

# An Analysis of Mechanical Properties of the Developed Al/SiC-MMC's

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**Abstract** Metal Matrix Composites (MMC's) have evoked a keen interest in recent times for potential applications. Advance composite materials like Al/SiC metal matrix composite is gradually becoming very important materials in manufacturing industries e.g. aerospace, automotive and automobile industries due to their superior properties such as light weight, low density, high strength to weight ratio, high hardness, high temperature and thermal shock resistance, superior wear and corrosive resistance, high specific modulus, high fatigue strength etc. In this study aluminum (Al-6063)/SiC Silicon carbide reinforced particles metal-matrix composites (MMCs) are fabricated by melt-stirring technique. The MMCs bars and circular plates are prepared with varying the reinforced particles by weight fraction ranging from 5%, 10%, 15%, and 20%. The average reinforced particles size of SiC are 220 mesh, 300 mesh, 400 mesh respectively. The stirring process was carried out at 200 rev/min rotating speed by graphite impeller for 15 min. The microstructure and mechanical properties like Proportionality (MPa) limit, Tensile strength upper yield point (MPa), Tensile strength lower yield point (MPa), Ultimate tensile strength (MPa), Breaking strength(MPa), % Elongation, % Reduction in area, Hardness (HRB), Density (gm/cc), Impact Strength (N.m) are investigated on prepared specimens of MMCs. It was observed that the hardness of the composite is increased with increasing of reinforced particle weight fraction. The tensile strength and impact strength both are increased with rising of reinforced weight fraction. Different mechanical tests were conducted and presented by varying the particle size and weight fractions of SiC.

**Keywords:** metal matrix composites (MMC's), silicon carbide (SiC), melt stirring technique

## 1. Introduction

Metal Matrix Composite (MMC) is engineered combination of metal (Matrix) and hard particles (Reinforcement) to tailored properties. Metal Matrix Composites (MMC's) have very light weight, high strength, and stiffness and exhibit greater resistance to corrosion, oxidation and wear. Fatigue resistance is an especially important property of Al-MMC, which is essential for automotive application. These properties are not achievable with lightweight monolithic titanium, magnesium, and aluminium alloys. Particulate metal matrix composites have nearly isotropic properties when compared to long fibre reinforced composite. But the mechanical behavior of the composite depends on the matrix material composition, size, and weight fraction of the reinforcement and method utilized to manufacture the composite. The distribution of the reinforcement particles in the matrix alloy is influenced by several factors such as rheological behavior of the matrix melt, the particle incorporation method, interaction of particles and the matrix before, during, and after mixing [1]. Non homogeneous particle distribution is one of the greatest

problems in casting of metal matrix composites [2]. Nai and Gupta [3] reported that the average coefficient of thermal expansion of the high SiCp end was reduced as compared to that of the low SiCp end. Hashim et al. [4] reported that the distribution of the reinforcement material in the matrix must be uniform and the wettability or bonding between these substances should be optimized. Aluminum-silicon carbide metal matrix composite has low density and light weight, high temperature strength, hardness and stiffness, high fatigue strength and wear resistance etc. in comparison to the monolithic materials [5]. However, aluminum alloy with discontinuous ceramic reinforced MMC is rapidly replacing conventional materials in various automotive, aerospace, and automobile industries [6]. Amongst various processing routes stir casting is one of the promising liquid metallurgy technique utilized to fabricate the composites. The process is simple, flexible, and applicable for large quantity production. The liquid metallurgy technique is the most economical of all the available technique in producing of MMC [7]. Aluminum alloy-based composites containing 10wt% alumina (size range: 150-225 mm) were prepared by liquid metallurgy technique using the vortex method [8,9]. The ZnO whiskers 25 vol% reinforced with Al-matrix composites were fabricated by a

squeeze casting process [10]. The quartz-silicon dioxide particulates reinforced LM6 alloy matrix composites were fabricated by carbon dioxide sand molding process [11]. Various researchers have utilized conventional stir casting technique for producing MMC [12,13,14,15] but still applied research is needed for successful utilization of the process for manufacturing of MMC.

In this study stir casting is accepted as a particularly promising route, currently can be practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production [16], and allows very large sized components to be fabricated. The cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth [17]. In general, the solidification synthesis of metal matrix composites involves producing a melt of the selected matrix material followed by the introduction of a reinforcement material into the melt. To obtain a suitable dispersion the stir casting method is used. The solidification of the melt containing suspended SiC particles is done under selected conditions to obtain the desired distribution.

