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Development and Testing of Metal Matrix Composite by Reinforcement of Sic Particles on Al 5XXX Series Alloy

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***Abstract* - This paper reviews the world-wide upsurge in metal-matrix composite research and development activities with particular emphasis on cast metal-matrix particulate composites. It involves the development of Composite material in which the desirable properties of two separate materials are combined by mechanically binding them together. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals. Here Aluminium 5083 used as the matrix material in which SiC added as the reinforced material. Present work was focused on the comparative study of behaviour of Aluminium 5083 with SiC as reinforcement produced by stir casting method and ultrasonic assisted stir casting method. Hardness and Density tests were employed to obtain the mechanical properties of specimens by adding different percentages of SiC and trend was compared between the samples developed by stir casting method and ultrasonic assisted stir casting method.**

Key Words: Al 5083 Alloy, SiC particles, Hardness, Density and Ultrasonic assisted stir casting process

I. INTRODUCTION

Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. A composite is a material that consists of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. A common example of composites would be disc brake pads, which consist of hard ceramic particles embedded in soft metal matrix and are also widely used. The most advanced examples used routinely on spacecraft. Composites in daily life simply refers to its application and essentiality in our life its plays a vital role in that, for example wood, concrete, plastic, epoxy fibre. In the past, various studies have been carried out on metal matrix composites. SiC, TiC, WC and B_4C are the most commonly used particulates to reinforce metal or alloy matrix or aluminium or iron. The study of SiC in Aluminium 5083 alloy is still rare and scarce and very limited studies have been reported. So the information and the data available on the mechanical properties are scarce which make this study a significant one. Moreover no research have been done on SiC reinforced Al 5083 composites which used ultrasonic assisted stir casting route for fabrication. Comparative reports of both routes (with or without ultrasonic probe) are also not available. This research area is still vacant and has scope for work in this particular field.

II. CLASSIFICATION OF COMPOSITES

MMC is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as ceramic or organic compound. Work on MMCs began in the 1950s since then researchers tried numerous combinations of matrices and reinforcements. This led to the development of product for aerospace, but resultant commercial applications were limited. The introduction of ceramic whiskers as reinforcement and the development of in-situ eutectics in the 1960s aided high temperature applications in aircraft engines. In the late 1970s the automobile industries started to take MMCs seriously. In the last 20 years, MMCs evolved from laboratories to a class of materials with numerous applications and commercial markets.

Composite may be broadly classified according to two ways

A) On the basis of Reinforcement
B) On the basis of Matrix

A. On the basis of reinforcement

Classification on the basis of Reinforcement is shown in Fig.1.

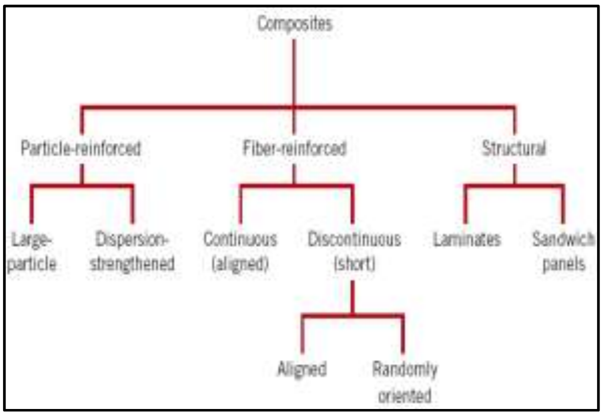

Fig. 1 Classification on the basis of reinforcement

1) Particle reinforced composite:

These can be further classified under two subgroups: (i) large particle and (ii) dispersion strengthened composites. The distinction between these is based upon reinforcement or strengthening mechanism.

a) Large-particle composites:

The term large indicate that particle-matrix interactions cannot be treated on the atomic or molecular level. Properties are a combination of those of the components. The rule of mixtures predicts that an upper limit of the elastic modulus of the composite is given in terms of the elastic moduli of the matrix (E_m) and the particulate (E_p) phases by:

$$E_c = E_m V_m + E_p V_p$$

where V_m and V_p are the volume fraction of the two phases. A lower bound is given by:

$$E_c = E_m E_p / (E_p V_m + E_m V_p)$$

Concrete is a familiar example of large-particle composite.

b) Dispersion-strengthened composites:

This type of composite contains small particulates or dispersions, which increase the strength of the composite by blocking the movement of dislocations. The dispersed is typically a stable oxide of the original material.

