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Solidifying behavior and Characterization of Al (LM6) +SICP Metal Matrix Composites

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***Abstract:** This paper presents the investigation of moderate properties of solidified Al (LM6)+SiCp metal matrix composite (AMMC). These AMMC is fabricated by considering five different parts of casting and different weight of SiCp for reinforcement. The SiCp wt. % is varied from 5 wt. % to 15 wt. % with a step size 5 %. During casting, temperature is measured using K-thermocouple and temperature vs. solidification curve is traced. These results are compared with the solidification results of Al (LM6) alloy. It is observed that the solidifying duration of AMMC increased as well as decreased liquid temperature by adding SiCp to it. The trend of the curve is also presented that the cooling rate and the duration of solidification are different for different part of casting. Mechanical property of the each five parts of casting is tabulated. It is observed from the properties that the mechanical properties of AMMC increased by increasing the wt. % of the reinforced particles SiCp.*

***Keywords:** LM6, SiC, AMMCs, Solidifying, Hardness, Tensile.*

I. INTRODUCTION

Aluminium metal matrix composites (AMMCs) exhibits moderate properties. It is an alternative to replace traditional materials used in locomotive industries. Being its potential properties, industries are also showing their demands in AMMCs. These AMMCs are being used to replacement of traditional materials in several uses, specifically different parts of locomotive; it needs a successful performance analysis [1]. AMMCs are increased its industrial applications as compared to other metal matrix composites. Mostly, Al alloy with SiCp composites are wide application in current industries. These AMMC are fabricated in different low cost techniques as melt process, powder metallurgy. These AMMCs exhibit good potential in loading surroundings especially fulfilling requirements as withstand in relatively high temperature along its other properties like high specific strength, high stiffness and good endurance limit. Therefore AMMCs can be useful to replace cylinder, piston head, connecting rod, driving shaft [2]. The AMMCs fabricated by stir casting technique have been influencing by several factors as size, weight fraction, distribution of reinforced particle. Ceramic particles i.e. SiC play a vital role during solidification, since these particles act as obstruction to heat flow inside the solute, constrain to fluid convection, and bring morphological variability in the solid-liquid interfaces.

The solidifying rate acts a significant role in microstructure of casting AMMCs, which is influenced their mechanical properties. Dutta and Surappa [3] have studied macro and micro structure of Al+Cu+SiCp composite with multidirectional solidifying settings. They have observed as increasing the volume fraction and heat transfer rate decreased at the level of macro-segregation reinforcements. Nath et al. [4] investigated the distribution of mica particle in composite (Al+Cu+Mg). They have used various molds by considering different heat flow configuration. They have determined as a casting size 12.5 mm (thin) could simply be fabricated. Rajan et al. [5] have presented the consequence of volume fraction in the solidification curves. They have considered three types mold with different heat extracting capacity viz. sand, steel and graphite. Jena et al. [9-10] have discussed SiCp reinforcement techniques in metal as well as polymer. Various attentions is required in stir casting technique to get homogeneous distribution of reinforced particles, good bonding, minimum porosity, stable reaction among reinforced material and matrix material. From the past literature, the foremost challenge is to get uniform dispersion of the reinforced ceramic particles using low cost conventional equipment and further its commercialization. The objective of the current work is to analyze the solidifying nature of the AMMC by varying particle (SiCp) reinforced wt. % in Aluminium alloy (LM6). For the analysis five step molds for sand casting and gravity die casting techniques are considered. The metallographic property is also examined.

II. EXPERIMENTATION

A. *Casting of MMCs*

In this section, the importance has been given to produce an affordable Al+SiC AMMC casting. The fabrication of AMMC (Al+SiC) is done using stir die casting technique. The aluminium+silicon alloy (LM6) is considered as matrix for the fabrication. The AMMC has been reinforced SiCp with weight percentage as 5 wt. %, 10 wt. % and 15 wt. %. The average size of SiCp is 400 mesh size taken to consideration. The basic composition of the matrix material (LM6) is presented in the Table 1. The thermo-physical properties of SiCp and LM6 are presented in the Table 2.

At the first stage, stir system is established by joining motor, gearbox and a mild steel stirrer. The LM6 is melted by a tilt electric resistance furnace in a range of 760 ± 10 ^{0}C. Graphite crucible is used for the melting LM6 in furnace.