From the past review, it is found that the number of research work on wear behaviour of MMCs have been published, but only few work related to the influence of weight fraction on mechanical properties like tensile strength, hardness, impact strength, percentage of elongation etc. have been reported. In this study, different weight fractions of Silicon Carbide particulates are added with aluminium matrix to fabricate the Al/SiC metal matrix composites. Different samples have been fabricated by melt-stirring casting and their microstructure, hardness, tensile strength, and impact strength are studied. In this study the influences of the reinforced particulate size (220 mesh, 300 mesh, 400 mesh) and weight fraction (5%, 10%, 15%, 20%) on mechanical properties like Proportionality (MPa) limit, Tensile strength upper yield point (MPa), Tensile strength lower yield point (MPa), Ultimate tensile strength (MPa), Breaking strength (MPa), % Elongation, % Reduction in area, Hardness (HRB), Density (gm/cc), Impact Strength (N.m) are investigated.

## 2. Fabrication of Al/SiC Metal Matrix Composites

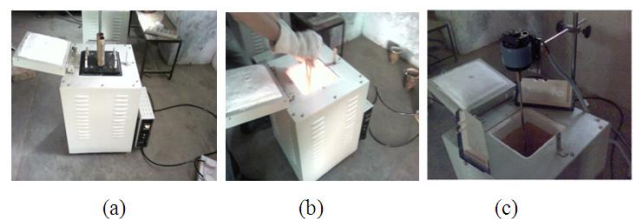
Silicon Carbide (SiC) reinforced particles of average particle size 220 mesh, 300 mesh, 400 mesh respectively are used for casting of Al/SiC-MMCs by melt-stir technique. Table 1 represents the chemical composition of commercially available Al-matrix used for manufacturing of MMC. Different dimensions of round bars with 5 vol%, 10 vol%, 15 vol% and 20% of reinforced particles of size 220 mesh, 300 mesh, 400 mesh respectively.

Experiments were carried out to study the effect of settling the reinforced particulates on the solidification microstructure and mechanical properties of the cast

MMC. In the present study, commercially available aluminium (AA6063) is used as matrix reinforced with Silicon Carbide (SiC) particulates. The melting was carried out in a clay-graphite crucible placed inside the resistance furnace. An induction resistance furnace with temperature regulator cum indicator is utilized for melting of Al/SiC-MMCs. Figure 1 (a) and (b) show an induction resistance furnace and temperature regulator cum indicator, respectively. A design and developed stirring setup is shown in Figure 1 (c). Aluminium alloy (Al 6063) was first preheated at 450 °C for 2 hours before melting and SiC particulates were preheated at 1100 °C for 1 hour 30 minutes. To improve the wetness properties by removing the absorbed hydroxide and other gases. The furnace temperature was first raised above the melting temperature, that is, 750 °C, to melt the matrix completely and then it was cooled down to just below the melting temperature to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed mechanically. The composite slurry was then reheated to a fully liquid state and mechanical mixing was carried out for 20min at 200rpm average stirring speed. In the final stage of mixing, the furnace temperature was controlled within  $760 \pm 10$  °C and the temperature was controlled at 740 °C. Moulds (size 40mm diameter  $\times$  170mm long) made of IS-1079/3.15mm thick steel sheet were preheated to 350 °C for 2 hours before pouring the molten Al/SiC - MMC. Figure 2 (a) shows the prepared permanent mould made of steel sheet utilized for casting of 40mm diameter  $\times$  170mm long bar. Figure 2 (b) shows mixing again manually before pouring. Figure 2 (c) shows pouring mixture of molten Al and SiC particles. Then fabrication of composite was followed by gravity casting. Similar process was adapted for preparing the specimens of varying mesh size and weight fractions.

**Table 1. Chemical composition of matrix Al 6063 alloy**

Elements of Al 6063	Si	Mn	Mg	Cu	Fe	Ti	Al
%	0.44	0.07	0.6	0.018	0.2	0.008	98.664



**Figure 1.** (a), (b) Induction resistance furnaces with temperature regulator cum indicator and (c) Melt-stirring setup utilized for casting of composites



**Figure 2.** (a) Permanent mould for 40 mm diameter round bar (b) Mixing again manually before Pouring (c) Pouring mixture of molten Al and SiC particles

### 3. Results and Discussion

Various Experiments were conducted on fabricated MMCs samples by varying weight fraction of SiC (5%, 10%, 15%, 20 %) and size of SiC particles (220 mesh, 300 mesh, 400 mesh) to analyze the casting performance characteristics of Al/SiC-MMCs.

