand mechanical properties of the MMCs degraded by such factors for improving the reliability of the MMCs. However,

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studies on the mechanical properties of the MMCs degraded by such environ-mental factors have been hardly carried out up to now in spite of many research results about mechanical properties of the MMCs, As a series of work for assessing the mechanical properties of the MMCs especially, Al-SiC$_p$ degraded by environment factors, mechanical properties of the corrosively degraded Al-SiC$_p$ were examined by room temperature tensile tests and Rockwell hardness measurement [4- 8].

The Al-SiC$_p$ composites have a significant reduction in fracture toughness and ductility, compared to the monolithic alloys. This is a major factor in the limited commercial exploitation of these materials to date, and could ultimately limit their breadth of application. Another consideration, which has a similar effect on their exploitation, is that they are difficult to machine, requiring the use of relatively expensive polycrystalline diamond. David L. McDanels [9] studied the mechanical properties and stress strain behaviour for several types of commercially fabricated aluminum matrix composites. The yield and tensile strengths of Al-SiC composites demonstrated up to a 60 percent increase over those of the unreinforced matrix alloys.

In this study, Al-SiC$_p$ composites with 5, 10, 15, 20, 25 and 30 wt. of SiC$_p$ were fabricated using casting process. The various properties viz. density, compressive strength, hardness test, direct tensile strength, surface roughness results are investigaded.

2. Experimental procedure

2.1. Material preparation

The chemical composition of the aluminum alloy 6061 and SiC$_p$ is given in Table 1. Al-SiC$_p$ composite specimens are fabricated through gravity die casting process using a designed and fabricated mild steel die. The induction furnace and open furnace were used to melt the material. Commercial aluminum was melted in the graphite crucible and the temperature was increased a little beyond its melting point, SiC particles were introduced into the melt. Simultaneously a stirrer was used to stir for about 10 minutes so as to avoid settling of SiC particles, and to promote uniform distribution of SiC particle in the matrix aluminum. After removing the graphite crucible from the furnace, the melt was once again stirred and subsequently poured into the die. The same procedure was repeated using different weight % of SiC$_p$ (viz. 5, 10, 15, 20, 25, and 30 wt. % of SiC$_p$) to fabricate valve guide with different compositions.

2.2. Fabrication of die for casting of valve guide

A mild steel die has been designed and fabricated for gravity die casting of Al-SiC$_p$ composite specimens. The die has been designed in such a way that at a single pouring, four specimens can be cast. The Fig. 1 shows photograph of the die for casting of Al-SiC$_p$ composite specimens.

2.3. Mechanical properties of the Al-SiC$_p$

Al-SiC$_p$ composites with 5, 10, 15, 20, 25 and 30 wt. % SiC$_p$ were fabricated using casting process. The various properties viz. density, compressive strength, hardness test, direct tensile strength, surface roughness were measured.

2.4. Density

The theoretical density was determined by comparing the sum of volume (weight divided by the density) of constituents and the volume of composite. For example, the density of Al-5 wt. % SiC$_p$ composites with 0.5 wt. % of Mg was determined as follows (Eq. 1):

$$\frac{100}{r_t} = \frac{5}{31490.1} + \frac{0.5}{17363.7} + \frac{94.5}{26487} \qquad (1)$$

Specific density of SiC$_p$ = 31490.1 N/m^3, Specific density of aluminum = 26487 N/m^3, Specific density of magnesium = 17363.7 N/m^3

From Eq. (1) the theoretical Specific density (r_t) for Al- 5 wt. % SiC$_p$ composites = 26628.579 N/m^3. Similarly, the density of other compositions of Al-SiC$_p$ composites was determined.

2.5. Compressive strength

Compression test was performed on both cast Al-SiC$_p$ composite specimens with length to diameter ratio of 1.5. Tests were performed using Universal Testing Machine (UTM) of 100 KN capacities. The sample was compressed between two flat platens and the maximum failure load was recorded. The compressive strength for cast Al-SiC$_p$ composites fabricated using open furnace melting and induction furnace melting.

2.6. Hardness test

The hardness was also measured for three samples of the each composition of the composites. The hardness for cast Al-SiC$_p$ composites fabricated using open furnace melting and induction furnace melting. The Rockwell hardness was measured on the polished surfaces of the samples using 'C' scale on Rockwell hardness tester. A diamond indenter with fixed indentation load of 196.2 N was used for all tests. The angle of diamond indenter is 120°. Three readings were taken for the samples of each composition and the average hardness was determined.

