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FABRICATION AND TESTING OF ULTRASONICALLY ASSISTED STIR CAST AA 5083-Sic_p COMPOSITES

R. S. Rana*, Rajesh Purohit* and S. Das**
*Department of Mechanical Engineering,Maulana Azad National Institute of Technology, Bhopal, (MP)
**Scientist, AMPRI, Bhopal, (MP)

ABSTRACT
Aluminum Matrix composites (AMCs) are light weight, high-strength materials with potential application in areas such as automobile, aerospace, defence, engineering and other industries. AMCs are projected to significantly reduce the overall weight of the vehicles and aircraft while maintaining satisfactory structural strength. Reinforcement of micron or nano-sized range particles with aluminium matrix yields improved mechanical and physical properties in composite materials. The distribution of nano sized reinforcing particles also changes morphology and interfacial characteristics of nanocomposites. In this study, AA 5083 alloy micron and nano SiC composites have been fabricated by Ultrasonic assisted stir casting. Different weight % of SiC particles Micron (3, 5, 8, and 10 wt%) and Nano (1, 2, 3 and 4 wt%) were used for synthesis of composites. SEM microstructure shows uniform distribution of SiC particles with agglomeration at some places. Various properties of composites like tensile strength, compressive strength, hardness, ductility, density were measured. Results revealed that the tensile strength, compressive strength and hardness of composites increases with increase the weight % of SiC particles and particle size reduction. However ductility of composites with micron SiC particles reduced in large value with increasing the weight % of SiC however with addition of nano SiC particles only a small reduction in ductility was observed. The application of ultrasonic vibration on the composite during melting not only refined the grain structure of the matrix, but also improved the distribution of nano-sized reinforcement.
***Keywords*:** Aluminum Matrix Composites, Ultrasonic Assisted Casting, Agglomeration, Nanocomposites.

I. INTRODUCTION

The engineering sector is always on the search for newer materials with superior properties combined with ease of fabrication, reproducibility and ability to vary the composition to attain a range of desired properties. The properties attainable in any alloy system are limited to a certain extent and reach a saturation limit; further improvement can be done by strengthening mechanism, controlling microstructure, alloying constituents, addition of modifiers etc. [1]. Aluminium matrix composites have drawn immense interest for various applications in making aerospace and automobile components due to their light weight, high strength, 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. Overall strength of such particle reinforced AMCs depends on size of the particles, the inter-particle spacing, volume fraction of the particles and the nature of matrix and reinforcement interface. Zhao et. al. [2] characterized the properties and deformation behaviour of aluminum matrix nano-composites. It was reported that the ultimate tensile strength and yield strength of nano-composites are enhanced with increasing the particulate volume fraction, which are markedly higher than those of Al composites synthesized by micro size particles. Mazahery A. et. al. [3] reported that incorporation of nano-particles into the aluminum matrix could enhance the yield and ultimate tensile strength considerably, while the ductility is retained. A. Sakthivel, et. al. [4] studied the mechanical properties of 2618 aluminum alloy MMCs reinforced with two different sizes (7 and 33 μm) and wt. % of SiC_p (0, 5 and 10 %) were fabricated by stir casting method. The results show that tensile strength of the composites increases with decreasing size and increasing weight fraction of the particles. The tensile strength of the forged composites was higher than those of the cast composites.

S. A. Sajjadi, et. al. [5] studied the mechanical properties of A356 aluminum alloy micron and nano Al_2O_3 composites fabricated by liquid metallurgy route. Results revealed that by increasing in Al_2O_3 percentage, the compressive strength shows an increasing trend. The results also show that the compressive strength of nanocomposites is greater than that of micro-composites. The compressive strength of composite can primarily be attributed to the significant grain refinement, the presence of reasonably distributed hard particulates, dislocation generation due to elastic modulus mismatch, coefficient of thermal expansion

mismatch between the matrix and reinforcement phase, load transfer from matrix to reinforcement phase and Orowan strengthening mechanism. Zhao et. al. [2] characterized the properties and deformation behavior of aluminum matrix nano-composites. It was reported that the elongation enhanced with increasing particulate volume fraction, which are markedly higher than those of Al composites synthesized by micro size particles. Ali Mazahery et. al. Ali Mazahery, et. al. [6] characterized cast A356 alloy reinforced with nano SiC_p composites and reported that hardness of the composites is higher than that of the un-reinforced alloy. It is maximum at 3.5 % of SiC_p nanoparticles. The higher hardness of the composites could be attributed to the fact that SiC_p particles act as obstacles to the motion of dislocation. The hardness increment can also be attributed to the reduced grain size. In this study, AA 5083 alloy micron and nano SiC composites has been fabricated by Ultrasonic assisted Stir casting. Different weight % of SiC particles Micron (3, 5, 8, and 10 wt%) and Nano (1, 2, 3, and 4 wt%) were used for synthesis of composites. SEM microstructure shows uniform distribution of SiC particles with some places agglomeration. Varies properties of composites like tensile strength, compressive strength, hardness, ductility, density were studied.