#### 3.1. Microstructure

Metallographic samples were sectioned from the cylindrical cast bars. A 0.5 % HF solution was used to etch the samples wherever required. To see the difference in distribution of SiC particles in the aluminium matrix, microstructure of samples were developed on Inverted type Metallurgical Microscope (Make: Nikon, Range-X50 to X1500). Figure 3 shows Micrograph of Al/SiC-MMC's samples for different Sizes (220 mesh, 300 mesh, 400 mesh) and weight fraction (5%, 10%, 15%, 20 %) of SiC particles. Optical micrographs showed reasonably uniform distribution of SiC particles. In this Al matrix SiC particles are clearly labeled.

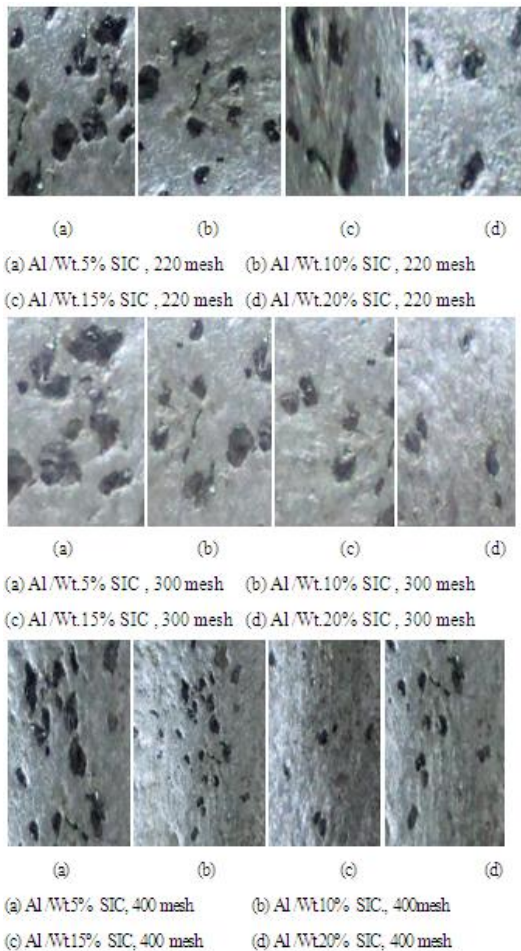


Figure 3. Micrograph of Al/SiC-MMC's samples for different Sizes and weight fraction of SiC particles

#### 3.2. Tensile Strength

The tensile test was carried out at room temperature on Universal Testing Machine Model-UTN-20, Sr.No.-4/79/239, Max. Capacity-2000 kgs, Make Blue Star Ltd. Figure 4 shows standard dimensions of specimen for Tensile Test. Test specimens of standard dimensions as

shown in Figure 5. were prepared of Al/SiC-MMC's for different size (220 mesh, 300 mesh, 400 mesh) and weight fraction (5%,10%,15%,20%) of SiC particles.

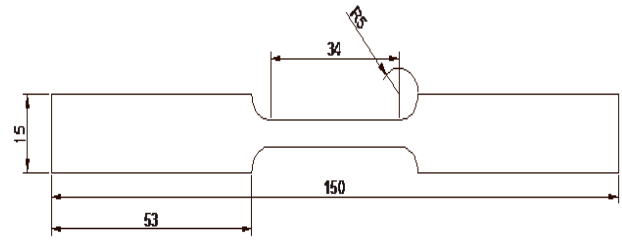


Figure 4. Standard specimen for Tensile Test

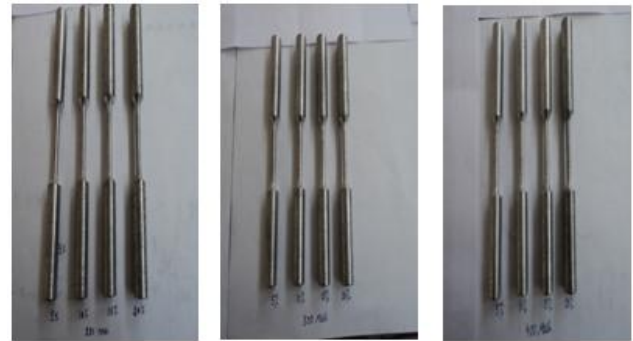


Figure 5. Standard specimen prepared by varying the mesh size and Wt. fraction of SiC for Tensile Test

