Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 1,Issue 12, December -2014

Comparison of Mechanical Properties and Microstructure of Aluminum alloy Micron and Nano SiC Composites fabricated by Ultrasonic Vibration

R. S. Rana*, Rajesh Purohit*, Sanjay Soni and S. Das**

*Department of Mechanical Engineering, Maulana Azad National Institute of Technilogy, Bhopal, (MP)
E-mail: ravindrarana74@gmail.com, rpurohit73@gmail.com;
**Scientist, AMPRI, Bhopal (MP)

Abstract *— Aluminium and aluminium alloys are widely used in industries due to low density, high corrosion resistance and thermal conductivity. However, in the engineering application aluminium alloys still have some problems such as relatively low strength, unstable mechanical properties. The mechanical properties can be improved by addition of ceramic particles like SiC etc. to fabricate metal matrix composites (MMCs). These composites are not only light weight, but have high-strength, Stiffness and wear resistance. In this study, AA 5083 alloy Micron and Nano SiC composites have been fabricated by Ultrasonic assisted Stir casting. Different weight % of Micron SiC (3, 5, 8, 10 Wt %) & Nano SiC (1, 2, 3 and 4 wt %) were used for synthesis of composites. Density, Elastic modulus, Tensile strength, Compressive Strength, Elongation, Hardness for aluminum alloy micron and nano SiC composites were measured. Microstructure characterization of both micron and nano SiC composites were carried out. Results revealed that porosity increases with increase the weight percentage of SiC. Al Nano SiC shows higher value of elastic modulus, tensile strength, compressive strength than Al Micron SiC Composites. Hardness of composites increases with increase in weight percentage of SiC. SEM micrograph shows uniform distribution of SiC particles with some places agglomeration. The application of ultrasonic vibration on the composite during melting not only refined the grain microstructure of the matrix, but also improved the distribution of Sub micron and nano-sized particles.*

Keywords*- component; formatting; style; styling; insert (key words) (minimum 5 keyword require) [10pt, Times new roman,Italic, line spacing 1.0]*

I. INTRODUCTION

Aluminium matrix composites have drawn immense interest for various applications in making aerospace and automobile components due to their light weight, high strength to weight ratio, high stiffness, lower cost, easy of fabrication and high dimensional stability. Particulate–reinforced Aluminum matrix composites (AMCs) are of particular interest due to their ease of fabrication, lower costs, recyclability and isotropic properties. Stir casting is well established process for producing MMCs that are reinforced with micron size ceramic particles. Melt stirring process has some important advantages e.g., the wide selection of materials, better matrix–particle bonding, easier control of matrix structure, simple and inexpensive processing, flexibility, applicability to large quantity production and excellent productivity for near-net shaped components [1]. However, there are some problems associated with stir casting of AMCs. Hashim et. al. [2] have identified four technical difficulties in stir casting: difficulty of achieving a uniform distribution of the reinforcement material; wettability between the two constituents, porosity in the cast structure and chemical reactions between the reinforcement material and the matrix alloy. Some recent studies have revealed that ultrasonic vibration is efficient in dispersing submicron and nanoparticles in the melt [3]. In order to achieve a uniform dispersion and distribution of nanoparticles in aluminum matrix nano composites, G.I. Eskin et al. [4], The young's modulus increases with increase in volume fraction of the reinforcement for Al-SiC composites. Many investigators have also found that the elastic modulus of Al-alloy increases by the dispersion of alumina and zircon etc. particles in the alloy. Extensive studies [5-7] have been made on evaluating the strength of discontinuously reinforced Al-alloys. It has been reported that SiC whisker and particle reinforcements in different alloy matrices improve the yield and ultimate tensile strength of the alloy up to 60 %, over the base alloy depending on the volume fraction of reinforcement, the type of matrix alloy and processing conditions. Ali Mazahery et.al. [8] have done characterization of cast A356 alloy reinforced with nano SiC composites. They reported that the yield strength, ultimate tensile strength and the elastic modulus are improved with the addition of nano particles although some reduction in ductility was observed.

Nrip Jit, et. al. [9] have fabricated composites $(A384.1)_{1-x}$ $[(SiC)p]_x$ containing 0, 0.10, 0.15 and 0.20 percent SiC with particle size 0.220 µm by modified stir casting technique. The addition of SiC in A.384.1 Al Alloy was found to increase proof stress and ultimate tensile strength with respect to unreinforced Al Alloy. The compressive properties of the Al alloy and MMC's revealed that the values of 0.2% proof stress and compressive strength increase with composition from x=0 to x=0.15 and decrease for x>0.15. While moving from as-cast to extruded, an increase in compressive strength and 0.2% proof stress was observed.

Ductility is one of the important aspects in the mechanical behaviour of composites. The tensile elongation decreases rapidly [10] with the addition of reinforcing particles. To maximize ductility for a particular volume fraction, the composite should have (i) uniform particle distribution, (ii) finer particles (<10 µm), uniform particle size distribution, (iii) a high interfacial strength (iv) control of particle shape, (v) a ductile matrix and (vi) use of different free particles. Additionally, composite fabrication and processing will influence the degree of flexibility available to meet most of these above requirements.

The contributions of several researchers regarding the effect of reinforcement on hardness of the composites are summarized as follows; The particulate reinforcements such as SiC, Al_2O_3 and aluminide [11-13] are generally preferred to impart higher hardness. Umanath k. [14] have fabricated Al 6061alloy based hybrid composites reinforced with mixtures of SiC and Al2O3 particles with 25 vol% by stir casting method. Results revealed that micro hardness (HV) of the composite specimens increase with increasing volume percentage of particulate reinforcement. This may be attributed to the solid solution hardening of the matrix by the addition of reinforcements to the alloy. Dontham setty .et. al. [15] investigated the effect of selected nanomaterials (SiC, B_4C, CNTs, 0.5 Wt %) on the microstructure and mechanical properties of A356 Nanocomposites.