II. EXPERIMENTAL PROCEDURES

Aluminum alloy 5083 has been selected as matrix alloy for synthesis of AMCs. The chemical compositions are shown in Table 1. Micron and Nano size Silicon Carbide particulates have been used as reinforcement material. SiC micron size particles average particles size was 35 µm SiC_p (99% Pure). SiC Nano particles of average particle size 40 nm (SiC_p-b, 99+% pure). SEM micrograph of micron SiC particles and TEM micrograph nano SiC particles are shown in Fig. 1 and 2 respectively.

Table 1 Composition of AA 5083 Al alloy

Element	Zn	Fe	Ti	Cu	Si	Pb	Mn	Mg	Cr	Al
Percent	0.03	0.173	0.04	0.0181	0.16	0.014	0.526	5.13	0.097	Balance

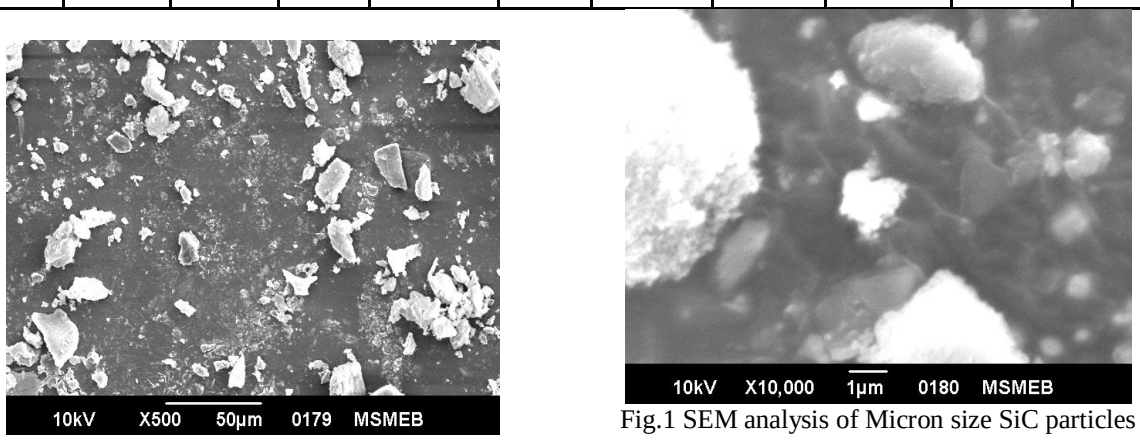

Fig.1 SEM analysis of Micron size SiC particles

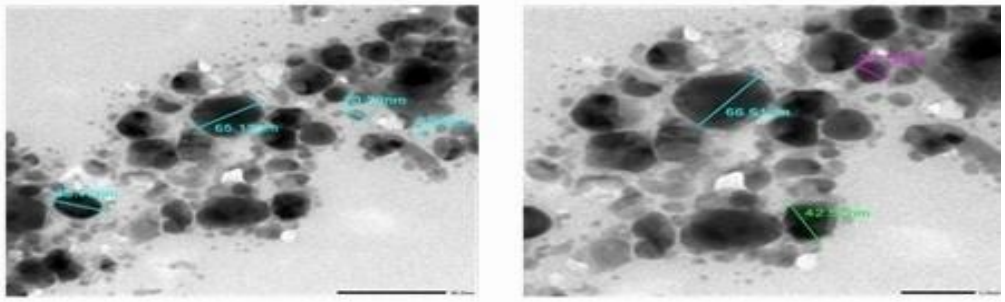
Fig. 2 TEM analysis of Nano SiC Particles

Synthesis of Aluminum alloy SiC_p Composites

The steps involved for synthesizing Al-SiC_p composites are as follows:

- Cutting the aluminium ingot into small pieces and placing them into a graphite crucible. The graphite crucible was placed in electric resistance furnace.
- Melting the aluminium alloy to a temperature 760^{o}C, added flux coveral 11 and degassed with dry nitrogen gas of grade I.
- Addition of the pre-heated micron SiC particles with different wt. % in the melt and stirring the

alloy melt with the help of a mechanical stirrer. After stirring ultrasonification of the composites with ultrasonic probe for about 5 minutes was done. Composites have been prepared for 3, 5, 8 and 10 wt. % of SiC particles separately. Similarly composites were prepared for 1, 2, 3 and 4 wt% of Nano SiC particles through ultrasonic assisted stir casting.

- After successful addition of particles, the composite melt was poured and solidified into a mild steel die in the form of cylindrical rods (20 mm diameter and 200 mm length).
- Standard samples were prepared for tensile test, compression tests, hardness test and microstructural analysis.