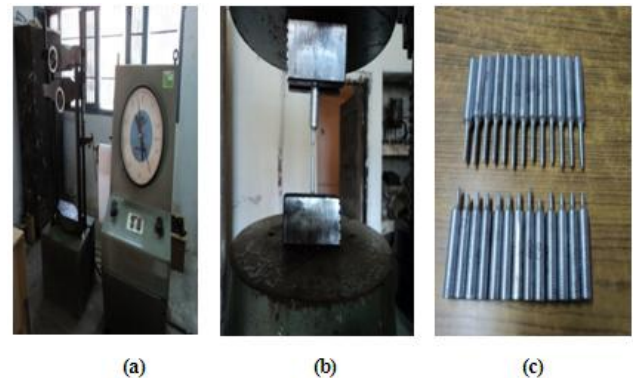


Figure 6. (a) UTM Machine (b) Testing of specimen on UTM Machine (c) Specimens after test

Procedure of Tensile Test is shown by Figure 6. (a) and (b) In Figure 6 (c) Twelve Specimens are shown after test. Graphs were plotted between tensile force (kgf) and Extension (mm) for twelve specimens. The values of tensile force are plotted on vertical axes and extension on horizontal axes. The specimen passes through the clearly defined stages i.e. limit of proportionality, Upper yield value, lower yield value, ultimate stress value and finally fractures strength value.

#### 3.3. Hardness

The Rockwell hardness test was done on Rockwell hardness tester as shown in Figure 8 (a) Model RAB, Sr.No.SN 4144, make SEU Pvt. Ltd. Twelve samples of Al/SiC-MMC's for different sizes and weight fraction of SiC particles were prepared. Figure 8. (b) and (c) Shows samples after test and hardness value on dial. The Rockwell hardness values with reference to scale HRB were taken for all samples and shown by graphs.

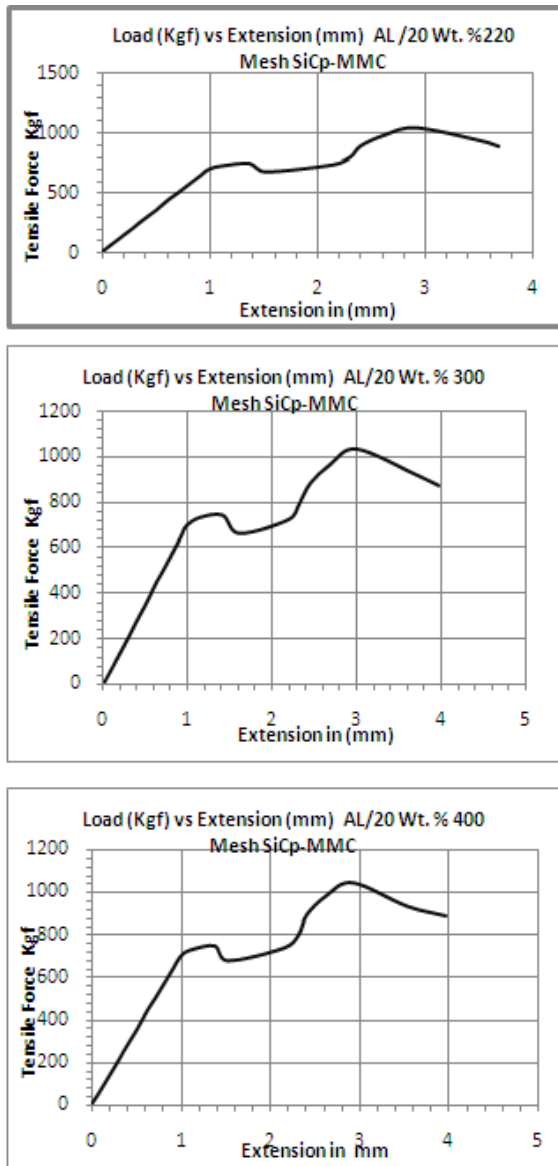


Figure 7. Graphs were plotted between Tensile force (kgf) and Extension (mm) for twelve specimens

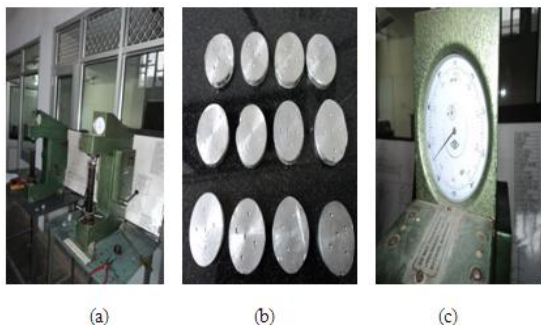


Figure 8. From left (a) hardness Tester (b) samples after test (c) hardness value on dial