2) Fiber-reinforces composites:

These are strong fibers imbedded in a softer matrix to produce products with high strength-to weight ratios. The matrix material transmits the load to fibers, which absorb the stress. The length-to-diameter, or aspect, ratio of the fibers used as reinforcement influences the properties of the composite. The higher is aspect ratio, the stronger the composite. Therefore, long, continuous fibers are better than short ones for composite construction. However, continuous fibers are more difficult to produce and place in the matrix. Shorter fibers are easier to place in the matrix but offer poor reinforcement.

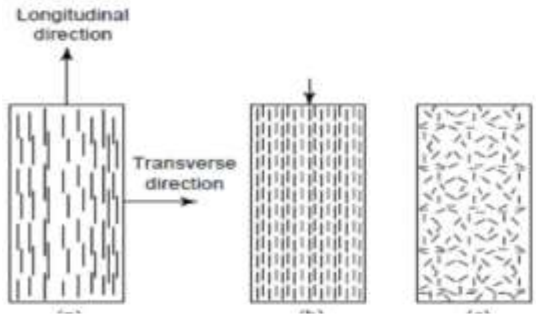

Fig. 2 Representation of (a) Continuous and aligned fiber composites (b) Discontinuous and aligned fiber composites (c) Discontinuous and randomly oriented composites

3) Structural composites:

a) Laminar composites

When multidirectional stresses are imposed within a single plane, aligned layers that are fastened together one on top of another at different orientations are frequently utilized. These are called laminar composites. These are generally designed to provide high strength and low cost at a lighter weight. A familiar laminar composite is plywood.

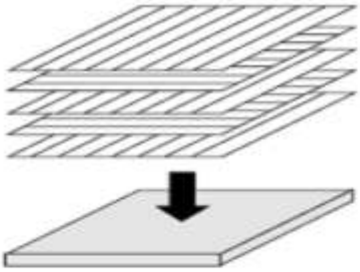

Fig. 3 Laminar Composite

b) Sandwich structures

These have thin layers of facing materials over a low density material, or comb core, such as a polymer foam or expanded metal structure. A familiar sandwich- structured composite is corrugated cardboard.

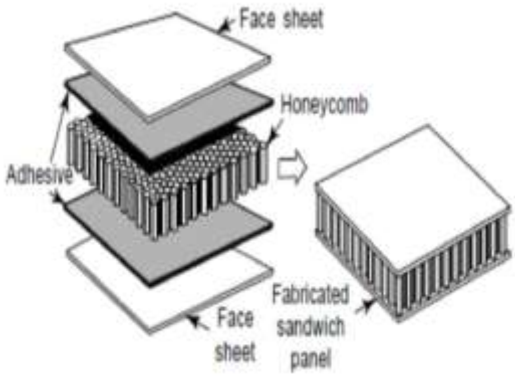

Fig. 4 Honeycomb Structure

B) Classification on basis of Matrix

Classification on the basis of Matrix is shown in Fig. 5.

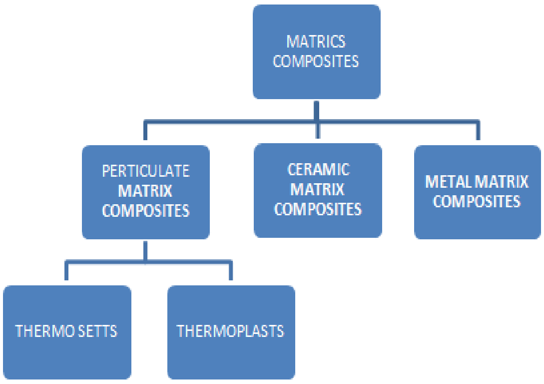

Fig. 5 Classification on the basis of matrix

1) Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminium, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.

2) Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase).

3) Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

Many research have been done on SiC reinforced Al 5083 which is fabricated by stir casting process but no research have been done on ultrasonic assisted stir casting route for fabrication. This led us to do significant work on this field. In this investigation SiC particulates reinforced Al 5083 composites test samples were fabricated and processed by both simple stir assisted and ultrasonic assisted stir casting route. The parameters of different wt. % of SiC addition in the Al 5083 alloy is examined to study the Hardness and density of processed specimen.