It is concluded from the literature survey that few studies has been carried out for the investigation of ultrasonic vibration effect on the microsturcture and mechanical properties of aluminium alloy composites. Some of the information is really appreciating. However there no information regarding the synthesis of both micron and nano SiC composites, mechanical [roperties and microstructure characterization of micron and nano SiC Composites fabricated by Ultrasonic Vibration. Ultrasonic cavitation assisted fabrication increase the mechanical properties of composites and improve the microstructure by avoid agglomeration and segregation of particles. Experimental results show a nearly uniform distribution and good dispersion of the nano-particles within the Al matrix, although some of agglomeration was also found.

II. EXPERIMENTAL

Aluminum alloy 5083 has been selected as matrix material for synthesis of AMCs. Aluminum alloy was supplied by chaudhary enterprise, Delhi. Aluminum 5083 alloy is highly resistant to attack by both seawater and industrial chemical environments, apart from retaining exceptional strength after welding.

2.1 Compositional Analysis: The compositional compositions of aluminium alloy was analyzed using Glow discharge spectrometer (model: GDS 500A, Leco, USA) and it is shown in Table 1.

Table-1

Element	Zn	Fe	Ti	Cu	Si	Pb	Mn	Mg	Cr	Al
% Present	0.03	0.173	0.04	0.0181	0.16	0.0140	0.526	5.13	0.097	Balance

2.2 Selection of Reinforcement Particles

In the present work micron and nano size Silicon Carbide particulates have been used as reinforcement material. SiC micron size particles were supplied by chaudhary enterprise delhi of 400 mesh and average particles size was 35 µm SiC (99% Pure). SiC Nano particles were supplied by M. K. Impex Corporation, Canada of average particle size 40 nm (SiC-b, 99 +% pure).

SEM and TEM analysis has been done to find out the size of Micron SiC and Nano SiC particles. SEM micrograph of micron SiC_p and TEM micrograph nano SiC_p are shown in Figure 4.1and Figure 4.2 respectively. Average particles size of micron SiC_p was found to be 35 µm and average particles of nano SiC_p was found to be about 40nm.

40nm.

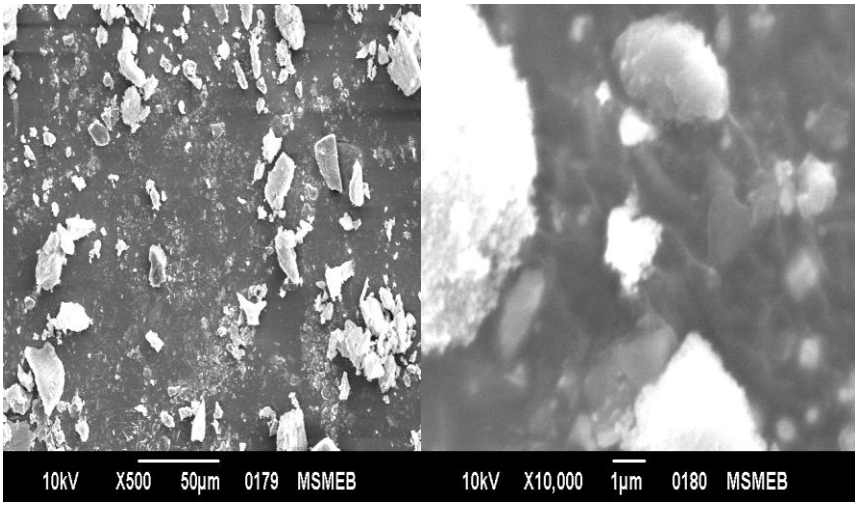


Figure: SEM analysis of Micron size SiC_p particles

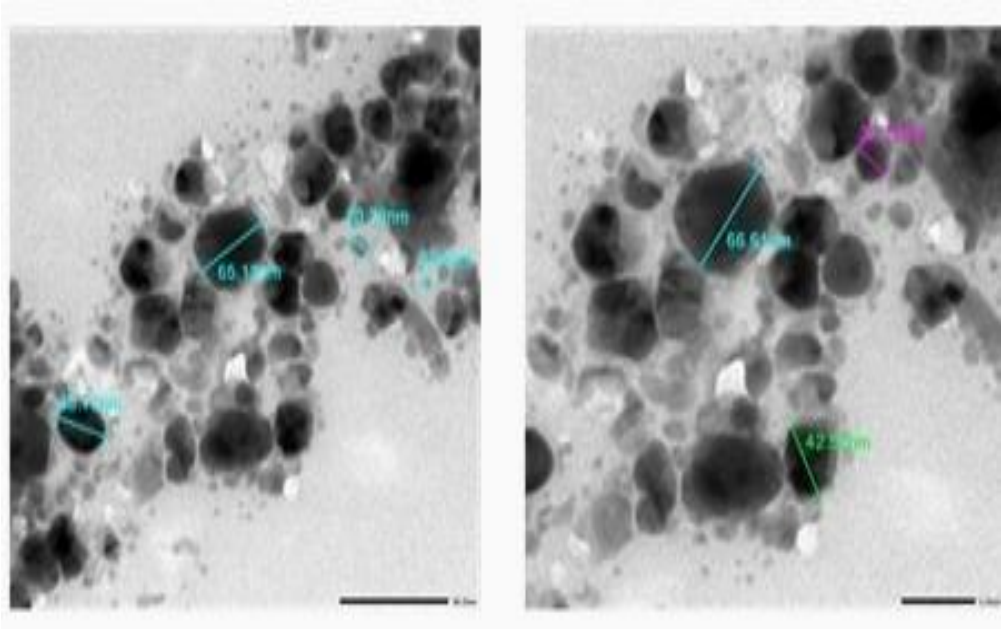


Figure 4.2: TEM analysis of Nano SiC_p Particles

2.3 Synthesis of Aluminum alloy SiC_p Composites

Aluminum 5083 alloy-SiC_p composites with 3, 5, 8 & 10 wt% micron SiC_p and 0,1, 2, 3, & 4 wt% Nano SiC_p were cast using ultrasonic assisted stir casting process.1.5 kg Aluminum 5083 alloy was melted in graphite crucible in electrical resistance furnaces at a temperature 760°C which is above the melting point temperature of the alloy. When the alloy reaches to a semi-pasty stage, the surface is covered with the flux agent (Coveral-11). About 5 grams of the flux was added to the molten alloy. After complete melting, the dross is removed from the surface using a graphite-coated skimmer. The dissolved gases were removed by passing dry nitrogen grade 1 gas into the melt for 5 minutes. Dross was also removed by nitrogen gas bubbling, most probably by mechanical action i.e., inert gas carrying the oxides to the surfaces of the melt.