2.7. Direct tensile strength

The direct tensile strength of Al-SiC$_p$ composites specimens were measured. For this purpose Al-SiC$_p$ composite samples were fabricated as per the ASTM standard as shown in Fig. 2. The cast composites were further machined to fabricate (tensile specimens). The tensile strength was measured on 100 KN universal testing machine.

2.8. Surface roughness

Cast Al-SiC$_p$ composite specimens were ground using surface grinder. They were polished using emery paper and then finished using diamond-lapping paste. The surface roughness on polished specimens was determined using Talysurf-6 surface roughness measuring instrument.

Table 1. Chemical compositions of the aluminum alloy and SiC$_p$ reinforcement

Aluminium Alloy 6061								
Element	Cu	Mg	Mn	Fe	Cr	Ni	Si	Al
Amount (wt.%)	0.21	0.86	0.02	0.14	.007	.008	0.46	Bal
SiC$_p$ reinforcements (Purity, grater than 99%)								
Element	Al	Ca	Cr	Fe	Mg	Mn	Ni	Ti
Amount (wt. %)	0.2	0.03	0.01	0.15	.008	.008	0.03	0.12

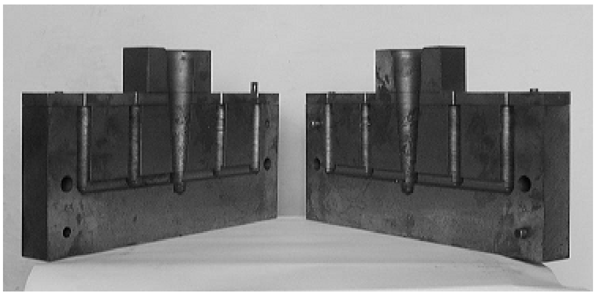

Fig. 1. Photograph of the die for valve guide.

2.9. Microstructure analysis

The Al-5 to 20 wt. % SiC$_p$ composite samples for microscopic study were prepared by grinding and fine polishing was done using diamond paste. After polishing the specimens were etched in dilute HNO_3 at 70°C for 40 seconds followed by quenching in water. The microstructure of the polished and etched specimens were observed using scaning electron microscopy (SEM). SEM equipped with an energy depressive X-ray spectroscope (Hitachi S70). Prior to examination using SEM, the specimen were cleaned in ultrasonic bath.

3. Result and discussion

3.1. Density of the Al-SiC$_p$ composites

The theoretical density was determined by comparing the sum of volume (weight divided by the density) of constituents and the volume of composite. The measured density also find as per the samples, these different between the theoretical and measured density shown in Fig. 3.

Theoretical and measured density of Al-SiC$_p$ composite specimens were increasing with increase in wt. % of SiC$_p$ from 5 to 30 wt. % of SiC$_p$. The theoretical density is more than the measured density.

3.2. Compressive strength of the Al-SiC$_p$ composites

Compressive test was performed on cast metal Al-SiC$_p$ composite specimens with length to diameter ratio of 1.5. Tests were performed on UTM of 100 KN capacity. The sample was compressed between two flat platens and the maximum failure load was recorded.

The compressive strengths were also measured for three samples of the each composition of the composites and the average valve of the compressive strength in the graphs with wt. % of SiC$_p$.

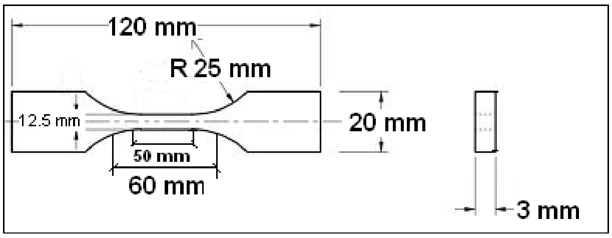

Fig. 2. Dimension drawing of the tensile test.

The Fig. 4 shows the compressive strength for cast Al-SiC_p composites fabricated using open furnace melting and induction furnace melting.The compressive strength in both the cases increases with increase in wt. % of SiC_p from 5 to 30 wt. % of SiC_p. The Al-SiC_p composites fabricated using induction melting show higher compressive strength values than those fabricated by open furnace melting.

3.3. Hardness test of the Al-SiC_p composites

The hardness was also measured for three samples of the each composition of the composites and the average valve of the hardness in the graphs with wt. % of SiC_p. The Fig. 5 shows the hardness for cast Al-SiC_p composites fabricated using open furnace melting and induction furnace melting. The hardness in both the cases increases with the increase in wt. % of SiC_p from 5 to 30 wt. % of SiC_p. The Al-SiC_p composites fabricated using induction melting show higher compressive strength values than those fabricated by open furnace melting. This can be attributed to uniform mixing.