III. SELECTION OF MATERIAL

Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weld ability, and corrosion resistance. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. Table 1 shows the Alloy Designation and their details.

Table 1 Designation of Cast Aluminium alloy

Alloy Designation	Details
1XXX	99% Pure aluminium
2XXX	Cu containing alloy
3XXX	Si , Cu/Mg containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Zn containing alloy

5XXX series aluminium alloy contain high percentage of magnesium in HCP structure at 65°C. Magnesium acts as strengthening agent, improves wettability of aluminium and has high corrosion resistant properties. It has small solubility of 3% at room temperature and 15.35% at 451°C (eutectic). Eutectic reaction gives K phase (FCC) and β phase (Al_3Mg_2). Figure 6 shows the Phase diagram.

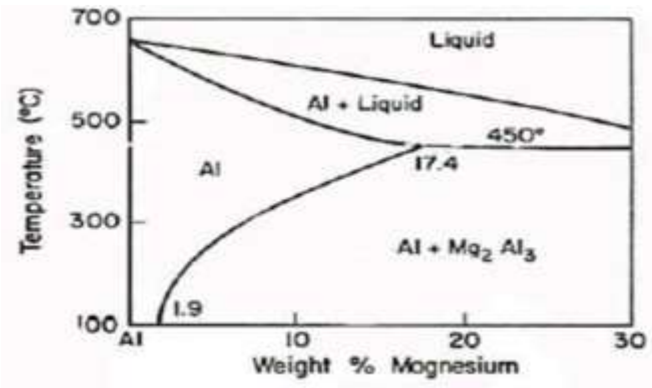

Fig. 6 Phase equilibrium diagram

Actual composition of Al 5083 which we considered for our work is given in table 2.

Table 2 Composition (wt. %) of Actual Al-5083

Element	Zn	Fe	Ti	Cu	Si	Pb	Mn	Mg	Cr	Al
% Present	0.03	0.17	0.04	0.01	0.16	0.014	0.52	5.1	0.09	Balance

The reinforcement material is embedded in to the matrix. The reinforcement does not always serve a purely structural task, but is also used to change physical properties such as wear resistance, friction coefficient and thermal conductivity.

Table 3 Reinforcements for various matrices

Reinforcement	Matrices
Boron, fiber (including coated)	Aluminium, titanium
Graphite fiber	Aluminium, magnesium, copper
Alumina fiber	Aluminium, magnesium
Silicon carbide fiber	Aluminium, titanium
Alumina-silica fiber	Aluminium
Silicon carbide whisker	Aluminium, magnesium
Silicon carbide particulate	Aluminium, magnesium
Boron carbide particulate	Aluminium, magnesium

Silicon carbide (SiC) is composed of carbon and silicon atoms in tetrahedral arrangement with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon carbide particulates have attained a prime position among the various discontinuous dispersions available for the synthesis of MMC. This is due to the fact that introduction of SiC to the aluminium matrix substantially enhances the strength, the modulus, the abrasive wear resistance and thermal stability. The density of SiC (3.2g/cm) is nearer to that of aluminium alloy AA6061 (2.7g/cm^3). The resistance of SiC to acids, alkalis or molten salts up to 800 degree Celsius makes it a good reinforcement candidate for aluminium based MMC. Furthermore, SiC is easily available and has good wettability with aluminium alloys. The type of the silicon carbide is F320, density is in between 1.29-1.35 g/cm3 and the mesh size is 29.2 ± 1.5 µm. Surface chemical values of F 320 silicon carbide are given in Table 4.

Table 4 Surface chemical values of F 320 silicon carbide

Product	%SiC	%Free C	%Si	%SiO_2	%Fe_2O_3
F 240 - F 800	99.50	0.10	0.10	0.10	0.05

IV. EXPERIMENT SETUP

Stir casting is the fabrication technique used widely for producing particle reinforced MMC having Al 5XXX series alloy as metal matrix and SiC as reinforcement. We have introduced ultrasonic probe during production of MMC. For manufacturing of composite samples and their testing, following machines and equipments are used.

i) Matrix (Al 5083 alloy) ii) Reinforcement (SiC)
iii) Weighing Machine iv) Crucible (Graphite)
v) Furnace vi) Mould (Mild Steel) vii) Stirrer
viii) Ultrasonic Probe (For ultrasonic stir casting only)
ix) Cutting Grinder x) Surface Polishing Machine
xi) Rockwell Hardness Testing Machine xii) Lathe
xiii) Scanning Electron Microscope (SEM)
Fig. 7 presents the setup of stir casting method.