After degassing, the surface is again cleaned and the temperature of the melt was increases to 780°C. It is worth mentioning that during degassing, the temperature of the melt was brought down to 680°C. This takes care of minimum gas absorption during bubbling. Stirring the alloy melt was done with the help of a mechanical stirrer and then added the pre-heated micron SiC_p particles with different wt. % in the melt. Again sonicating the composite melt with ultrasonic probe. For Ultrasonic Assisted stir casting of composites the ultrasonic vibrator/probe with 1200 watt power and 20.20 KHz frequency was inserted in the melt.

2.4 TESTING OF MECHANICAL PROPERTIES

Density Measurement

The experimental density of SiC particles were measured according to archimedian method. The small pieces cut from alloy and composites weighted first in air and then in water. The theoretical densities were calculated using the rule of

mixture according to the mass fraction of micron and nano particles. Porosity were reported by difference between theoretical density and experimental density. Density of AA 5083 alloy is 2.66 gm/cm^3 and density of SiC is 3.22 gm/cm^3.

Elastic Modulus Measurement

The elastic modulus of AA 5083 alloy and composites was measured with the help of dynamic elastic properties analyzer (Model: Depa light system, Jagdish electronics, Bangalore). This instrument works on the principle that vibration signal generated by exciting test specimen using impulse tool is analysed using Fast Fourier Transform (FFT). The vibration signal is displayed as FFT graph and also displayed digitally on the screen. Using the resonant frequency value, the elastic modulus is calculated. The dimension of the sample was 68.5 mm x 37.4 mm x 21.12 mm. Five readings of each samples were taken and the mean value is reported.

Tensile Test

Tensile properties of the AA5083 alloy and composites were analysed by carrying out tensile test on the universal testing machine of 1000KN capacity. Tensile tests were carried out with a crosshead speed of 1mm/min, which corresponds to nominal strain rate of 0.001 per second. During the tests, the load & elongation data were captured by induced software and these data were used for further analysis. Specimens were prepared according to ASTM E8 standard for the testing of materials.

Compression Test

Compression Specimen were prepared according to ASTM D695 standard for the testing of materials maintaining the L/D ratio of 1.5. Cylindrical specimens with 30mm diameter and 45 mm length were prepared.

Elongation Measurements:

Elongation measurement were done during tensile testing of specimens by marking the initial gauge length over the specimens and after tensile testing again measuring the increase in length with the help of vernier calliper. The percentage increase in gauge length is reported as elongation of aluminum matrix composite with different percentage additions of silicon carbide.

Hardness Measurement:

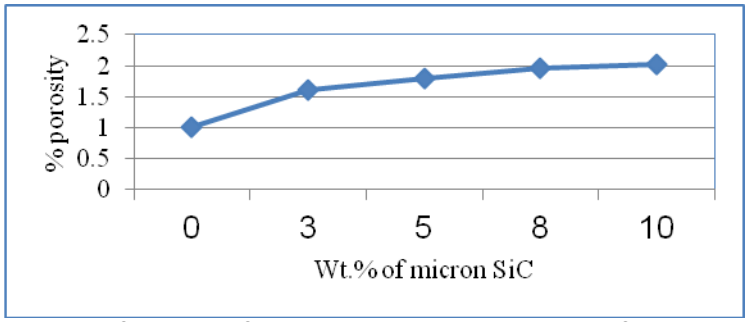
In hardness test, first of all samples of 20 mm dia. and 15mm length in cylindrical section were carefully cut from defect free reason of cast specimen. The specimen was polished metallogarphically and the opposite sides of the samples were made perfectly parallel before hardness measurement. Samples were polished on the polishing machine by using 400, 600, 800 grit emery paper. Hardness test were carried out using Brinell hardness test with a load of 150 kgf. The hardened-steel ball of 5 mm diameter was used as indentor.

Microstructure Study:

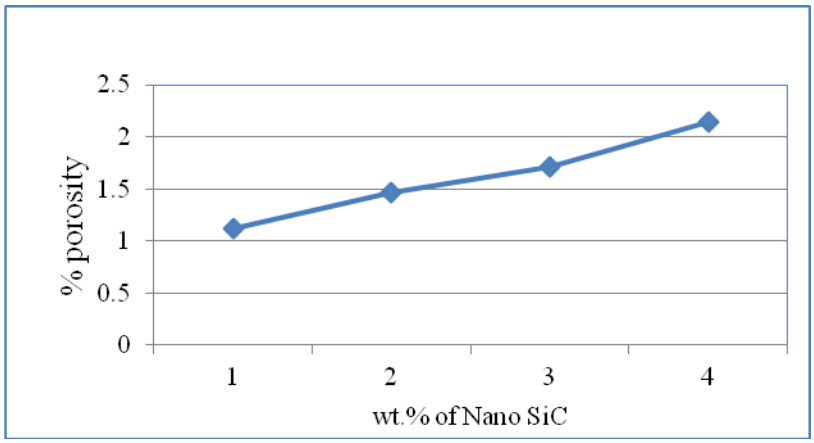
Microstructural characterizations were done using scanning electron microscope to observe the microstructure of sample surface and distribution of micron and nano SiC particles in aluminium alloy. The micrographs were taken in secondary electron (SE) mode. This analysis was done by a scanning electron microscope equipped with Energy Dispersive X-Ray Spectroscopy (EDS) (Model: JEOL 6390 A Analytical scanning electron microscope, JEOL Limited, Japan).