### 3.4. Density

Density of Twelve samples of Al/SiC-MMC's for different Sizes and weight fraction of SiC particles were measured by using Archimedeian principle. Standard blocks of 15X15X10 mm were made as sample pieces. The schematic of the set up designed and fabricated for the density measurement. Steel rod of 2mm diameter is bent in U shape, one end of the rod is brazed with the

rectangular steel sheet of 3mm thickness and the other end is free. The whole set up is placed over the electronic weighing machine pan having least count (LC) of 0.1mg. Distilled water was filled up to a mark in a standard beaker of 100ml, which was placed over the wooden slab and it should be free from the electronic balance. Sample pieces were freely suspended with a piece of thread from the upper end of the steel rod. Initially weight of the sample in air ( $w_1$ ) is measured, later the same sample was immersed in distilled water, and weight ( $w_2$ ) of the sample was recorded. The actual density was calculated using the following equation.  $Density = w_1 / (w_1 - w_2)$ . Results are shown by graphs.

### 3.5. Impact Strength

Impact Test was carried out on Izod Impact Testing Machine and results were recorded in table. According to size and weight fraction of SiC particles Twelve Specimens Al/SiC-MMC's were prepared of Square cross-section of size (10X10X75) with single V-notches as shown in Figure 9 (a), (b) and (c). The size of V-notches is 45° and 2mm depth. Figure 9 (d) shows specimens of Al/SiC-MMC's after IZOD Test.

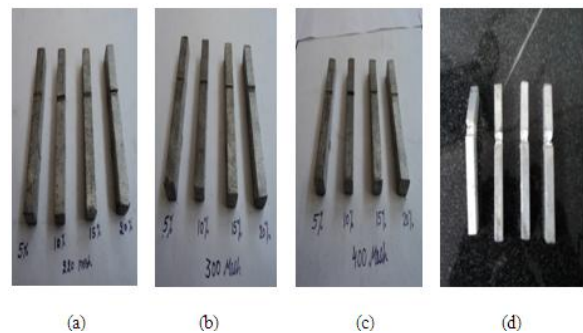


Figure 9. (a), (b) and (c) Twelve Specimens of Al/SiC-MMC's (d) Specimens of Al/SiC-MMC's after IZOD Test

### 3.6. Result Graph

Effect of size and weight fraction of SiC particles of Al/SiC-MMC's on mechanical properties like Proportionality (MPa) limit, Tensile strength upper yield point (MPa), Tensile strength lower yield point (MPa), Ultimate tensile strength (MPa), Breaking strength (MPa), % Elongation, % Reduction in area, Hardness (HRB), Density (gm/cc), Impact Strength (N.m) are presented in graphs [Figure 10 to 19] as shown hereunder. In these graphs all above properties are taken on vertical axes and Wt.% of SiC on horizontal axes.

