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Fabrication and Characterisation of aluminium based SiC and Al_2O_3 reinforced composites by stir casting

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Abstract

Particulate reinforced metal matrix composites (MMCs) are potential materials for a variety of applications due to their beneficial of physical and mechanical properties. The objective of this experimental investigation is to manufacture mono metal matrix composites (MMMC) and hybrid metal matrix composites (HMMC) using aluminium A356 as matrix alloy and SiC and Al_2O_3 is used as reinforcement particle with changing the wt. % of the reinforcement particle. Composites are fabricated by stir casting method. The results shows that the composite materials revealed better mechanical and physical properties, like hardness, high ultimate tensile strength, wear properties, high impact strength. It has been found that with increase in the wt. % of the reinforce particle wear resistance, hardness and tensile strength of hybrid MMC improved than the unreinforced A356 and mono MMC.

Keywords*-Aluminium, silicon carbide, Metal matrix composites, Hybrid MMC, Reinforcement, Stir casting*

I. INTRODUCTION

People, materials, and engineering have developed over the passage of time and are enduring to do so. The improvement of society has historically depended on the advancement of materials to work with. The development of composite materials is one of the main innovations in the field of technology and material science [1]. The major classifications of engineering materials are polymers, metals, composites and ceramics [2]. Composites based on metals and alloys are known as Metal Matrix Composites that is a result from combination of two or more materials, one of which is a metal and other is a non metal [3]. MMC have become one of most important material which is used in aerospace, automotive, defence and many engineering applications [4]. It is most commonly used because of its certain properties like high strength, stiffness and low density. MMCs have been used commercially in aluminum crank cases with strengthened cylinder surfaces and fiber reinforced pistons and as well as particle-strengthened brake disks [5]. In this paper aluminium based metal matrix composites with alumina (Al2O3) silicon carbide (SiC) as reinforcement material were considered to find their mechanical and physical properties.

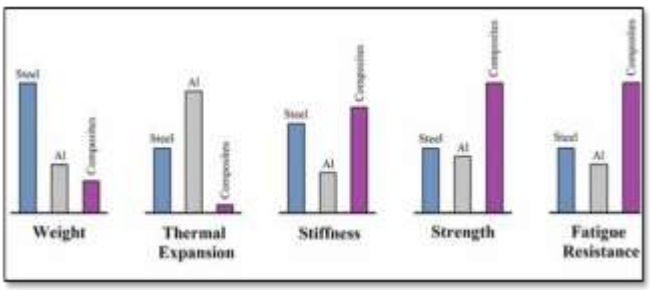


Fig. 1 Comparison between conventional monolithic and composite materials [1]

II. EXPERIMENTAL METHOD AND PROCEDURE

2. 1Materials:

For this study Aluminium-Silicon-Magnesium alloy A356 (LM25) was selected as the matrix alloy. The Al-7%Si-0.3Mg alloy is widely used for the casting of high strength components in automotive, aerospace and military applications [2]. It was selected because of its thermophysical properties like tensile strength 234 MPa, Thermal conductivity 151 W/mK, density 2.67 g/cm^3, and coefficient of thermal expansion 21.5 X10^{-6}/ ºC) [4]. Alumina (Al_2O_3) and Silicon carbide (SiC) were used as reinforcement material to manufacture mono composites and hybrid composites. Three different weight percent 4 , 8 and 12 of SiC and Al_2O_3 were used individually for mono composites and 2, 4, and 6 of both for hybrid composites were used in this experiment.

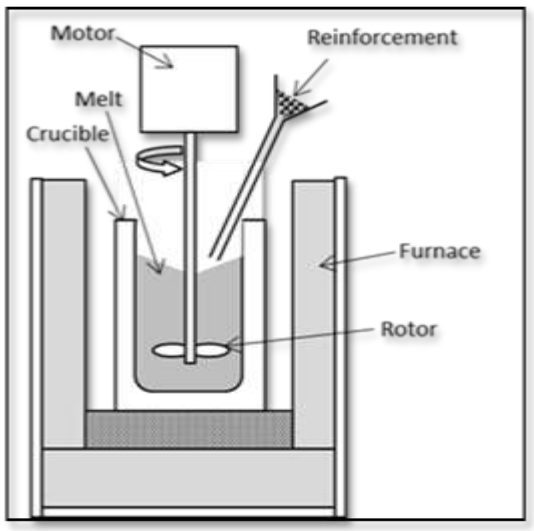
Table 1. Thermophysical properties of SiC and Al_2O_3 particles [6-7]