Results and Discussions:

Variation of porosity with different weight % of Micron SiC and Nano SiC are shown in figure 5.1 and figure 5.2 respectively. It is observed from the figure that porosity increases with increasing weight percent of SiC_p and decreasing particle size. This is due to the effect of low wettability and agglomeration at high reinforcement content and pore nucleation at the matrix–SiC particles interfaces. Moreover, decreasing liquid metal flow associated with the particle clusters leads to the formation of porosity. Also, with a same weight percent [3%] of SiC particles, the porosity of nano-composite is more than that of micro-composite because of the low wettability, more agglomeration and more number of particles in case of nano particulate composites in comparison with micro particulate composites. micro particulate composites.



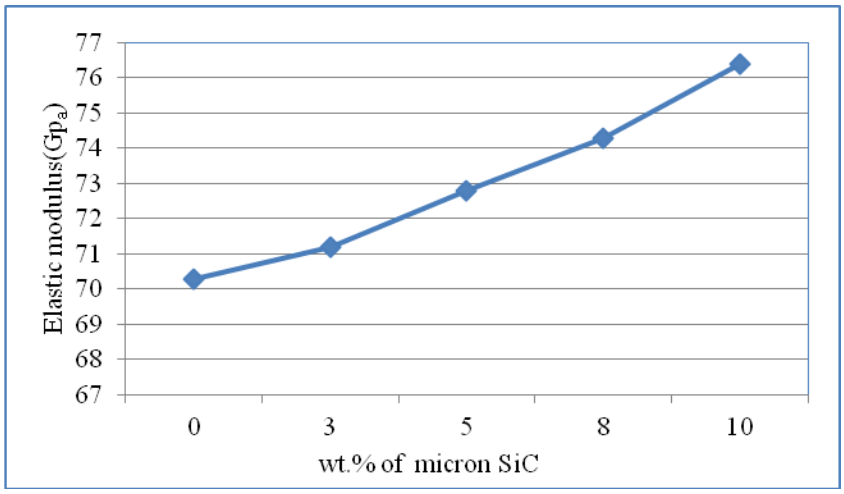
Variation of porosity of composites with weight percent of Micron SiC



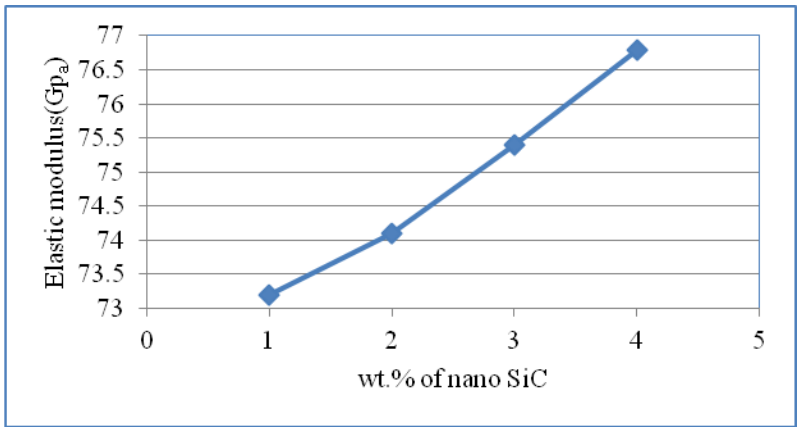
Variation of porosity of composites with weight percent of Nano SiC

Figure 5.3 and Figure 5.4 shows the variation of elastic modulus of Micron and Nano SiC Aluminum matrix composites with respect to weight percent of reinforcement. It is clear from the figures that the elastic modulus increases with increasing weight % of SiC particles. The increase in elastics modulus of Al-10wt % micron SiC composite is 8.6% as compared to Al alloy. In case of composite with nano SiC, elastic modulus also increases with wt. % of nano SiC. For the same weight % of micron and nano SiC (3 wt. %) the elastic modulus are 71.2 and 75.4 GPa respectively. The composite with 4wt % nano SiC have highest elastic modulus in case of nano composites.

It is generally accepted that reducing the reinforcement size improves mechanical properties of the composites for a given particle volume fraction, because of the smaller inter-particle spacing and larger work hardening rate. The decrease in the particle size increases both the effects of direct strengthening and indirect strengthening. As the SiC particle size decrease, the interfacial area between the matrix and the SiC particles also increase, and more load can thus be transferred from the matrix to the SiC particles. It should be noted that a large interfacial area can also facilitate the generation of more dislocations in the matrix, thereby improving the mechanical properties of the composites. On the other hand, the larger-sized particles fracture more easily than the smaller ones during tensile testing.



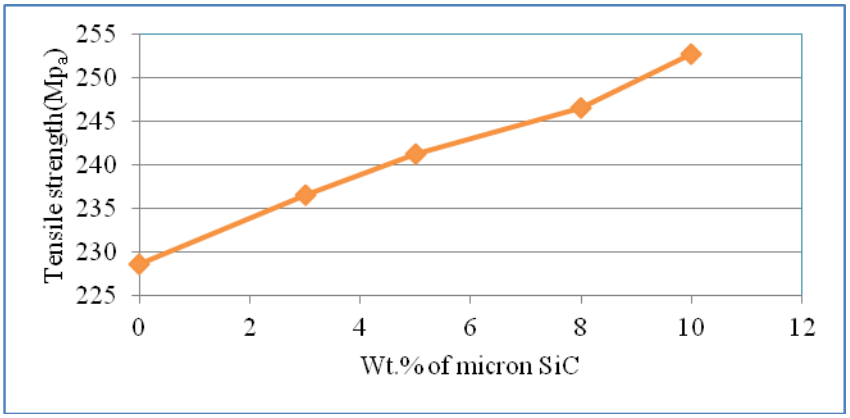
Variation of elastic modulus of Al micron SiC_p composites with weight percent of Micron SiC_p