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Table1: Basic composition of the matrix material (LM6)

Elements	Si	Cu	Mg	Fe	Mn	Ni	Zn	Pb	Sb	Ti	Al
Percentage (%)	10-13	0.1	0.1	0.6	0.5	0.1	0.1	0.1	0.05	0.2	Rest

Table 2: Thermo-physical property of SiCp and LM6.

Properties	SiCp	LM6
Density(gm/cm^3)	3.2	2.66
Average particle size (mesh)	400	-----
Thermal conductivity(W/m/K)	100	155
Specific heat (J/Kg/K)	1300	960

Graphite crucible is used for the melting LM6 in furnace. The SiCp are preheated at 1000^{0}C for 2 hours to remove moisture and make their surface oxidized. The furnace temperature is first raised above the liquidus temperature of LM6 and gets completely melt and is then down the temperature just below the liquidus temperature to keep the molten slurry into a semi-solid state. Second stage, the preheated SiCp are mixed using manual stirrer. Then the composite slurry is reheated by increasing furnace temperature to melting temperature of LM6 to get a fully liquid state and then the automatic mechanical stirrer (600 rpm) is stirred (for 10 minutes).

B. *Cooling curves*

The molten slurry is poured into the stepped silica sand mold and metallic mold (shown in Figure 1). The pouring temperature was 730 ^{0}C. Five different K-type thermocouples (i.e.T_1, T_2, T_3, T4 & T_5) are used to read the temperature in different section of cast during the solidification (shown in Figure 2). The solidifying trends of casting in mold are received using data acquisition system and that is presented in Figure 3. Finally, the solidification curves of the both LM6+SiCp AMMC and LM6 alloy are compared.

Figure 1: (a) Sand mold; (b) Metal mold.

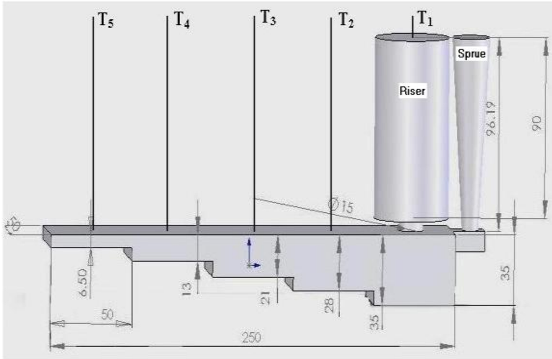


Figure 2: The Model view and dimensions (in mm) of the mold cavity with five different thermocouples (T_1, T_2, T_3, T_4 and T_5).

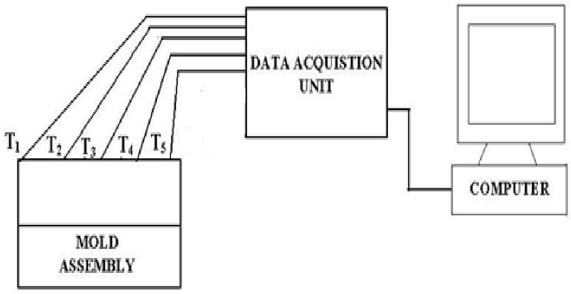


Figure 3: Block diagram of data acquisition set-up for casting.

C. *Microstructure of as cast MMCs*

AMMC test samples are prepared for metallographic testing. These samples are polished by using 220–320–500–1000 mesh emery paper. Then the samples are carved by etchant (Keller's reagent) followed by drying. Finally, these samples are used for testing (microstructure) using Scanning Electron microscope (Make-JEOL, Model-JSM 6360).

D. *Hardness of cast MMCs*

Sample specimens are prepared from the cast AMMC for hardness testing. Specimen surfaces are polished using emery papers. Hardness testing is performed on the prepared samples by taking load 250 N. The indenter impression is observed using Brinnel microscope. The results are tabulated using standard formula. The average value is considered from the 10 repeated test performed on each sample.