Property	Reinforcements		Matrix alloy
	$SiC_{(p)}$	$Al_2O_{3(p)}$	A356
Melting point (ºC)	2700	2072	557-613
Density (g/cc)	3.2	3.95	2.67
Thermal conductivity (W/m ºC)	120	35	151
Coefficient of thermal expansion (10^{-6}/ ºC)	4.0	8.4	21.5
Specific heat capacity (J/Kg ºC)	750	880	963

2.2 Method:

The composite samples were fabricated by liquid metal stir casting process [8]. During stirring, mechanical four-blade chromium oxide plasma spray coated stainless steel stirrer

was introduced into the melt and stirring was started. The plasma spray coating of chromium oxide to the S. S rod and blades of the stirrer is necessary to avoid the immigration of ferrous ions from the stirrer into the molten metal. Optimum speed of stirring was maintained at 400 rpm. When vortex is forms in the melt region during stirring, reinforcement particles were added manually in the melt. The magnitude of the reinforcement particles injected into melt was chosen as 4, 8 and 12 wt. % of silicon carbide, alumina and equal weight percentage content of both. Before the addition of reinforcement particles into the melt they were preheated at 800 to 900ºC for one to three hours in electric heated muffle furnace to removes the moisture, adsorbed gases, and impurities from the surface to make their surfaces oxidized. Magnesium was used as a wetting agent. The addition of 1 wt. % magnesium to the melt promotes wetting [9]. There was a supply of cover flux and hexachloroethane (C_2Cl_6) tablet or in the form of powder into the liquid metal in crucible to minimize the oxidation of molten aluminium alloy and remove hydrogen gases by chemical reaction with metal. Table shows the composition of fabricated samples in different experiments.



(a)

(b)

Fig. 2 (a) Schematic view of stir casting process [8] (b) SS four blade stirrer coated with CrO2 plasma spray

Table 2: composition of the fabricated samples in different experiments

Sample No.	Sample Name A356 +	Composition (wt %)		
		A356 (gm)	SiC (gm)	Al_2O_3 (gm)
1	Base alloy	840.14	0	0
2	Base alloy with simple stirring	910.12	0	0
3	4 wt. % SiC	868.23	34.72	0
4	8 wt. % SiC	850.45	68.04	0
5	12 wt. % SiC	882.77	105.93	0
6	4 wt. % Al_2O_3	811.97	0	32.47
7	8 wt. % Al_2O_3	825.87	0	66.07
8	12 wt. % Al_2O_3	805.44	0	96.65
9	2 wt. % SiC + 2 wt. % Al_2O_3	850.45	17.01	17.01
10	4 wt. % SiC + 4 wt. % Al_2O_3	877.44	35.09	35.09
11	6 wt. % SiC + 6 wt. % Al_2O_3	832.56	49.95	49.95

III. RESULTS AND DISCUSSIONS

3.1 Mechanical Behavior:

3.1.1 Hardness Testing: Since hardness is an indication of a materials resistance to plastic deformation. Hardness tests for A356 alloy and its composites were carried to study the effect of wt. % variation of reinforcement particles on A356 alloy and its composites.

(*a*) *Brinell hardness test:* Brinell hardness number is calculated using the equation