III. RESULTS AND DISCUSSIONS

3.1 Microstructure: Fig. 3 shows the micrograph of Al-2 wt. % SiC_p composites which shows uniform distribution of Nano SiC_p particles. The microstructure shows two phases one is α- Al and intermetallic phases (Mg_2Si). By comparing it with phase diagram the possible intermetallic compound could be Mg_2Si, Al_3Mg_2 as well as SiC_p. The intermetallic phase was formed by precipitation on the grain boundaries.

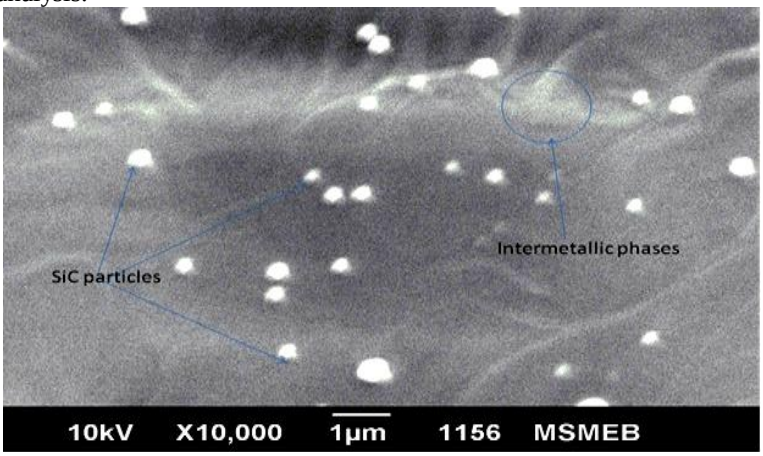

Fig. 3 SEM Micrograph of composite with 2 % nano SiC_p

3.2 Density Measurement: The experimental density of Al-SiC_p composites were measured according to Archimedes principle. The small pieces were cut from alloy and composites and 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. Porosities were reported by difference between theoretical density and experimental density. Density of aluminium alloy is 2.66 gm/cc and density of SiC particles is 3.22 gm/cc.

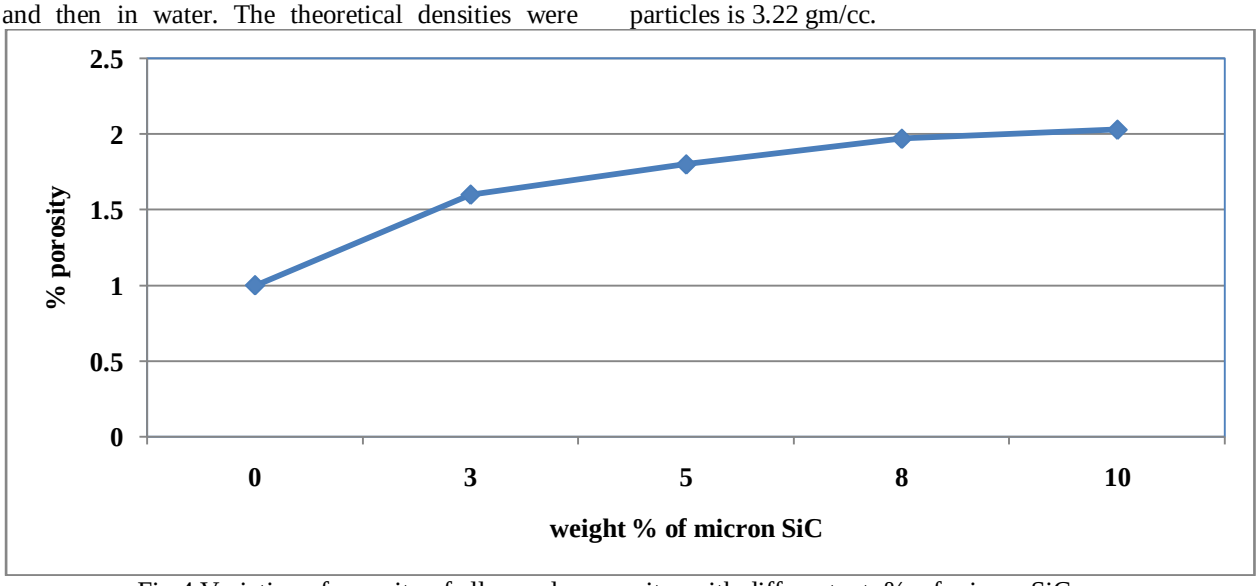

Fig.4 Variation of porosity of alloy and composites with different wt. % of micron SiC