E. *Density of cast MMCs*

Density of casted AMMC is calculated using Archimede's principle. Specimens (8mm diameter and 20mm heights) are initially preheated with 120 ^{0}C for 1 hour using furnace and the weights are measured. Then polymeric gel coating is applied to sample surfaces for closing surface porosities. Further specimen is suspended into double distilled water at 25^{0}C and weight is determined. The density of Alloy (LM6) and SiCp are considered as 2.660 g/cm^3 and 3.200 g/cm^3 respectively. Density is calculated using equation (1).

$$\rho = \frac{W_{PH}}{W_{SW}} \qquad (1)$$

where ρ = density of specimen, W_{PH} =the weight of preheated specimen and W_{SW} = the weight of specimen when it suspended into water. Density is also calculated using the mixture rule.

III. RESULTS AND DISCUSSIONS

A. *Density and porosity of the as cast MMCs*

Density and porosity of the samples are given in Table 3. Experimental density is measured by water displacement and theoretical values calculated from rule of mixture. The porosity is calculated using equation (2).

$$\text{Porosity (\%)} = \frac{\rho T - \rho Exp}{\rho T} \times 100 \qquad (2)$$

where, ρ_T is the theoretical density measured from rule of mixture (ROM), and ρ_E is the density measured by water displacement method.

It is seen that the sand cast specimen shows the highest porosity (9.13%) as the microstructural flaws higher in sand casting. The gravity die cast alloy LM6 shows less porosity (4.53%). It is observed the porosity content decreases in metal mold casting compared to sand mold. Because of the the faster cooling rate, the distribution of the reinforced particle occurs uniformly and decreased the porosity formation during solidification. In AMMC the porosity increases with increasing SiCp weight fraction. The lowest porosity obtained in case of 5% SiCp i.e. 6.32% and the highest porosity in case 15% SiCp i.e. 7.21%.

Table 3: Density and porosity are tabulated for the both the alloy (LM6) and AMMCs using sand cast and gravity die cast.

Specimen	ρ_{Th} (g/cm^3)	ρ_{Exp} (g/cm^3)		Porosity (%)	
		Sand Cast	Gravity Die	Sand Cast	Gravity Die
LM6	2.6638	2.4661	2.5431	7.42	4.53
LM6+SiC 5wt%	2.6906	2.4715	2.5206	8.14	6.32
LM6+SiC 10wt%	2.7174	2.4788	2.5304	8.78	6.88
LM6+SiC 15wt%	2.7442	2.4963	2.5463	9.13	7.21

B. *Hardness of cast AMMCs*

Hardness of cast AMMCs (obtained from the both sand cast and gravity die cast) by altering weight fraction of SiCp is shown in Figure 4. It is observed that AMMCs obtained from gravity die cast gives higher hardness as compared to sand cast. It is also observed that the wt. % of SiCp has a greater influence on hardness value and the hardness value are gradually increased by increasing weight fraction of SiCp. The maximum hardness value is measured as 107.4 BHN in LM6+15wt% SiCp AMMCs specimen.

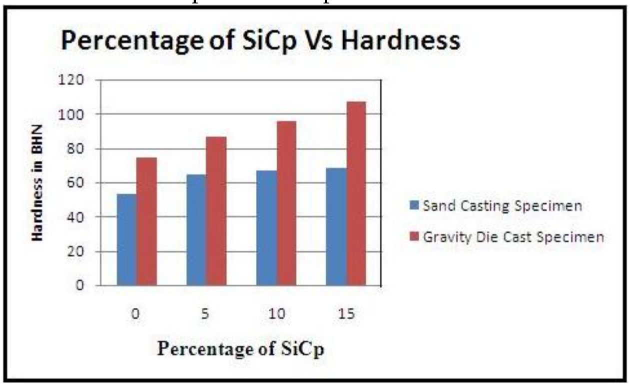


Figure 4: Hardness results by varying wt. % of SiCp.

C. *Analysis of cooling curves*

SiCp is reinforced in addition to alloying element to form AMMCs, generally influence the solidification duration and distribution of temperature in different sections of cast and in its solidification curve. These variations are also observed in the trend of the cooling curve. These effects are showing significantly in microstructure and thermo-mechanical properties of the material. Figure 5 to Figure 8 show the cooling curve of the AMMCs by reinforced SiCp with variation of 5wt%, 10wt% and 15 wt% for both the sand casting and gravity die casting. It is found that eutectic solidification of LM6 starts at temperature 572 °C and ending at 570 °C. Whereas after reinforcement of SiCp in LM6, the eutectic solidification temperature changes.