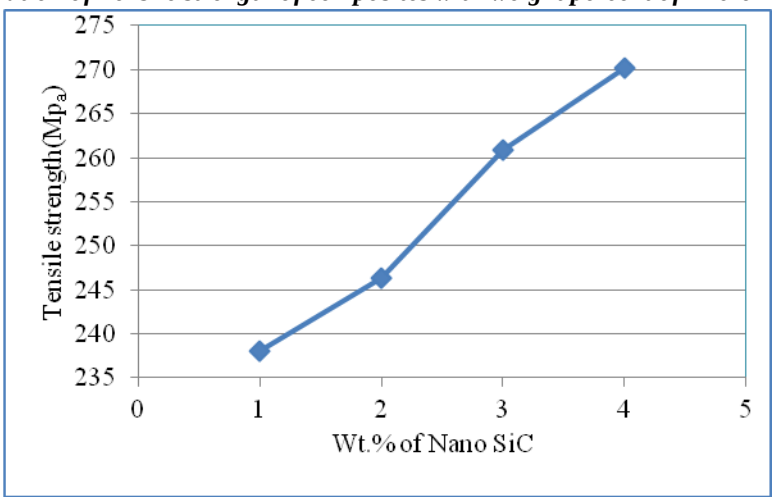
Variation of elastic modulus of Al-SiC_p composites with weight percent of Nano SiC_p

The variation of tensile strength of Micron SiC and Nano SiC reinforced Aluminum matrix composites with weight percent of reinforcement are shown in figure 5.5 and figure 5.6 respectively. Tensile strength increases with increasing wt.% of SiC particles. The percentage increase of tensile strength is higher in case of 8% micron SiC composites. It may be due to more SiC particles present in matrix and give the more strength to the matrix

Percentage increase in tensile strength of alloy with the addition of 10% micron SiC particles is 10.58 %. For the same weight % of SiC (3wt.%) particles the tensile strength of Micron and Nano SiC composite are 236.5MPa and 260.9MPa respectively. Al-4% nano SiC have the maximum tensile strength of 270.2 MPa.



Variation of Tensile strength of composites with weight percent of Micron SiC_p



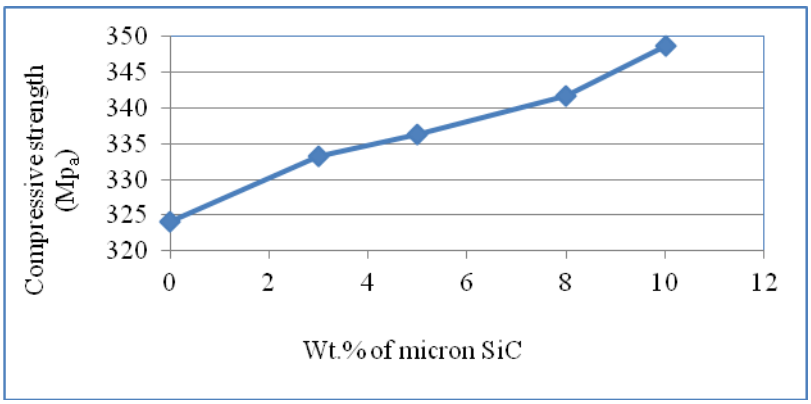
Variation of Tensile strength of composites with weight percent of Nano SiC_p

Tensile strength of Al-Nano SiC_p composites is higher because of two reasons- First, each larger-sized particle has larger interface area with the matrix, and thus endures higher stress concentration. Second, the particle fracture strength is controlled by the intrinsic flaws within the particle. Since the size and number of flaws is limited by the size of the particle, larger particles are more likely to fracture because they have a greater statistical probability of containing a flaw that is greater than the critical size [16]. Since the fractured particles cannot withstand any load, but act as preferential failure sites, the composites with larger SiC particle size show lower mechanical properties as compared to that with smaller particle size.

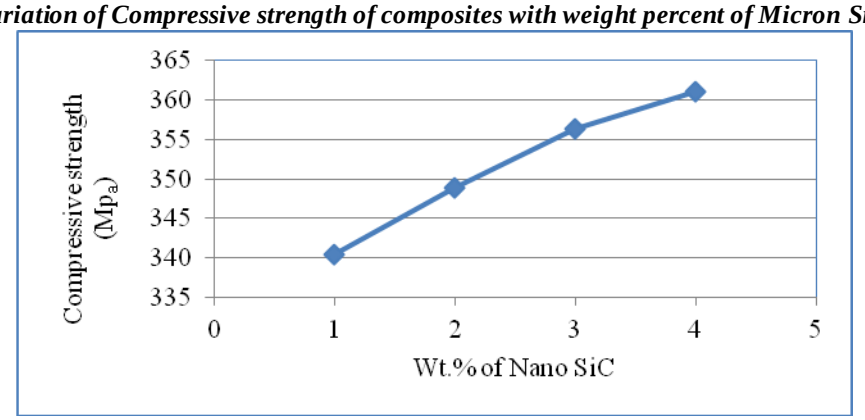
Variation of Compressive Strength of composites with weight % of Micron SiC_p and Nano SiC_p are shown in figure 5.7 and figure 5.8 respectively. It is clear from the figure that compressive strength increases with increasing weight percent of SiC particles and composites shows higher compressive strength than the aluminum alloy. This is due to the grain refinement and strong multidirectional thermal stress at the Al/SiC interface which play a significant role in the high strength of the composites. SiC particles have grain-refined strengthening effect, which is improved with increasing weight percent of SiC particles since they act as the heterogeneous nucleation catalyst for aluminum [17, 18] during solification.

The difference between the coefficient of thermal expansion (CTE) values of matrix and ceramic particles generates thermally induced residual stresses and increases dislocations density upon rapid solidification during the fabrication process. The interaction of dislocations with the non-sharable nano particles increases the strength level of the composite samples.