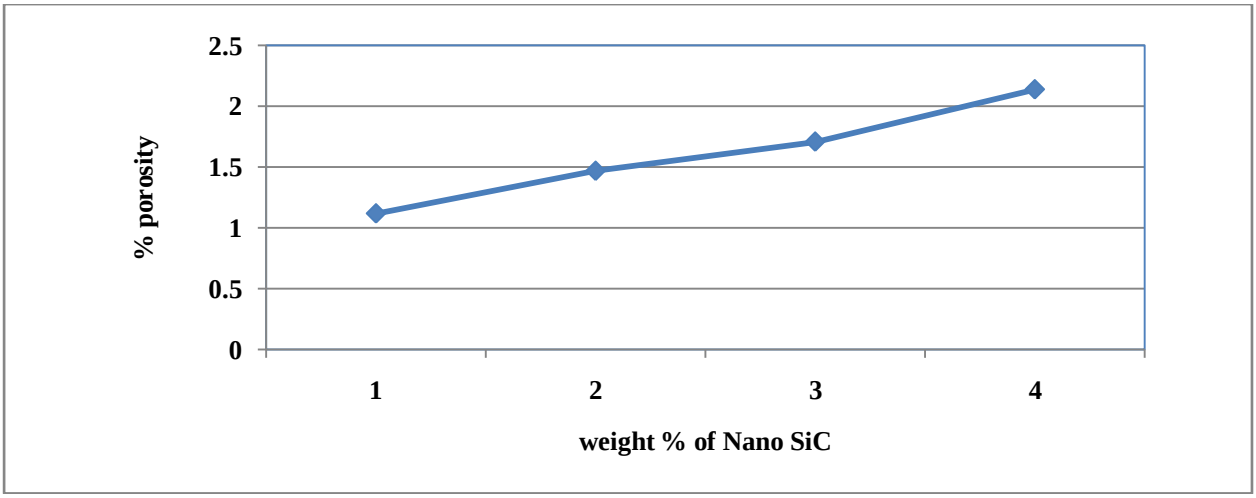

Fig.5 Variation of porosity of composites with different wt. % of Nano SiC

Porosity increases with increasing SiC weight percent 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 interfaces. Moreover, decreasing liquid metal flow associated with the particle clusters leads to the formation of porosity.

3.3 Tensile and compressive Strength: From the Fig. 6, 7, 8 and 9 following observations were made:
(i) The Alloy have the lower tensile strength and compressive strength.
(ii) The tensile strength and compressive strength of composites with 10 % micron SiC_p is higher than 1 & 2 % Nano SiC_p.
(iii) The tensile strength and compressive strength of composites with 3% nano SiC_p is higher than 10 % Micron SiC_p.
(iv) The highest tensile strength and compressive strength was observed in the case of 4% nano SiC_p.
Fig. 10 shows the tensile strength and Compression Strength of Alloy, composites with Micron SiC_p and Composites with Nano SiC_p.

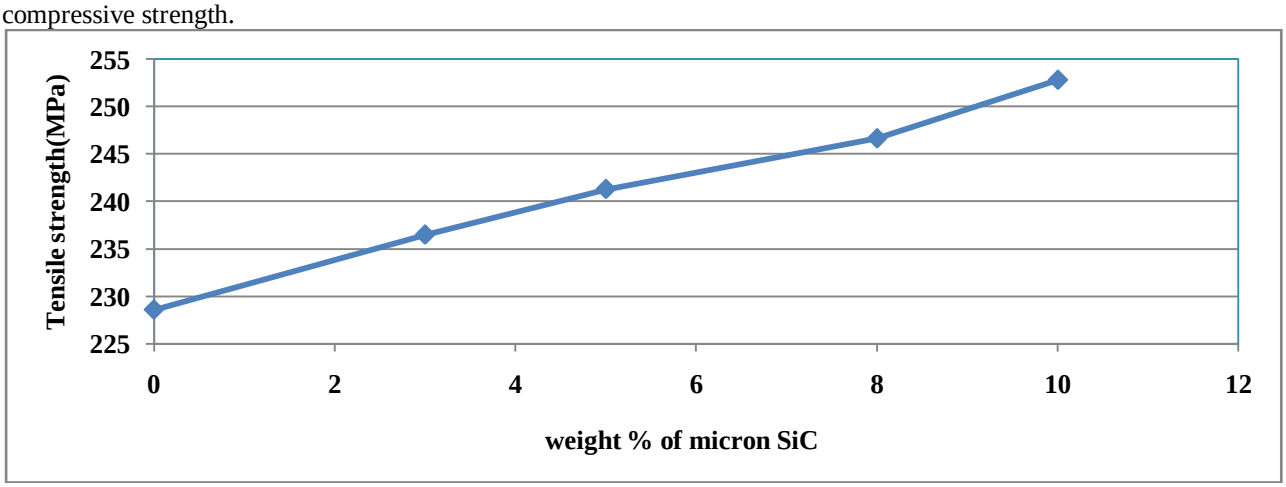

Fig.6 Variation of Tensile strength of alloy and composites with different wt. % of micron SiC_p