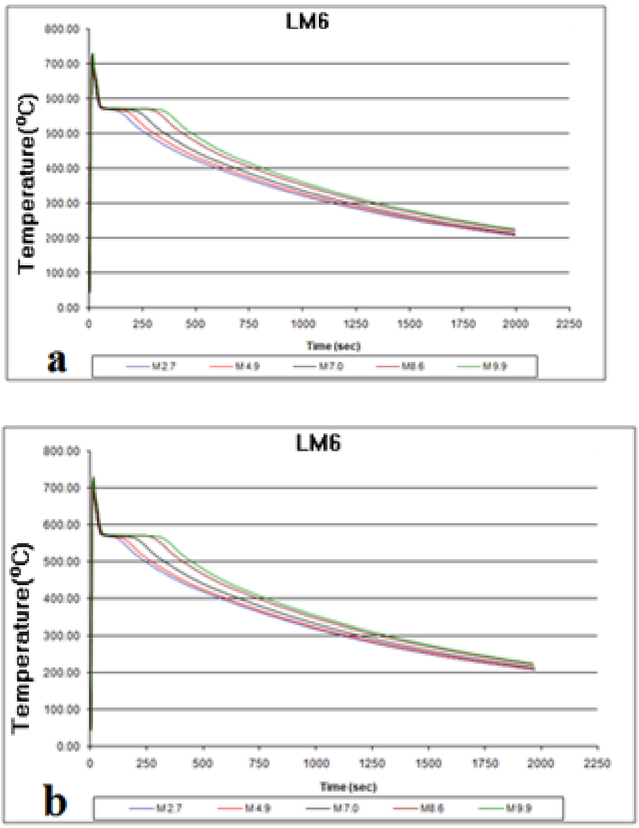


Figure 5: Cooling trends of LM6 at different section of casting (a) sand casting and (b) gravity die casting.

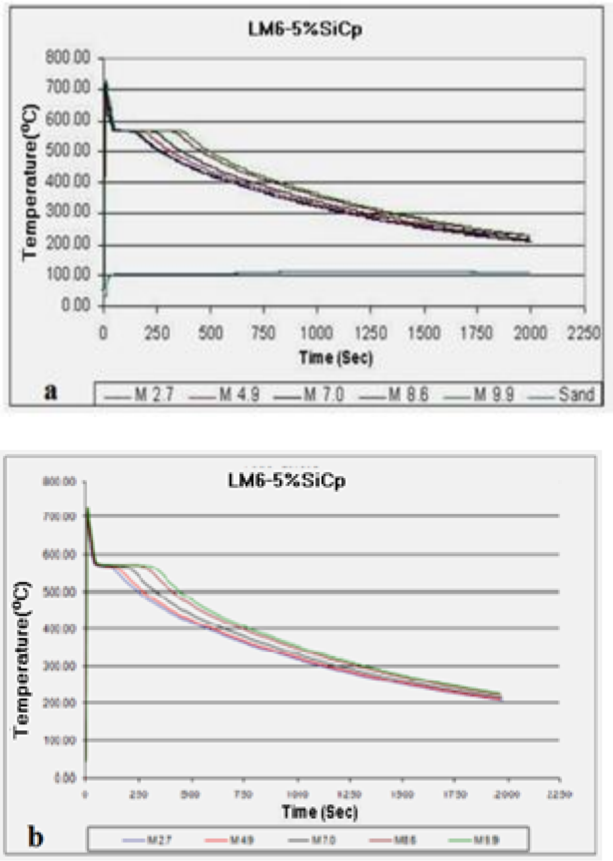


Figure 6: Cooling trends of AMMC with 5wt% SiCp at different section of casting (a) sand casting and (b) gravity die casting.