3.4. Direct tensile strength

The direct tensile strength of the cast Al-5, 10, 15, 20, 25 and 30 wt. % of SiC_p composites were measured. For this purpose Al-SiC_p composite samples were fabricated as per the ASTM standard. The tensile strength was measure on 100 KN universal testing machine. The direct tensile strengths were also measured for the three samples of the each composition of the cast Al-SiC_p composites and the average tensile strength are shown in Fig. 6.

The tensile strength increases with increase in weight % of SiC_p up to 15 % and decrease with increase in weight % from 20 to 30 weight percent. The variation in measured values of the tensile strength about the average was within ± 2.5 % of the average valve. The Al-SiC_p composites fabricated using induction melting show higher direct tensile strength values than those fabricated by open furnace melting

3.5. Surface roughness

Cast Al-SiC_p composite specimens were ground using surface grinder. They were polished using emery paper and then finished using diamond-lapping paste. The surface roughness on polished specimens was determined using Talysurf-6 surface roughness measuring instrument. The surface roughness is decreasing with increasing wt. % of SiC_p com-posites. It is shown in Fig. 7.

3.6. SEM analysis

The microstructures of cast Al-SiC_p composites specimen were studied by SEM. The SEM micrographs clearly indicate that the SiC particulates are dispersed uniformly in Al matrix even at wt. percentage as high as 15 weight %. Fig. 8 shows microstructure of Al-SiC_p composite with 5% wt. of SiC particulates. The SiC particulates are observed to be in irregular shape.

The microstructure of Al-SiC_p composite with 10% wt. of SiC particulates is shown in Fig. 9. The microstructure of Al-SiC_p composite with 15% wt. of SiC particulates is shown in Fig. 10.

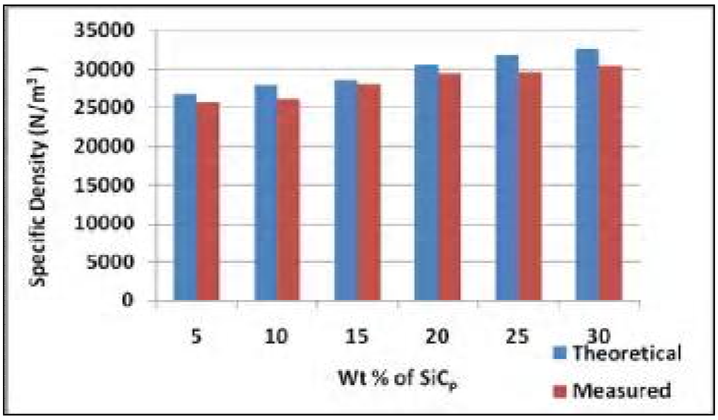

Fig. 3. Specific Density of the Al-SiC_p Composites.

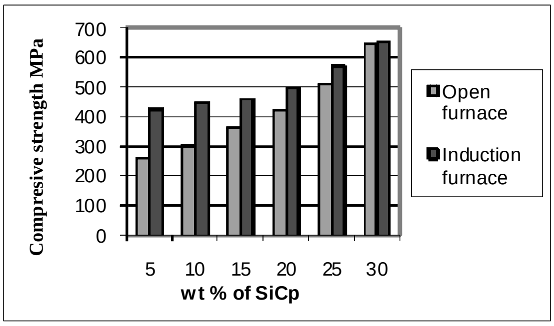

Fig. 4. Variation of compressive strength with wt. % of SiC$_{p.}$

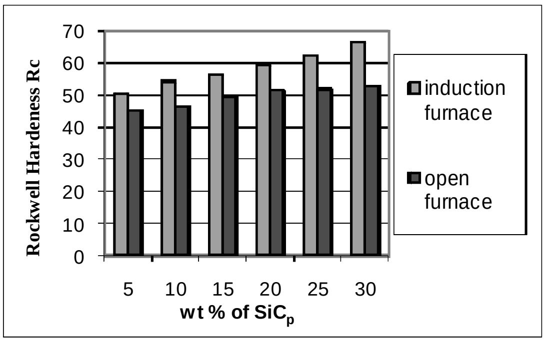

Fig. 5. Variation of the hardness of the induction and open furnaces.