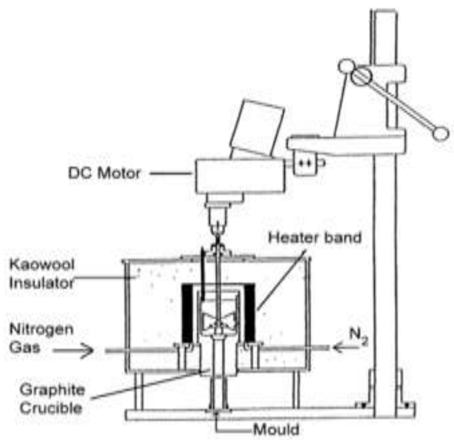

Fig. 7 stir casting

Fig. 8 and Fig. 9 presents the Schematic diagram and setup of ultrasonic stir casting method respectively.

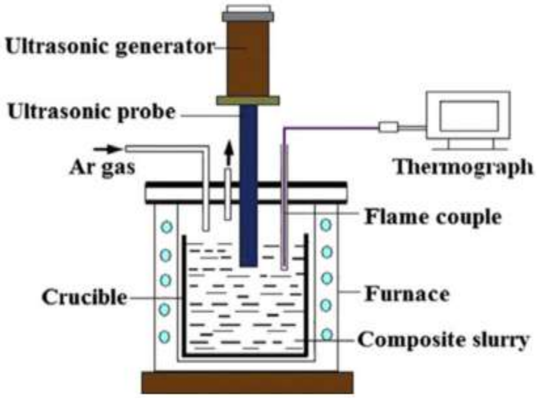

Fig. 8 Ultrasonic Assisted Stir Casting Process

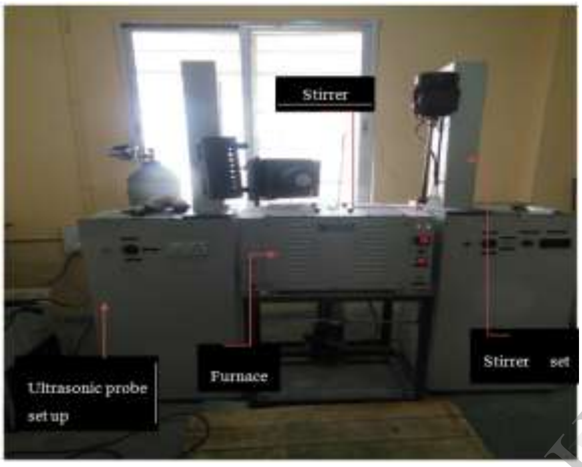

Fig. 9 – Ultrasonic Stir Casting set up

High power ultrasound was introduced into molten aluminium during solidification of aluminium dendrites. Dendrite that is formed during casting having large grain and many branches which is harmful structure in metal. In order to suppress the generation of dendrite structure during casting, an active method was introduced by using high power ultrasound to break dendrite arms and to increase the number of nuclear seeds. The grain sizes of the aluminium treated by the high power ultrasound were decreased and the shape became spherical. The sizes were same at the different power of ultrasound when the power approached threshold level. There were also harmful small cavities created when the power of ultrasound exceeds desired power range. This useless extra ultrasonic power generated vapours of molten aluminium and these vapour was fixed as small cavities in the solid aluminium after solidification. (Choi et. al., 2009). The microstructure of the sample produce by using ultrasonic probe is shown in fig. 10. Various samples developed for Hardness and density testing by both the methods is shown in fig. 11.