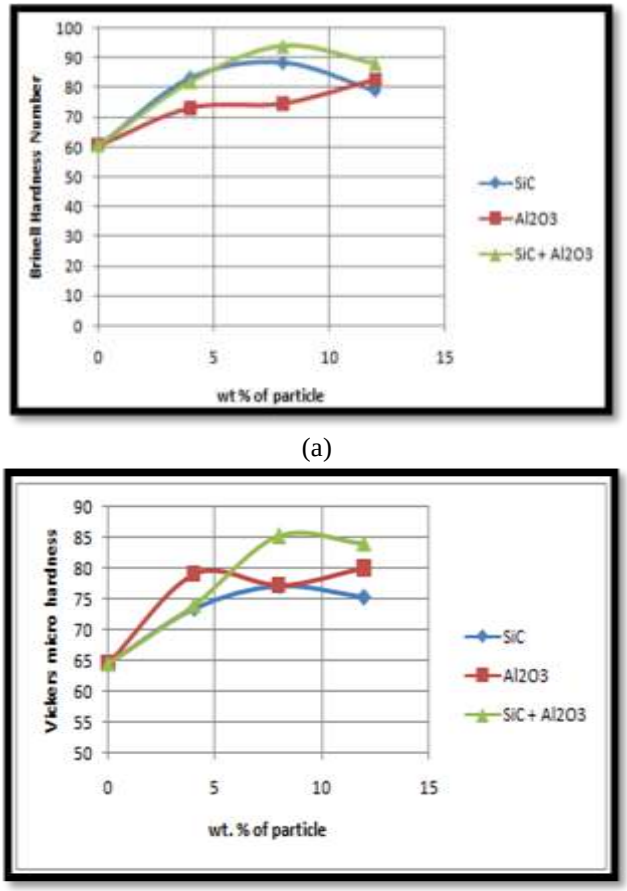
$$BHN = \frac{2P}{\pi D(D-(D^2-d^2)^{1/2})} \quad \text{.....(1)}$$

Where
P = Applied load (Kgf)
D = Diameter of the indenter ball (mm)
d = Diameter of the impression

Fig. 3 Samples of Brinell hardness

The diameter of the indenter ball is 2.5 mm and load is 187.5 Kgf for seven seconds was applied. For each specimen at least three separate measurements taken at random places on the surface of the specimens to take the average reading. The results of Brinell hardness test for unreinforced A356 alloy and its composites with wt. %

variation of SiC, Al2O3 and (SiC + Al2O3) reinforcement particles in Al matrix are shown in graph.



(a)

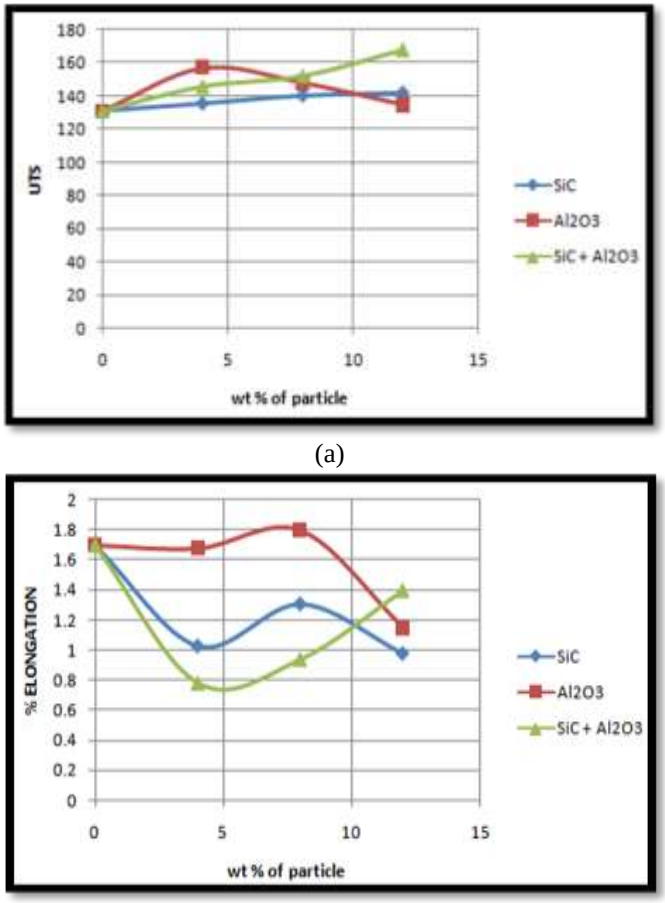
(b)

Fig. 4 Comparison of (a) Brinell hardness and (b) Vickers micro hardness test of A356 alloy and its composites with wt. % variation of SiC, Al2O3 and SiC + Al2O3 particles

(b) Vickers Micro hardness test: Micro hardness testing is a method for measuring the hardness of a material on a microscopic scale. A precision diamond indenter is impressed on the each sample at load 200 gm for dwell time 20 sec. the impression length, measured microscopically at 100x optical zoom, and the applied load are used to calculate a hardness value.