The Al- Nano SiC composites shows highest compressive strength. According to the Orowan mechanism, the nano-SiC particles act as obstacles to hinder the motion of dislocations near the particles in the matrix. This effect of particles on the matrix is enhanced gradually with the increase of particulate volume fraction [19, 20].



Variation of Compressive strength of composites with weight percent of Micron SiC_p



Variation of Compressive strength of composites with weight percentage of Nano SiC_p **Elongation of aluminum alloy and composites**

Elongation test were performed to observe the percentage variation of ductility of aluminum matrix composite with addition of different percentage of silicon carbide particles. Figure 5.10 and Figure 5.11 shows the variation of elongation of Al SiCp composites reinforced with micron and nano SiC paticles. In case of Al-micron SiCp composites, elongation decrease with increasing weight % of micron SiCp. However in case of Al-nano SiCp composites, the elongation remains rather constant with increasing weight % of nano SiC particles.

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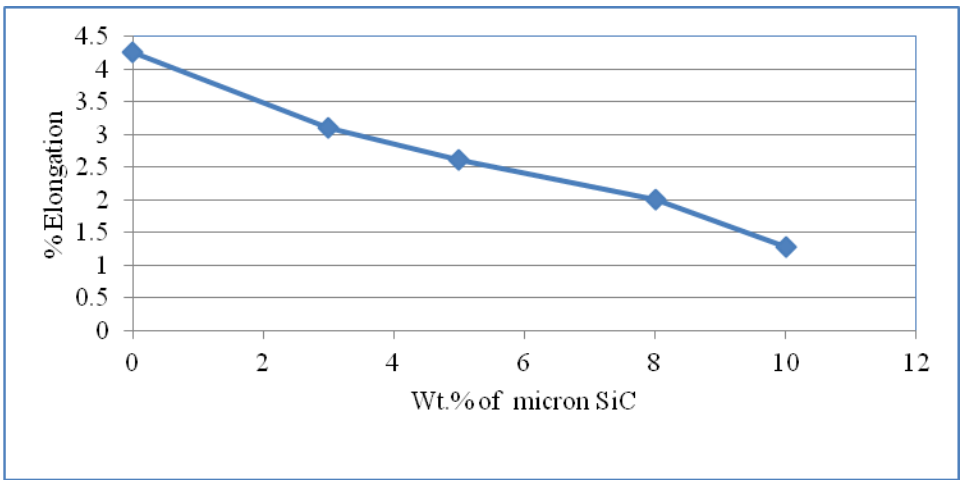
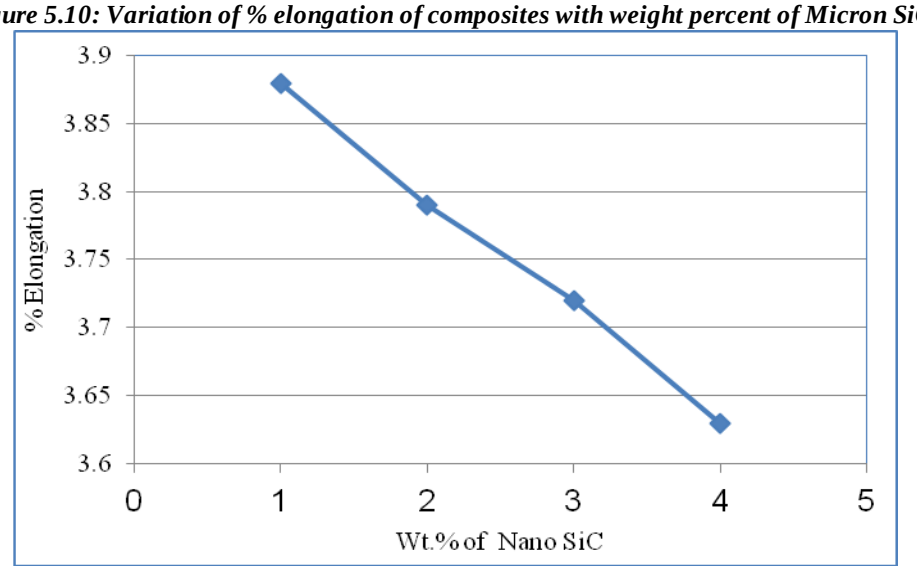


Figure 5.10: Variation of % elongation of composites with weight percent of Micron SiC_p



Variation of % elongation of composites with weight percent of Nano SiC_p

Normally, micron-sized particles are used to improve the ultimate tensile and the compressive strength of the metals and alloys. However, the ductility of the MMCs deteriorates significantly with high ceramic particle concentration in the case of composites with micron size SiC_p. It is of interest to use nano-sized ceramic particles to strengthen the metal matrix while maintaining good ductility. It is noted from observation that the elongation remains almost same with the addition of nano particles. This is one of the advantages of nano composites.

Hardness tests were carried out to observe the effects of wt. % of silicon carbide on aluminum alloy matrix. Variation of Hardness of Aluminum alloy micron SiC composites and nano SiC_p composites are shown in figure 5.13 and figure 5.14 respectively. It is observed that with increase in weight % of SiC_p and decrease in particles size hardness of composites increases. The hardness of the composites is higher than that of the un-reinforced alloy.

The higher hardness of the composite samples relative to that of the Al-alloy could be attributed to the reducing grain size and existence of SiC hard particles acting as obstacles to the motion of dislocations [21].

Also, the hardness of nano-composites was greater than that of micron composites because of the more influence of nano particles on the strengthening mechanism (Orowan mechanism).

At high weight percent of SiC scattering of hardness results increases because of non-uniform distribution of the reinforcement particles. It should be mentioned that agglomeration occurs as a result of higher viscosity of the molten metal and increasing tendency to clump the particles together due to high surface tension and poor wetting between the particles and the melt.