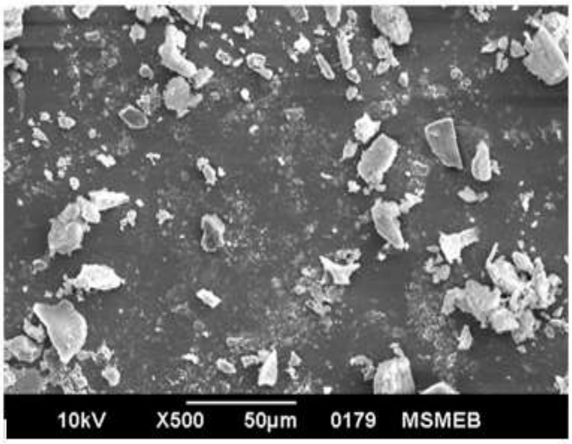

Fig. 10 SiC powder embedded within an aluminium matrix

Fig. 11 hardness test specimen

V. RESULTS AND DISCUSSION

A) Hardness Measurement

A Hardness Testing Machine Model- TRSN-D/TRSNT-D is used for the hardness measurement. The surface being tested generally requires a metallographic finish and it was done with the help of 100, 220, 400, 600 and 1000 grit size emery paper. For measuring hardness of Al soft alloy, BHN scale is used. The specification of BHN scale is that the load applied on the smooth surface is 187.5 Kg and the indenter ball diameter is 2.5mm is used. The dwell time was 8 seconds for each sample. The total five reading is taken from the different point on the sample and average is calculated.

The result of hardness test for alloy 5083 MMCs with wt.% variation of reinforcement SiC without probe (means that simple stir casting process) and with probe (means that ultrasonic assisted stir casting process) are shown in table 5 and table 6.

Table. 5 Hardness (BHN without probe)

SAMPLE 500 rpm	1	2	3	4	5	Avg.
0% SiC	54	52	58	49	55	53.6
3% SiC	64	59	58	69	62	62.4
5% SiC	76	77	70	80	71	74.8
8% SiC	82	75	76	80	74	77.4
10% SiC	78	85	79	88	84	82.8

Table. 6 Hardness (BHN with probe)

SAMPLE 500 rpm	1	2	3	4	5	Avg.
0% SiC	60	59	57	56	59	58.2
3% SiC	68	69	60	61	64	64.4
5% SiC	83	85	75	74	76	79
8% SiC	85	84	80	79	81	82
10% SiC	84	86	90	81	79	85

Fig. 12a and fig. 12b shows the trend of Hardness of specimen of different weight % of SiC without and with probe respectively.

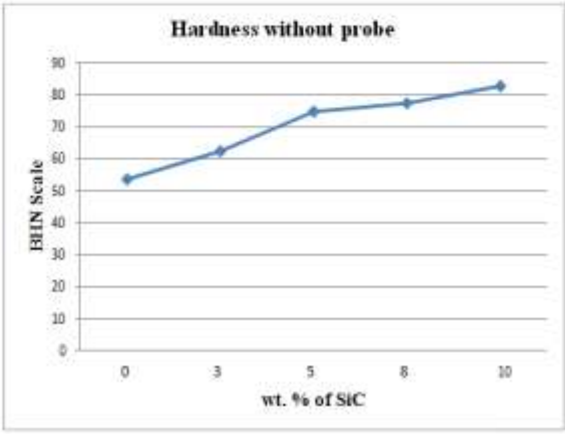

Fig. 12a Hardness (Without probe)

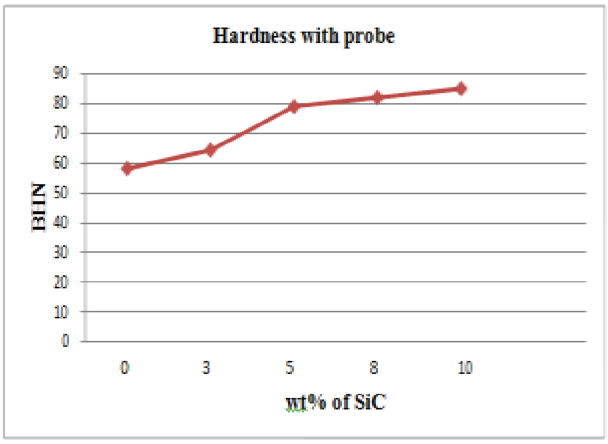

Fig. 12b Hardness (with probe)

Fig. 13 shows the Hardness of specimen at different wt % of SiC for without and with probe collectively in bar graph.