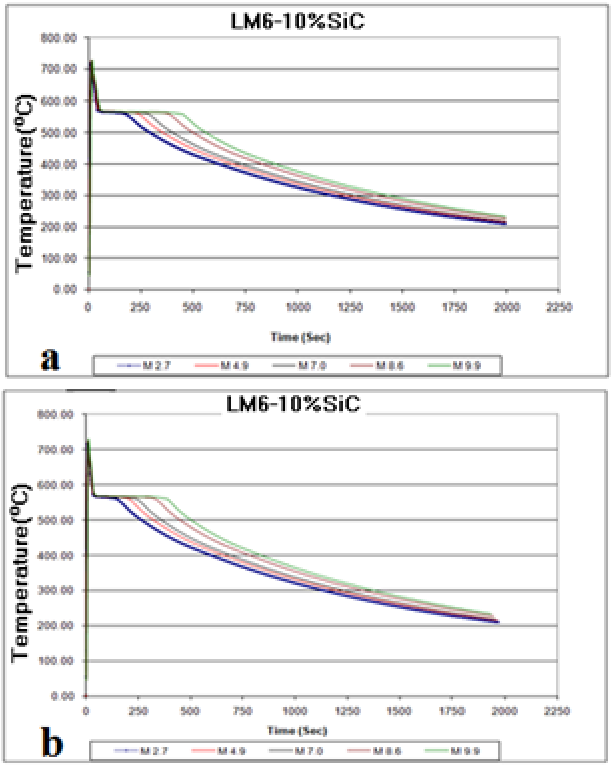


Figure 7: Cooling trends of AMMC with 10wt. % SiCp at different section of casting (a) sand casting and (b) gravity die casting.

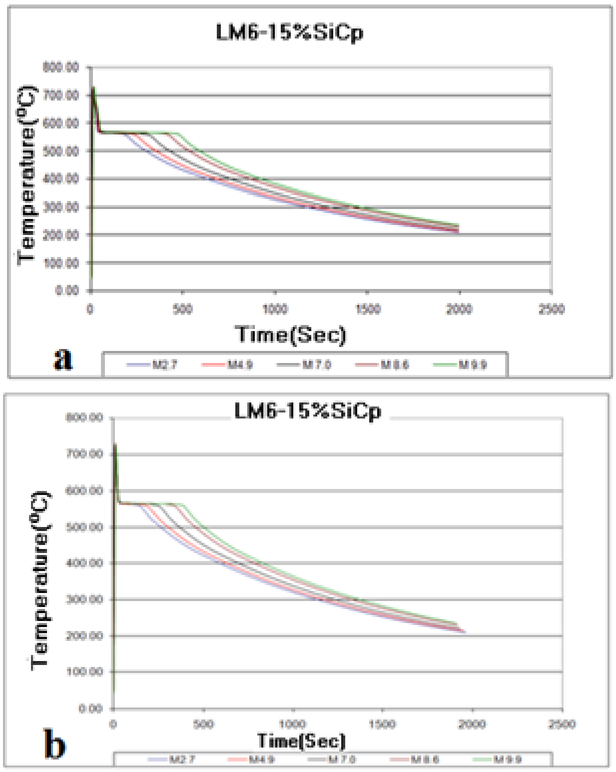
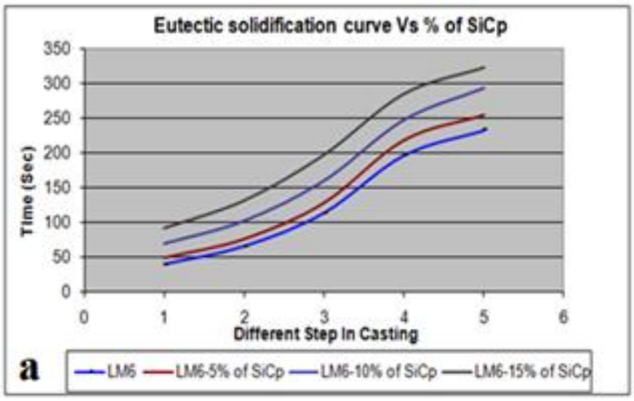


Figure 8: Cooling trends of AMMC with 15wt% SiCp at different section of casting (a) sand casting and (b) gravity die casting.

The comparisons of effect of wt% SiCp in eutectic solidification duration (start and end gap) at different sections of both sand and gravity die castings are shown in Figure 9. By reinforcing SiCp increases solidifying period. These effects are more significant in conductivity molds. In case of LM6 alloy solidifying in metal mold, the total duration to solidify decreases with adding of SiCp as compared to sand mold casting. It is found that by increasing the wt. % of SiCp in AMMCs the eutectic solidifying duration increases at sections of the castings.