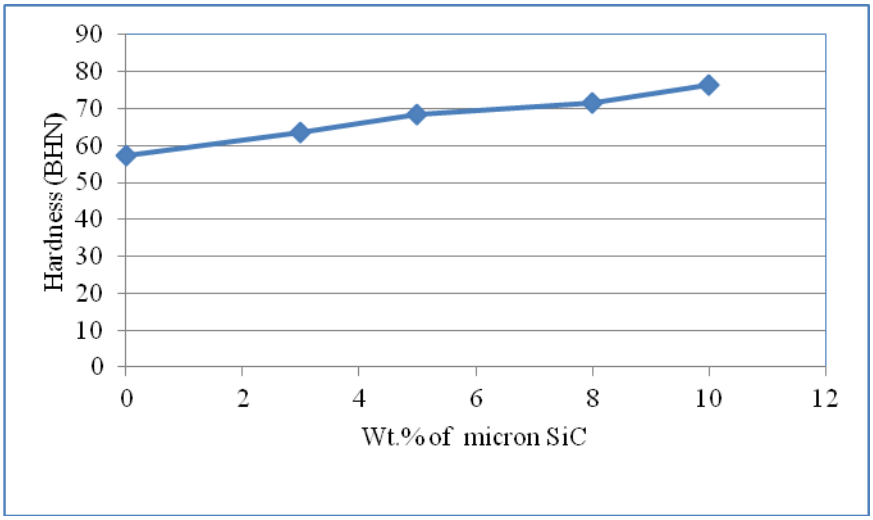


Figure 5.13: Variation of hardness of composites with weight percent of Micron SiCp

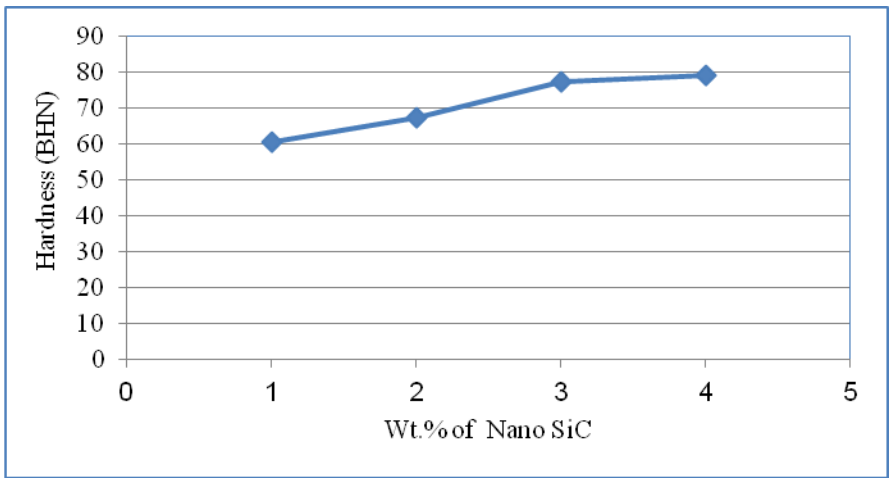


Figure 5.14: Variation of hardness of composites with weight percentage of Nano SiC particles

0

Figure 5.32 and Figure 5.33 shows the scanning electron micrographs of the composites with 8wt. % and 10wt. % Micron SiC. In the SEM microstructure with 8wt.% and 10wt.% micron SiC white reasons shows the SiC particles and black reasons shows the α- Al phase. It is observed that the particles are uniformly distributed throughout the matrix for the cast composites. The SiC particles, Intermetallic phases and porosity is indicated in the SEM image by the arrow marks.

Agglomeration of particles in some regions is clearly visible; this is due to the presence of porosity associated to it. Presence of entrapped air and moisture in the reinforcement particles results in the porosity after casting.

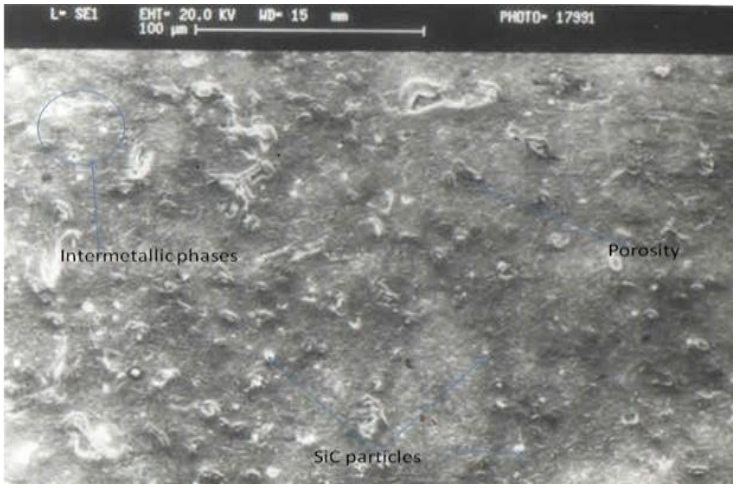
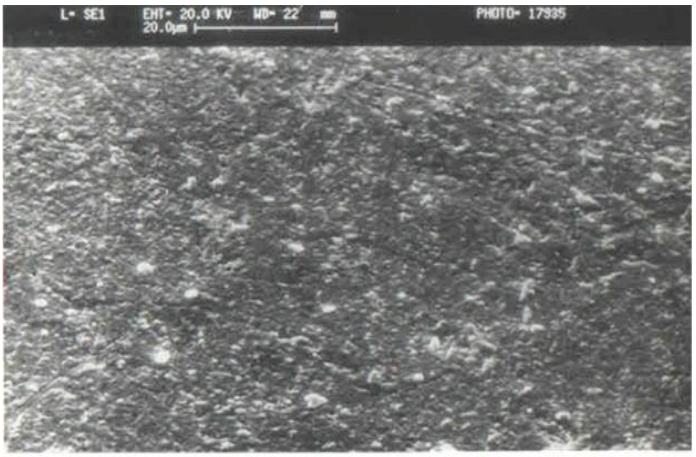
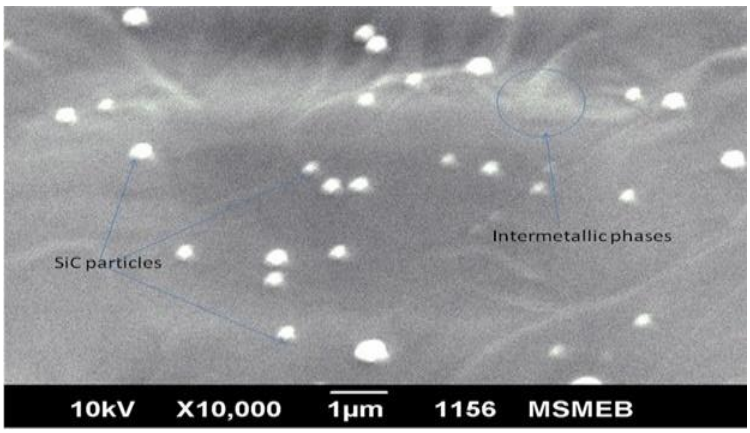