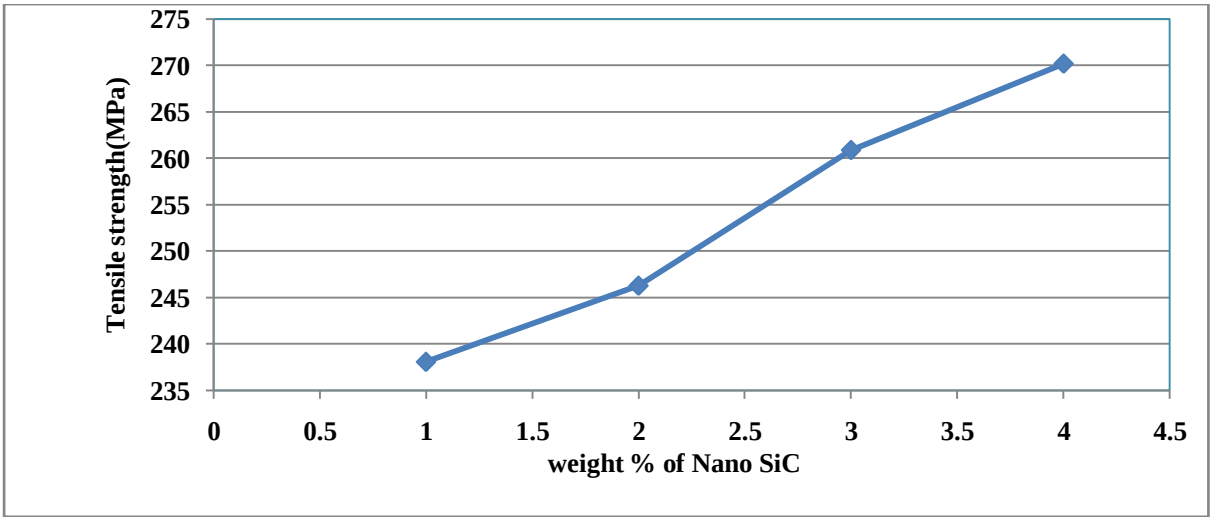

Fig.7 Variation of Tensile strength of composites with different wt. % of Nano SiC

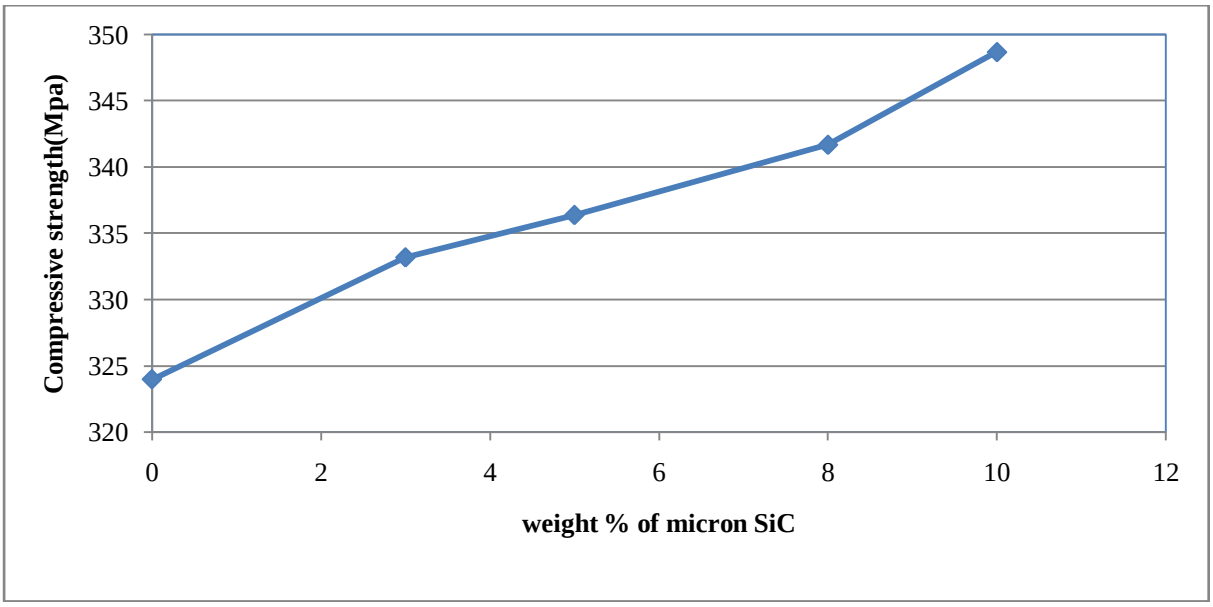

Fig 8 Variation of compressive strength of alloy and composites with different wt. % of micron SiC