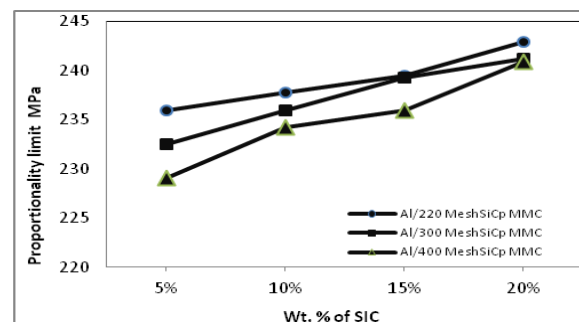


Figure 10. Proportionality (MPa) limit Vs Wt.% of SiC

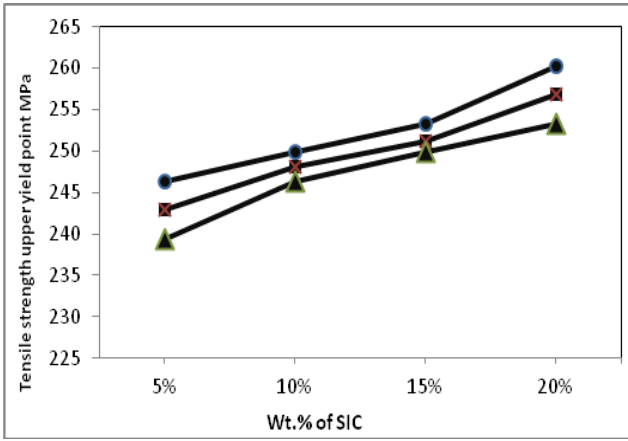


Figure 11. Tensile strength upper yield point (MPa) Vs Wt.% of SiC

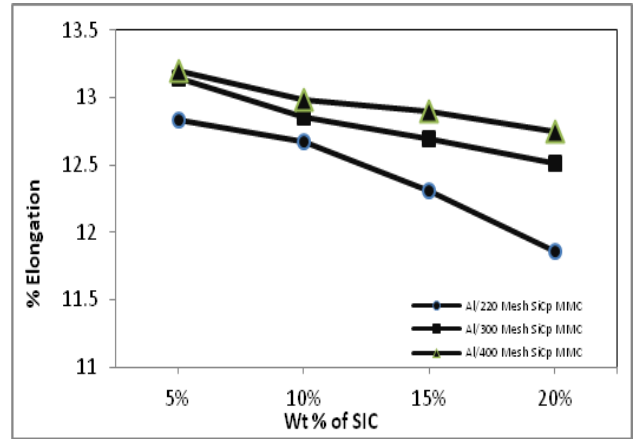


Figure 15. % Elongation Vs Wt.% of SiC

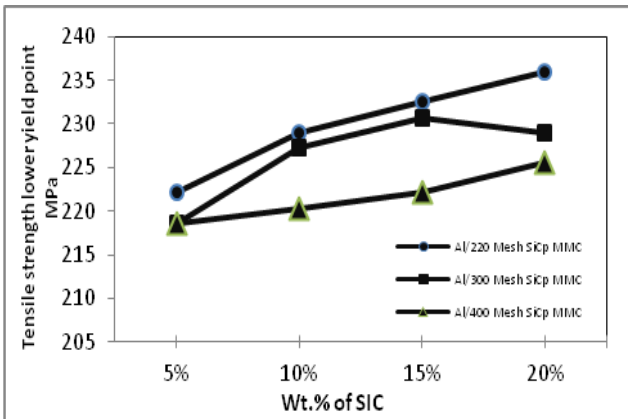


Figure 12. Tensile strength lower yield point (MPa) Vs Wt.% of SiC

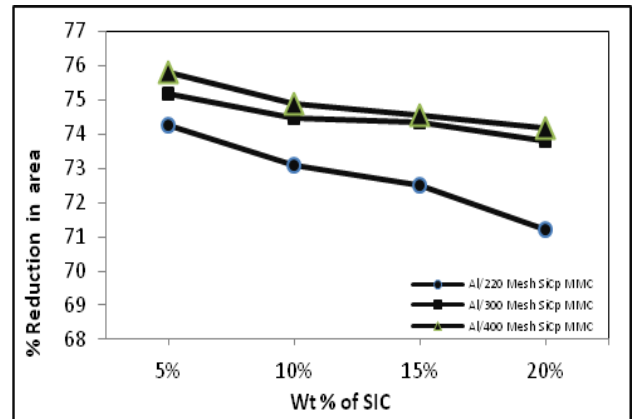


Figure 16. % Reduction in area Vs Wt.% of SiC

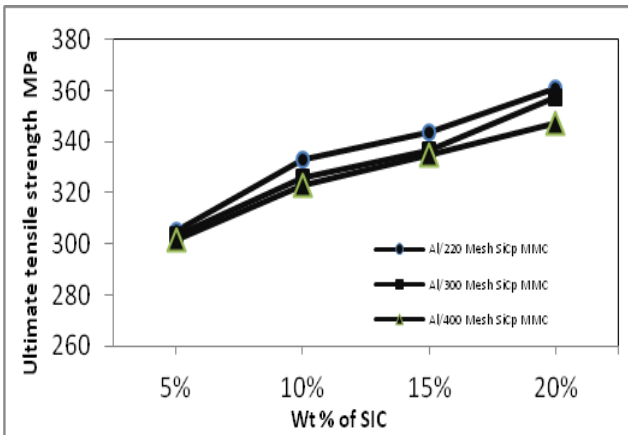


Figure 13. Ultimate tensile strength (MPa) Vs Wt.% of SiC

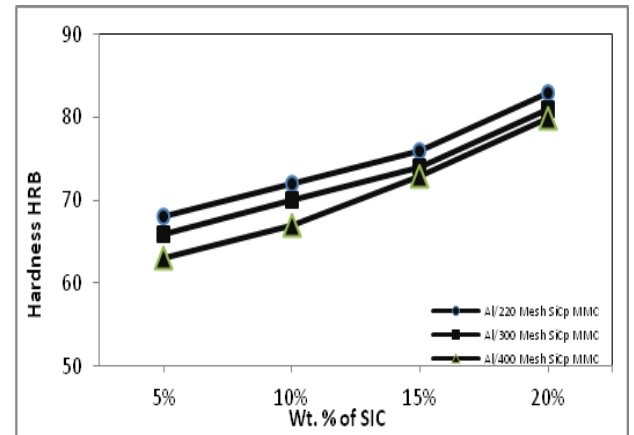


Figure 17. Hardness (HRB) Vs Wt.% of SiC

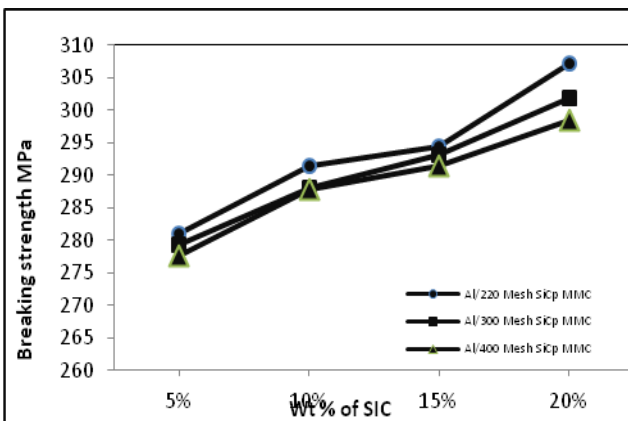


Figure 14. Breaking strength (MPa) Vs Wt.% of SiC

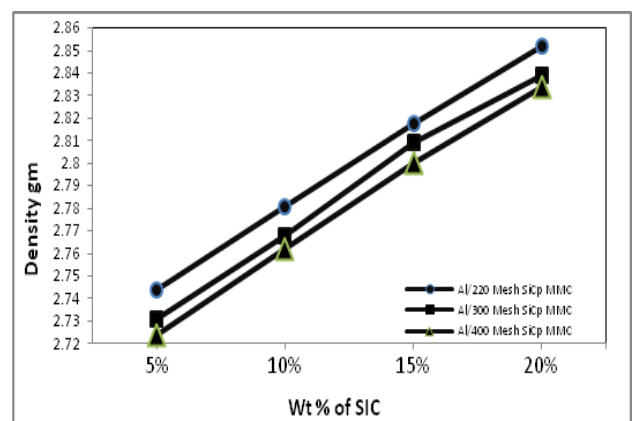


Figure 18. Density (gm/cc) Vs Wt.% of SiC

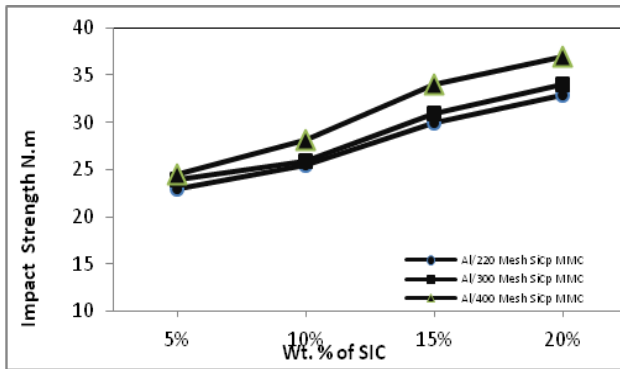


Figure 19. Impact Strength (N.m) Vs Wt.% of SiC

## 5. Conclusions

The experimental study reveals following conclusions:

(a) **Microstructure:** Optical micrographs showed reasonably uniform distribution of SiC particles and this is good agreement with earlier work. Homogenous dispersion of SiC particles in the Al matrix shows an increasing trend in the samples prepared by applying stirring casting technique.

(b) **Tensile Strength:** From the result graphs Proportionality (MPa) limit, Tensile strength upper yield point (MPa), Tensile strength lower yield point (MPa), Ultimate tensile strength (MPa) and Breaking strength (MPa) increases with the increase in reinforced particulate size (220 mesh, 300 mesh, 400 mesh) and weight fraction (5%, 10%, 15%, 20%) of SiC particles. % Elongation and % Reduction in area decreases with the increase in reinforced particulate size (220 mesh, 300 meshes, 400 mesh) and weight fraction (5%, 10%, 15%, 20%) of SiC particles.