Brinell hardness test and Vickers Micro hardness test were carried on variation of wt. % of SiC, Al2O3 and (SiC + Al2O3) reinforced mono and hybrid composites and effect was observed that there is no large variation in the trend of micro hardness and Brinell hardness as a results of reinforcement addition. It can be seen from that the hardness of the hybrid reinforced composites is higher than that of the unreinforced alloy A356 and mono composites [10]. The hardness of the composites is increased with increasing the wt. % of the reinforcement particles. The cause of higher hardness of the composites might be that SiC, Al2O3, SiC + Al2O3 particles in the soft matrix act as obstacles to the motion of dislocation [11]. The hardness increment can also be caused due to the reduced grain size of the matrix phase. However in case of 8 wt. % and 12 wt. % hybrid composites shows the highest hardness value. The reason being hybrid composite is producing very fine sized dendrites, low porosity and uniform distribution of reinforcing phases [12].

3.1.2 Tensile Testing: Tensile test were used to assess the mechanical behavior of the matrix alloy and its composites. A universal testing machine is used for tensile testing.



(a)

(b)

Fig. 5 Variation of (a) Ultimate tensile strength & (b) elongation of A356 alloy and its composites with wt % variation of reinforcement particle

Figure 5 (a) shows the variation of ultimate tensile strength of A356 alloy and its composites with wt. % variation of reinforcement particles. In general, the ultimate tensile strength increases with increase in the reinforcement content. Higher values of UTS were observed at 8 wt% & 12 wt % in case of hybrid composites. Improvement is noted when A356 is reinforced with 10 wt. % and 15 wt. % of (SiC + Al2O3). In certain cases increase in reinforcement particles SiC, Al2O3 content leads to the reduction in strength values. At 12 wt. % of Al2O3 low value of tensile strength noted. This might be the result of more agglomeration of particles and higher degree of defects and micro-porosity present in the composite at higher reinforcement particles content increasing dislocations and other defects around SiC and Al2O3 particles due to the

difference in thermal expansion coefficients of A356 and reinforcement particles, might result in debonding of the interface and decrease in UTS in the composites with more SiC and Al2O3 weight percent [13].

Fig 6: tensile specimens

Figure 5 (b) shows the variation of elongation of A356 alloy and its composite with different wt. % of reinforcement particles. It can be seen that the elongation decreases with addition the 4 wt. % of reinforcement particle in both mono and hybrid composites. This may be the result of greater agglomeration of particles, brittleness and higher degree of micro-porosity present in the composite with higher SiC, Al_2O_3 and (Al_2O_3 + SiC) content [14]. Besides, the increased wt. % of particles would decrease the effective slip distance of dislocations during the tensile deformation, which would lead to the decrease of the elongation. Further addition of 8 and 12 wt. % SiC and (Al_2O_3 + SiC) particles increase in ductility is observed. But in case of Al_2O_3 % elongation decreased at 12 wt. %. may be the result of greater agglomeration of particles [10].

3.2 Physical Behavior:

The porosity content of alloy and its composites generally affecting the mechanical properties of MMC like hardness, tensile strength, yield strength and ductility. Development of porosity and reinforcement particles reduced the plastic deformation of matrix at which point failure initiated. Figure 6 shows the % porosity with % wt of reinforcement particles. Increased in porosity was observed with increase in reinforcement particle in mono composites. porosity level increased, since the interfacial area of particles was increased. The causes of porosity formation are air bubbles entering the melt matrix material, water vapour on the particles surfaces, gas entrapment during stirring process, evolution of hydrogen, and shrinkage during solidification [15]. In case of hybrid composites (SiC + Al2O3) decrease in porosity was observed at 8 % and 12 wt. % of reinforcement particle. The porosity content of the cast composites with wt. % variation of reinforcement particles were measured in the range 1.54% to 9.83%. This porosity content are quite high can be due to the composite slurries were not degassed effectively and the casting process was carried out in the open atmosphere [15].