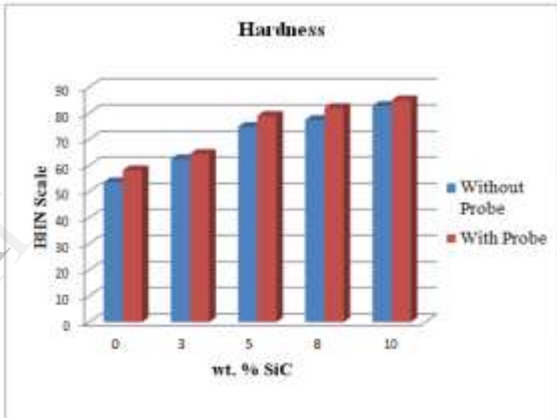

Fig. 13 Comparative Bar Graph of Hardness

Test shows that the Hardness increases with the increase in wt % of SiC in specimen irrespective of use of ultrasonic probe. This also shows that the Hardness of the specimen produced with the help of ultrasonic probe is more in comparison to the specimen without using ultrasonic probe.

B) Density Measurement

The theoretical and experimental density of the Al-SiC composite measured. Theoretical density obtained by rule of mixture and experimental density values for the composites studied for different wt. % of reinforcements. Table 7 shows the theoretical density of specimen as well as practical value of density without and with probe at different wt. % of SiC reinforcement.

Table. 7 Density measurement of Specimen

SAMPLE%	Theoretical (g/cc)	Practical(g/cc) Without Probe	Practical(g/cc) With Probe
0%	2.7	2.67	2.681
3%	2.736	2.679	2.691
5%	2.76	2.681	2.701
8%	2.84	2.689	2.734
10%	2.93	2.699	2.755

Fig. 14 shows the Density of specimen at different wt % of SiC for without and with probe collectively in bar graph.

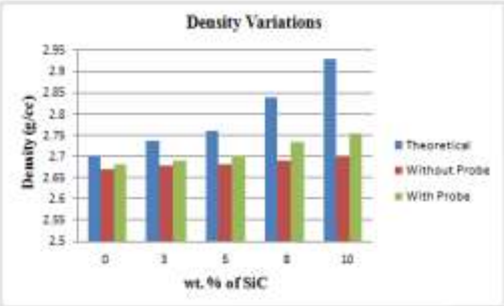

Fig. 14 Comparative Bar Graph for Density Variations

Table 8 shows the variations of porosity was also calculated and it revealed that porosity increased with increase in wt. %.

Table 8 Porosity Measurement

SAMPLE%	% Porosity With Probe	% Porosity Without Probe
0%	1.11	0.7
3%	2.08	1.64
5%	2.86	2.13
8%	5.31	3.7
10%	7.88	5.9

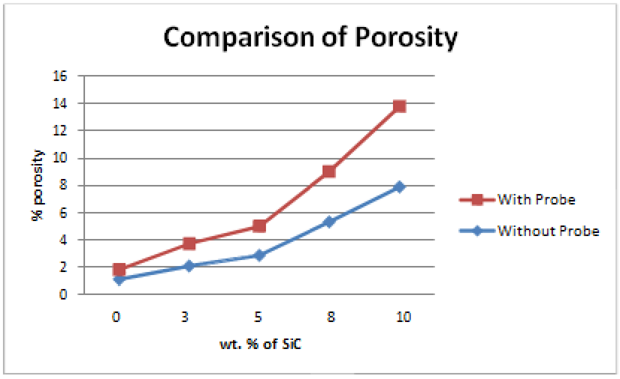

Fig. 15 Comparison of porosity

VI. CONCLUSION

It is concluded that hardness increased by increasing the weight % of SiC in composites. Hardness also increased in which ultrasonic probe was used from those which were made by simple stir casting method and the samples showed homogeneous trend in the components. By the increment of reinforcement micron particle in Al-SiC composites density increased. Density also increased by ultrasonic probe assistance at particular reinforcement micron particle level. Porosity increased by increasing wt. % of SiC as well as by using ultrasonic probe.

Therefore it can be concluded that in Stir casting processing route the mechanical properties increased by increasing wt. % of SiC and also with ultrasonic assisted stir casting route. Ultrasonic stir casting route proved to be the prominent route for fabrication of composites.

VII. FUTURE SCOPE

More weight % of SiC can be mixed by preheating it up to 1100°C. Process can be repeated on the casted product in order to improve its interfacial bonding. Semi solid state mixing can be done by passing through eutectic point of the binary diagram.

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