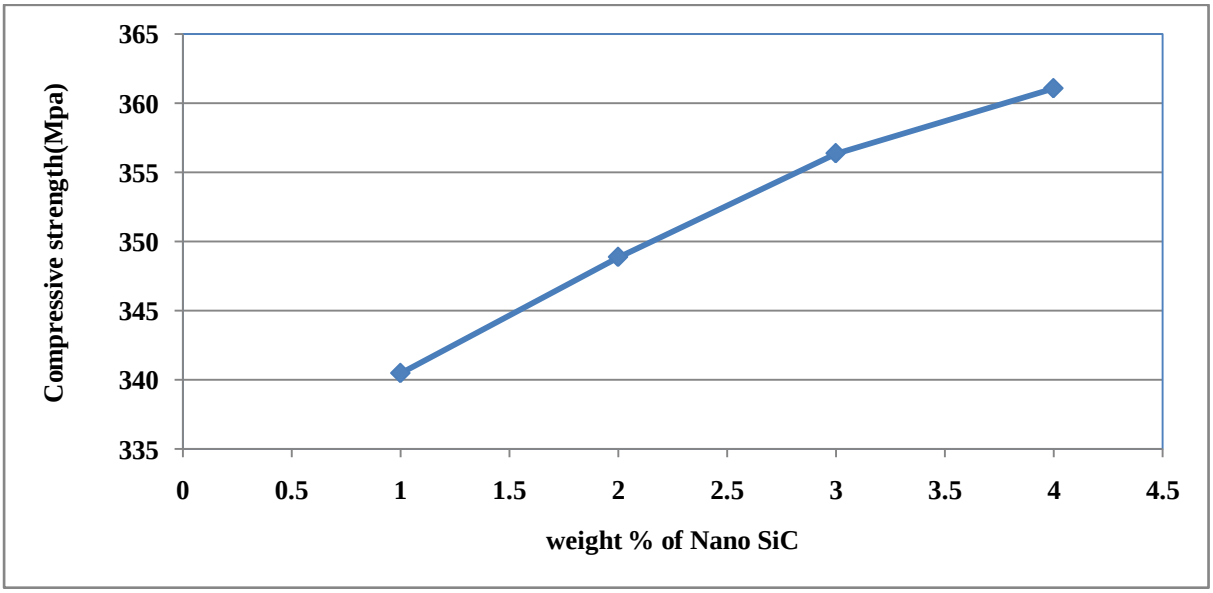

Fig.9 Variation of compressive strength of alloy and composites with different wt. % of nano SiC

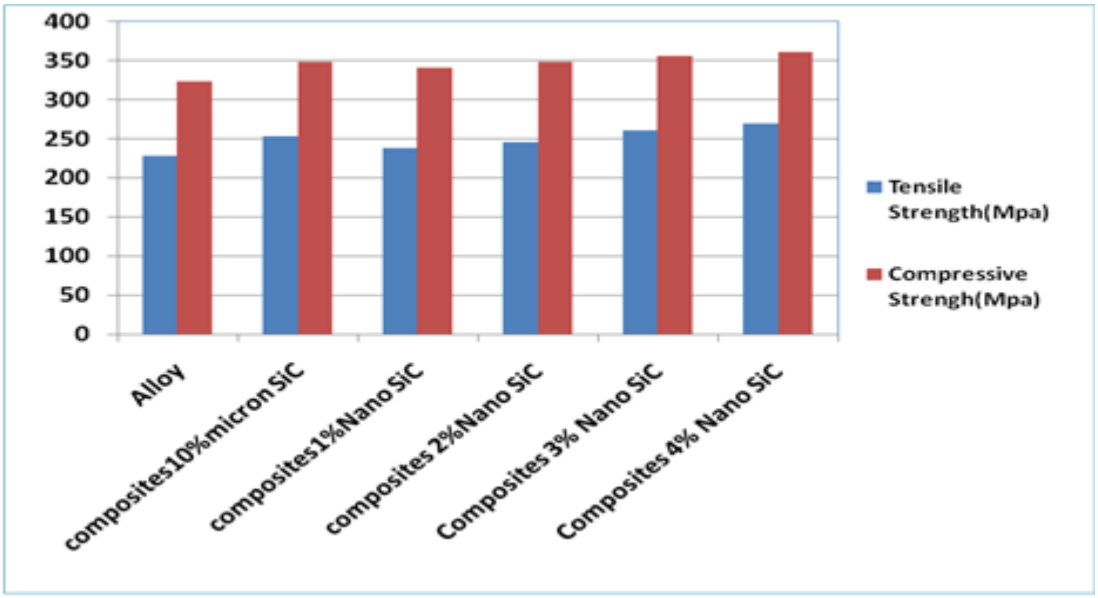

Fig. 10 Tensile strength and Compression Strength of Alloy, composites with 10 % Micron SiC_p and Composites with Nano SiC_p

Tensile strength and compressive strength of Nano 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 SiC_p flaws within the particle. Since the size and number of flaws are 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 [7]. Since the fractured particles cannot withstand any load, but act as preferential failure sites, the composites with larger SiC_p particle size show lower tensile and compressive strength as compared to that with smaller particle size. The grain refinement and strong multidirectional thermal stress at the Al/SiC interface are also important factors which play a significant role in the high strength of the composites. SiC particles have grain-refined strengthening effect, which is improved with increasing volume fraction since they act as the heterogeneous nucleation catalyst for aluminum [8]. 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. 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 [9, 10].