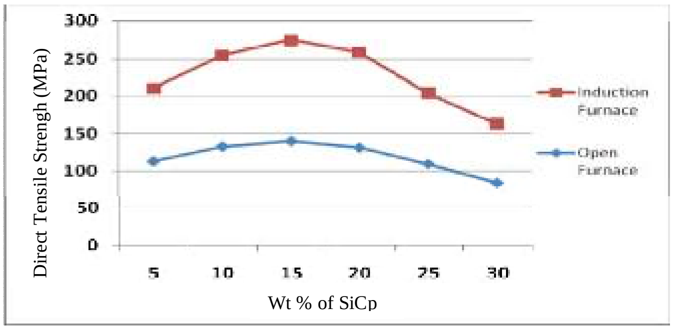

Fig. 6. Variation of direct tensile strength of Al-SiC$_p$ with wt. % of SiC$_{p.}$

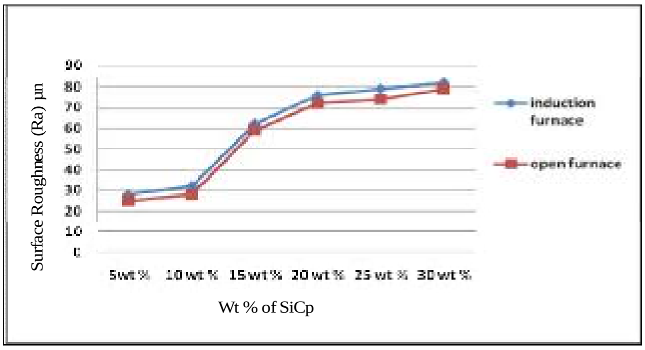

Fig. 7. Variation of surface roughness of Al-SiC$_p$ with wt. % of SiC$_{p.}$

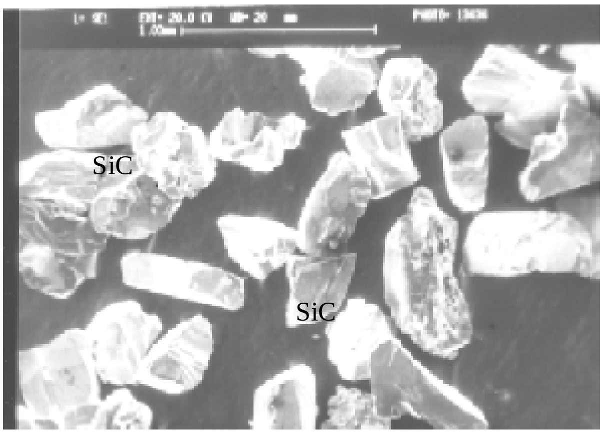

Fig. 8. Typical Microstructure of Al-SiC$_p$ composite 5 wt. % SiC$_p$.

Fig. 9. Typical Microstructure of Al-SiC$_p$ composite 10 wt. % of SiC$_p$.

Fig. 10. Typical Microstructure of Al-SiC$_p$ composite 15 wt. % SiC$_p$.

4. Conclusions

Aluminum based metal matrix composites are the most promising materials for the future automotive and other applications. The Al-SiC$_p$ composites were fabricated using induction melting show higher compressive strength values than those fabricated using open furnace melting. Al-SiC$_p$ composites fabricated using induction melting exhibited better mechanical properties than the composites processed in open furnace.

Al-SiC$_p$ composite poppet valve guides with 5 to 30 wt. % of SiC$_p$ were successfully fabricated by casting process. These guides possess very good surface finish.

The compressive strength, density and hardness of Al-SiC$_p$ composites increase with increase in wt. percent of SiC particulates for all the composites tested. The tensile strength decreases when the amount of reinforcement content exceed to 30 wt. % of SiC.

These SEM micrographs clearly indicate that the SiC particulates are dispersed uniformly in Al matrix even at wt. percentage as high as 15 wt. %. The SiC particulates are observed to be in irregular shape.

Acknowledgments

The authors wish to thank Prof. R. Sagar, IIT Delhi for his help in testing the all mechanical properties.

Nomenclature

Al	aluminum
Ca	cadmium
Co	cobalt
Cu	copper
Cr	chromium
Fe	Ferrous
Mg	Magnesium
Mn	Manganese
Ni	Nickel
Ti	Titanium
Si	Silica
SiC	silicon carbide
SiC$_p$	silicon carbide particulate
ρ_t	theoretical specific density

Subscripts

p	particulate
t	theoretical
i	inlet, inside

L	longitudinal pitch
o	outlet, outside
pp	pinch point
0	restricted dead state
s	steam
sat	saturation state
t	total, tube
T	transverse pitch
w	water, wall

Reference

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