Figure 5.32: SEM Micrograph of composite with 8wt. % micron SiC



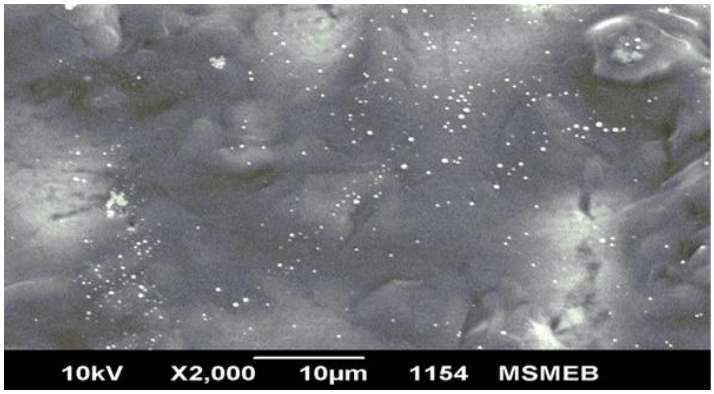
SEM Micrograph of composite with 10wt. % micron SiC

SEM micrograph of composites with 2% nano SiC at X 10000 magnification. It is observed from figure that SiC particles are uniformly distributed in the matrix. Figure 5.35 shows the micrograph of 2% nano composite at higher X 13000 magnification. The different particle types are clearly visible in this micrograph.

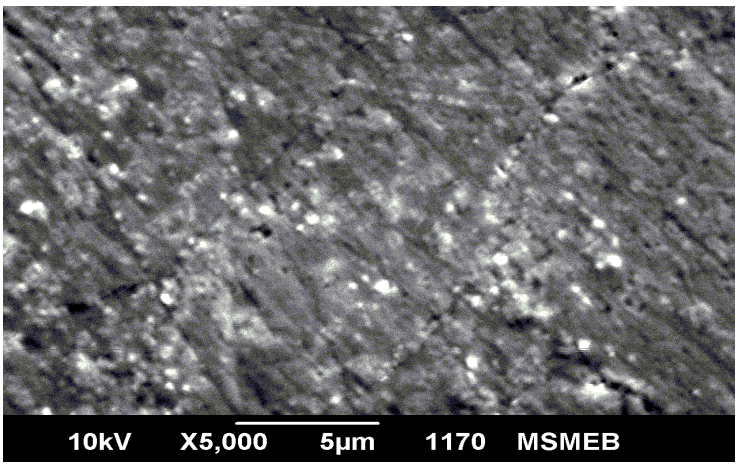


SEM Micrograph of composite with 2wt. % Nano SiC

Figure 5.36 shows the micrograph of composites with 3wt.% nano SiC. It is observed from figure that SiC particles are uniformly distributed in the matrix. Figure 5.37 shows the micrograph of composites with 4wt.% nano SiC. It is observed from figure that SiC particles are uniformly distributed in the matrix. At some places porosity and clustering were observed.



SEM Micrograph of composite with 3wt. % Nano SiC



SEM Micrograph of composite with 4wt. % Nano SiC

III. CONCLUSIONS

(1) Aluminium matrix micron (3, 5, 8 and 10 wt. %) and nano (1, 2, 3 and 4 wt. %) SiC_p composites have been successfully fabricated by ultrasonic assisted stir casting process.

(2) The experimental density is nearer to the theoretical density of composites. Porosity of composites could be decreased significantly due to the ultrasonic treatment and nitrogen degassing. Moreover the porosity was controlled below 2.14 % after 5 minutes of ultrasonic treatment, proposing an effective method for degassing particulate reinforced aluminum alloy composites.

(3) The elastic modulus of Al-SiC_p composites increases with increase in the weight % of SiC particles. The elastics modulus of composites with 10 wt. % micron SiC_p is 8.6 % higher than that of the AA 5083 Al alloy. The Al- 4 wt. % nano SiC_p composites have shown highest elastic modulus.

(4) Tensile strength increases with increase in wt. % of SiC particles. For same weight % of SiC particle (3 wt. %) the tensile strength of Micron and Nano SiC composite are 236.5MPa and 260.9MPa respectively. Al-4 wt. % nano SiC_p composites have shown the maximum tensile strength of 270 MPa among all the samples tested.

(5) The hardness of the composites is higher than that of the un-reinforced alloy and hardness of the composites increases with increasing weight percent of the SiC particles and with decreasing particles size. Composites with 10 wt. % micron SiC have higher hardness (77 BHN) in all micron SiC composites. However composite with 4 wt. % nano SiC shows highest value of hardness (79.2 BHN) among all the samples tested.

(6) The compressive strength increases with increase in wt. % of SiC particles. Al-4 wt. % nano SiC_p composites have shown the maximum compressive strength of 361 MPa among all the samples tested.

(7) The elongation of composites with micron SiC_p particles decreases considerably with increasing weight % of micron SiC particles. In case of composites with nano SiC particles the elongation remains almost same.

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