3.4. Elongation: Fig.11 shows the comparison of % elongation of alloy, composites with micron SiC_p and composites with nano SiC_p particles. Normally, micron-sized particles are used to improve the ultimate tensile and the compressive strength of the alloy. 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. The application of ultrasonic vibration on the composite melt during the casting not only refined the grain structure of the matrix, but also improved the distribution of nano-sized reinforcement.

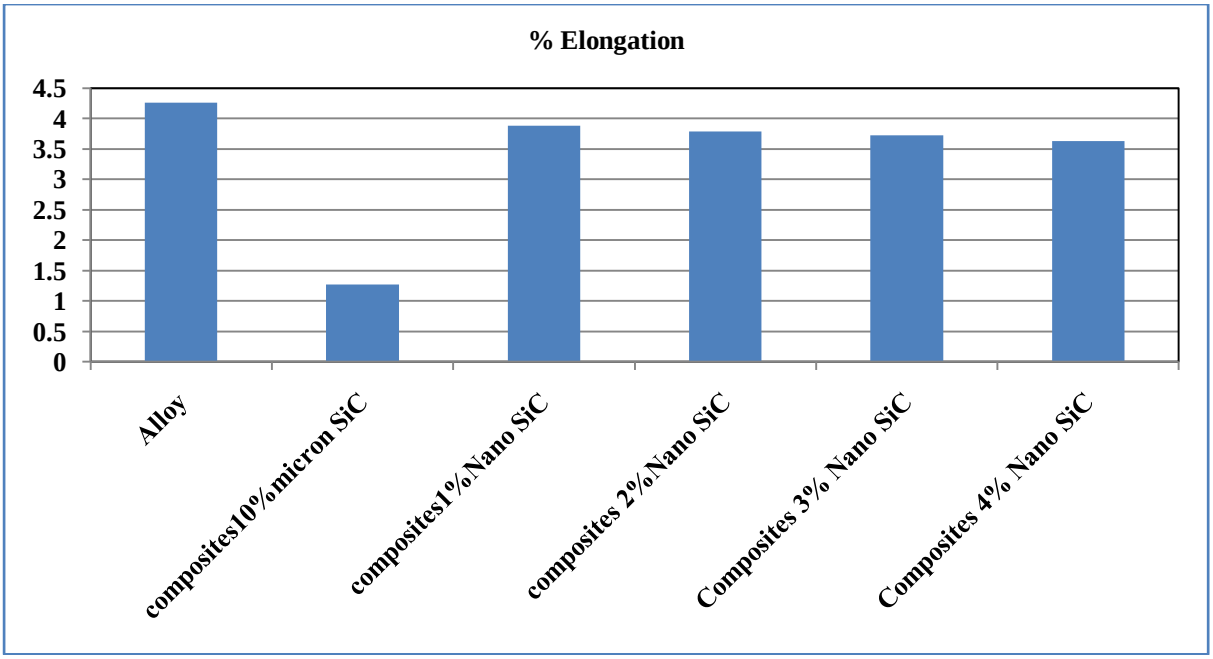

Fig.11 Percentage elongation of Alloy, composites with Micron SiC_p and Composites with Nano SiC_p

3.5 Hardness: Fig.12 shows the comparison of hardness of alloy, composites with micron SiC_p and composites with nano SiC_p. From the graph it is observed that (1)-The Alloy have lower hardness. (2)-The hardness of composites with 10 % micron SiC_p is higher than 1 and 2 % Nano SiC_p. (3)- The hardness of composites with 3 % nano SiC_p is slightly higher than 10 % Micron SiC_p composites. (4)-The highest hardness was observed in the case of 4% nano SiC_p composites. The hardness of the composites is higher than that of the alloy and hardness of the composites increases with increasing weight percent of the particles and with decreasing particles size. The higher hardness of the composite samples relative to that of the Al-alloy matrix could be attributed to the reducing grain size and existence of SiC_p hard particles acting as obstacles to the motion of dislocation [11]. Also, the hardness of 3 & 4 % nano SiC_p composites was greater than that of micron SiC_p composites because of the more influence of nano particles on the strengthening mechanism (Orowan mechanism). At higher SiC weight percent, 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.