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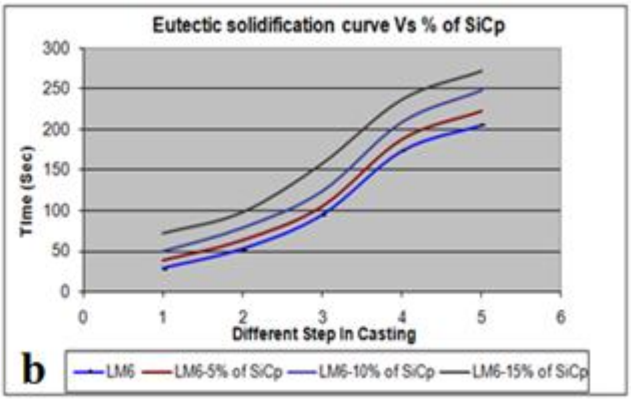


Figure 9: Effect of wt. % SiCp in eutectic solidification time at different section of casting (a) sand casting and (b) gravity die casting.

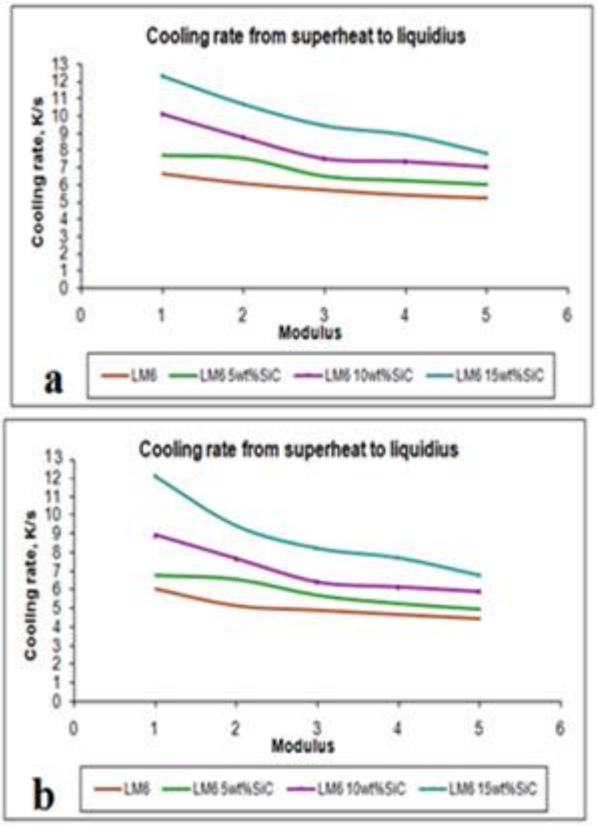
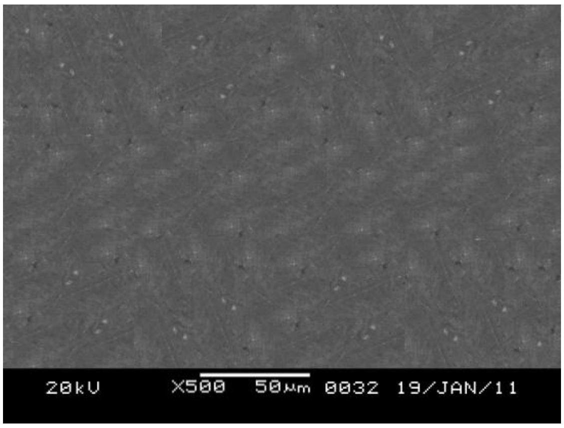


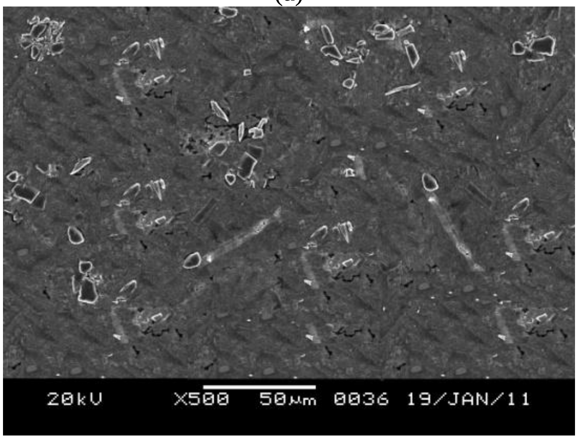
Figure 10: Cooling rates from superheat to liquidus (a) sand casting & (b) gravity die casting.