(c) **Hardness (HRB) and Density (gm/cc)** increases with the increase in reinforced particulate size (220 mesh, 300 mesh, 400 mesh) and weight fraction (5%, 10%, 15%, 20%) of SiC particles. Maximum Hardness (HRB) = 83 and Maximum Density (gm/cc) = 2.852 gm/cc has been obtained at 20 % weight fraction of 220 mesh size of SiC particles.

(d) **Impact Strength (N.m)** decreases with the increase in reinforced particulate size (220 mesh, 300 mesh, 400 mesh) and increases with the increase in weight fraction (5%, 10%, 15%, 20%) of SiC particles. Maximum Impact Strength = 37.01 N-m has been obtained at 20 % weight fraction of 400 mesh size of SiC particles.

## References

- [1] Hashim, J., Looney, L. and Hashmi, M.S.J., "Particle Distribution in Metal Matrix Composites." Part-I, *Journal of Materials Processing Technology*, 123: 251-257. 2002.
- [2] Nather, S., Brabazon, D. and Looney, L., "Simulation of the Stir Casting Process," *Journal of Materials Processing Technology*, 143-144: 567-571. 2003.
- [3] Nai, S.M.L. and Gupta, M., "Synthesis and Characterization of Free Standing, Bulk Al/SiC Functionally Gradient Materials: Effects of Different Stirrer Geometries," *Material Research Bulletin*, 38: 1573-1589. 2003.
- [4] Hashim, J., Looney, L. and Hashmi, M.S.J., "Metal Matrix Composites: Production by the Stir Casting Method," *Journal of Materials Processing Technology*, 92-93: 1-7. 1999.
- [5] Manna, A. and Bhattacharyya, B., "Study on Different Tooling Systems during Turning for Effective Machining of Al/SiC-MMC," *The Institution of Engineers (India) Journal-Production*, 83: 46-50. 2003
- [6] Allison, J.E. and Cole, G.S., "Metal Matrix Composite in Automotive Industry: Opportunities and Challenges," *Journal of Mechanical Science*, 19-24. 1993.
- [7] Surappa, M.K., "Microstructure Evolution during Solidification of DRMMCs: State of the Art," *Journal of Materials Processing Technology*, 63: 325-333. 3078 A. MANNA ET AL. 1997.
- [8] Yang, J., Pickard, S.M., Ctedy, C., Evans, A.G. and Mehrabian, T., "The Stress/Strain Behavior of Aluminium Matrix Composites with Discontinuous Reinforcements," *Acta Metallurgica Materialia*, 39: 1863-1870. 1997.
- [9] Lloyd, D.J., Lagace, H., Mcleod, A. and Morris, P.L. (1989). Micro Structural Aspect of Aluminium Silicon Carbide Particulate Composites Produced by a Casting Method, *Materials Science and Engineering*, A107: 73-79.
- [10] Guo, Z., Xiong, J., Yang, M. and Li, W., "Microstructure and Properties of Tetrapod-like ZnO Whiskers Reinforced Al Matrix Composite," *Journal of Alloy and Compounds*, 461: 342-345. 2008.
- [11] Sulaiman, S., Sayuti, M. and Samin, R., "Mechanical Properties of the As-Cast Quartz Particulate Reinforced LM6 Alloy Matrix Composites," *Journal of Material Processing Technology*, 201: 731-735. 2008.
- [12] Zhou, W. and Xu, Z.M., "Casting of SiC Reinforced Metal Matrix Composites," *Journal of Materials Processing Technology*, 63: 358-363. 1997.
- [13] Gupta, M., Lai, M.O. and Lim, C.Y.H., "Development of a Novel Hybrid Aluminium Based Composite with Enhanced Properties," *Journal of Materials Processing Technology*, 176: 191-199. 2006.
- [14] Ourdjini, A., Chew, K.C. and Khoo, B.T., "Settling of Silicon Carbide Particles in Cast Metal Matrix Composites," *Journal of Materials Processing Technology*, 116: 72-76. 2001.
- [15] Srivatsan, T.S., Sudarshan, T.S. and Lavernia, E.J., "Processing of Discontinuously-Reinforced Metal Matrix Composites," by *Rapid Solidification, Progress in Material Science*, 39: 317-409. 1995.
- [16] M.K. Surappa, J. Mater., "Fabrication of Al-Al<sub>2</sub>O<sub>3</sub>/Grp Metal Matrix Composites 3079," in *Proc. Tech.* 63, 325-333. 1997.
- [17] D.M. Skibo, D.M. Schuster, L. Jolla, "Process for preparation of composite materials Containing nonmetallic particles in a metallic matrix, and composite materials made by," *US Patent No.* 4 786 467, 1988.