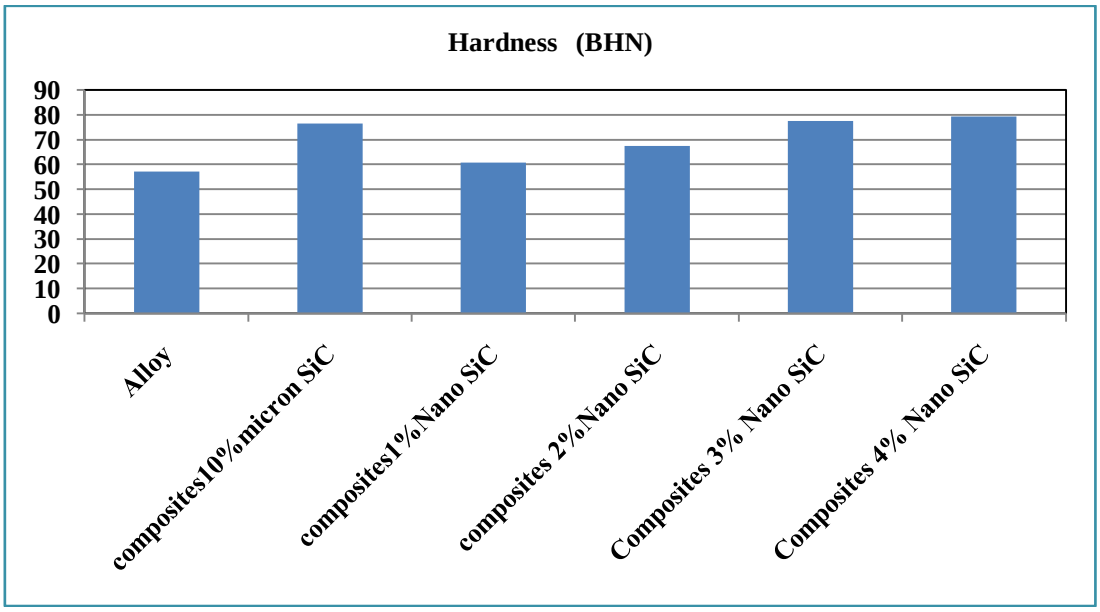

Fig.12 Comparison of Hardness of Alloy, composites with Micron SiC_p and Composites with Nano SiC_p

IV. 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) Porosity of composites could be decreased significantly by the ultrasonic treatment and nitrogen degassing. Moreover the porosity was controlled below 2.14 % after of 5 minutes of ultrasonic treatment, proposing an effective method for degassing particulate reinforced aluminum alloy composites.

(3) Tensile strength increases with increase in wt. % of SiC_p particles. Al-4 % nano SiC_p composites have the maximum tensile strength of 270 MPa.

(4) The compressive strength increases with increase in wt. % of SiC_p particles. Al-4% nano SiC_p composites have the maximum compressive strength of 361 MPa.

(5) Composites with 10 % micron SiC_p have higher hardness (77 BHN) among all the micron SiC_p composites. However, Al- 4% nano SiC_p composite shows highest value of hardness (79 BHN).

(6) 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_p the elongation remain almost same.

REFERENCES

[1] Rupa Dasgupta, Humaira Meenai, "SiC particulate dispersed composites of an Al–Zn–Mg–Cu alloy: Property comparison with parent alloy", Materials Characterization, 54, 2005, 438-445.

[2] Y Zhao T, S L Zhang, G Chen, X N Cheng, C Q Wang, "In situ (Al2O3+Al3Zr) NP /Al nano composites synthesized by magneto-chemical melt reaction", Composite Science Technology, 68, 2008, 1463-1470

[3] 3.A.Mazahery, H.Abdizadeh., H.R. Baharvandi, "Development of high-performanceA356/nano-Al2O3 composites", Material Science Engineering A 518, 2009, 61–64.

[4] A. Sakthivel, R. Palaninathan, R. Velmurugan, P. Raghothama Rao, "Production and mechanical properties of SiCpp particle-reinforced 2618 aluminum alloy composites", Journal of Material Science 43, 2008, 7047–7056.

[5] S. A. Sajjadi, H.R. Ezatpour, H. Beygi, "Microstructure and mechanical properties of Al–Al2O3 micro and nano composites fabricated by stir casting", Materials Science and Engineering A 528, 2011, 8765– 8771.

[6] Ali Mazahery, Mohsen Ostad Shabani, "Characterization of cast A356 alloy reinforced with nano SiC_p composites", Transactions Nonferrous Metallurgical Society, China 22, 2012, 275-280.

[7] Y. L. Shen, E. Fishencord, and N. Chawla, "Correlating Macrohardness and Tensile Behavior in Discontinuously Reinforced Metal Matrix Composites", Scripta Materila, 42, No. 5, 2000, 427–432.

[8] M. C. Watson, T. W. Cline, "The use of single fibre push out testing to explore interfacial mechanics in SiC monofilament-reinforced Ti: A photoelastic study of the test", Acta Metall Mater, 40, 1992, 131-139.

[9] FM Hosking, Portillo Folgar F, R Wonderlin, R Mehrabian, "Composite of aluminium alloys: fabrication and wear behaviour", Journal of Material Science, 17, 1982, 477–98

[10] M Habibnejad-Korayema, R Mahmudia, W J Pooleb, "Enhanced properties of Mg-based nano-composites reinforced with Al2O3 nano-particles", Material Science & Engineering A, 519 (1-2), 2009, 198-203.

[11] P S Cooke, P S Werner, "Pressure infiltration casting of metal matrix composites", Journal of Material Science Engineering A, 144, 1991, 189-193.