D. *Analysis of microstructure*

The microstructures of both sand cast and the gravity die cast specimens are compared (shown in Figure 11 and Figure 12). These plots show that gravity die casting samples are enhanced in quality of microstructure as compared to sand casting samples. As the cooling rate is faster and dendrite arms are broken down in gravity die casting, so fine-grain equiaxed microstructure is obtained. It imparts that the gravity die casting is free from porosity and other flaws as compared to sand casting. The dendrite structure formed in die casting owing to the consequence of super-cooling in certain areas protrude as spikes into the super-cooled regions. Once it begins, it grows fast than adjacent areas. The percentage of primary α-Al phase in sand cast AMMCs is more as compared to gravity die cast. Inversely, as the rate of heat transfer is higher in gravity die casting, so the solubility of Si in α-Al primary phase is increased. It is also addressed the increasing in heat transfer rate followed by shifting the equilibrium curves during phase transformation. This is optimistically resulted in strengthening of primary α-Al dendrites in gravity die cast alloys. High cooling reveals supersaturated structure. The structures are produced more fine intermetallic by natural aging process. Since gravity die cast samples exhibited higher amount of solid solubility of Si than that of sand cast alloy, finer and higher amount of intermetallic can be expected to precipitate in gravity die cast matrix. Al+Si type precipitate phase can be normally formed in the Al matrix.



(a)



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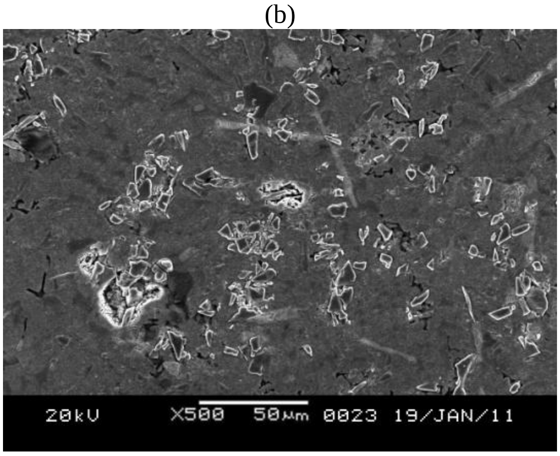

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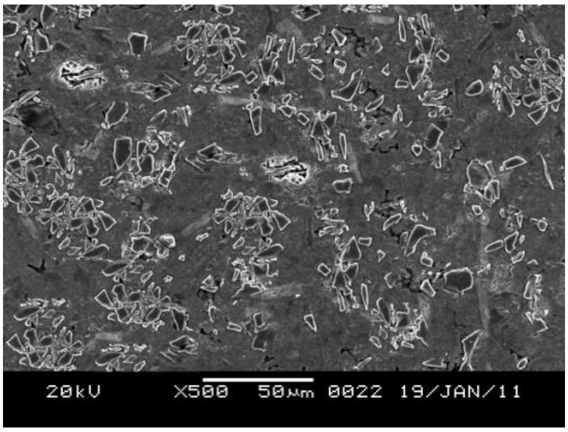
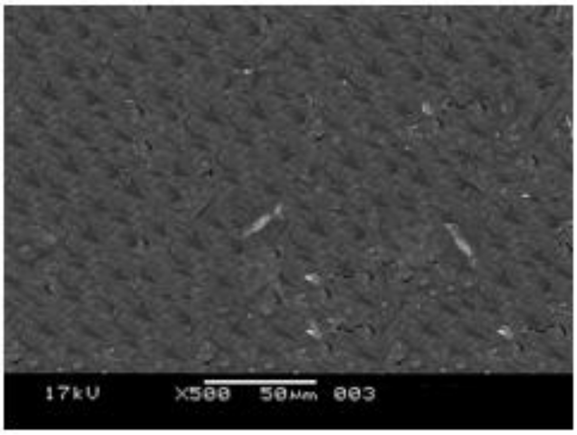
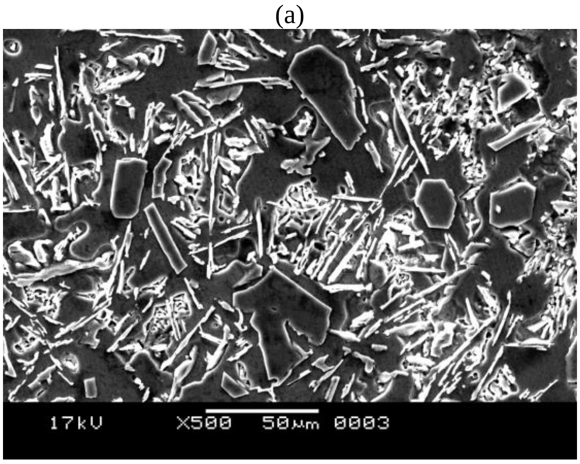


(d)

Fig. 11: Microstructural views of sand cast AMMCs at different wt. % SiCp: (a) LM6, (b) 5%wt% of SiCp, (c) 10%wt% of SiCp, (d)15%wt% of SiCp.



(a)



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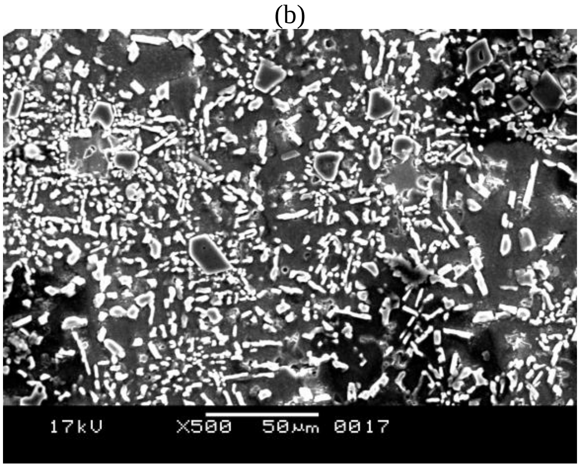

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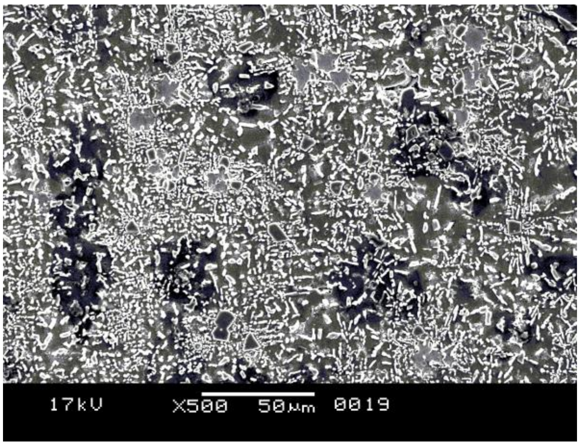

(d)

Figure 12: Microstructural views of AMMC in gravity die cast at different wt. % SiCp. (a)LM6, (b) 5 wt. % SiCp.(c) 10 wt. % SiCp (d)15wt.% SiCp.

IV. CONCLUSIONS

Solidification curves are plotted by performing experimentations in cast samples of LM6 and cast AMMC. The reinforced SiCp is altered by considering wt. % of SiCp with the range 5 wt. % to 15 wt. % and fixed step size 5 %. The concluding lines are stated as:

- By adding wt. % SiCp, the cooling rate increased. The thermal conductivity of metal mold is more compared to sand mold; molten slurry poured into metal mold is greater cooling rate.
- Further, SiCp reinforced into the aluminium alloy LM6 formed AMMC that enhances the eutectic solidifying duration because the dispersions are ceramic SiCp and thermal insulator in nature which have dominated heat conductivity and thermal diffusivity.
- The solidification time varied at different sections of cast. For LM6 alloy solidifying in the metal mold, the total solidifying duration decreased with increased wt. % SiCp compared to sand mold cast.
- Again, by increasing wt. % of SiCp in casted AMMC, the porosity increased. It is also understood that the sand cast specimens are having the more porosity as compared to gravity die cast specimens.
- Hardness increased by increasing the weight fraction of SiCp in AMMCs specimens. The specimens produced in Gravity die cast are showing greater hardness.
- Microstructures of cast AMMCs contain primary (a dendritic structure of primary (Al-rich) dendrites, eutectoid) phase and eutectic regions. SiCp are fenced with eutectic regions.
- The microstructure outcomes explain that the distribution of SiCp is not uniform in case of sand casting. However, the gravity die casting samples are enriched microstructure.

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