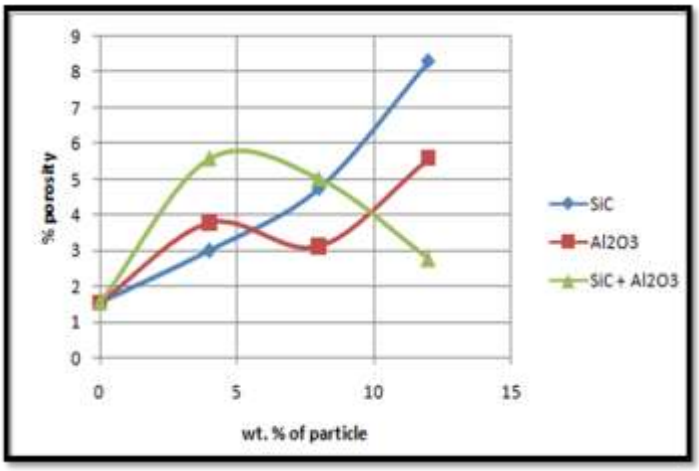


Fig. 7 Comparison the porosity content of alloy and its composites with wt. % variation of SiC, Al2O3 and (SiC+Al2O3) particles

3.3 Microscopic Behavior:

Microstructure was visualized with the help of optical microscope. The specimens were visualized on different magnifications (200X and 400X) to show the presence of reinforcement and its distribution on the metal matrix.

(I) Optical Microstructure of unreinforced A356 alloy :

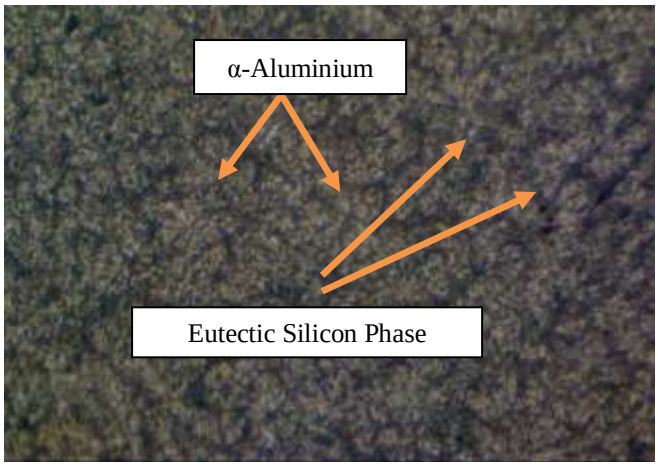


Fig. 8 Optical microstructure of unreinforced A356 alloy at (a) 200X

Because A356 aluminum alloy belongs to the hypoeutectic alloy, A356 aluminum alloy begins with growth of α-Al primary solid phases and Al-Si eutectic in between the dendrite arms during solidification process [10-11]. The microstructures indicated the uniform distribution of eutectic Si particles due to stirring of Si needles gets fragmented. It can be seen that the microstructure of cast A356 alloy shows the dendritic morphology of α-Al and eutectic Al-Si phase in between the dendritic arms. The white phase as shown in the microstructure is the α-Al, it is the matrix phase. The dark phase which is equally distributed in the microstructure is the eutectic silicon phase.

(II) Optical Microstructure of unreinforced A356 alloy with Silicon Carbide particles :

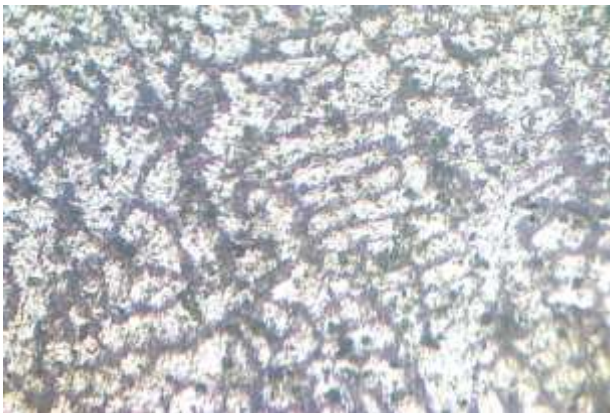


Fig. 9 Optical microstructures of unreinforced A356 alloy with 4 wt. % Silicon Carbide particles at 200X

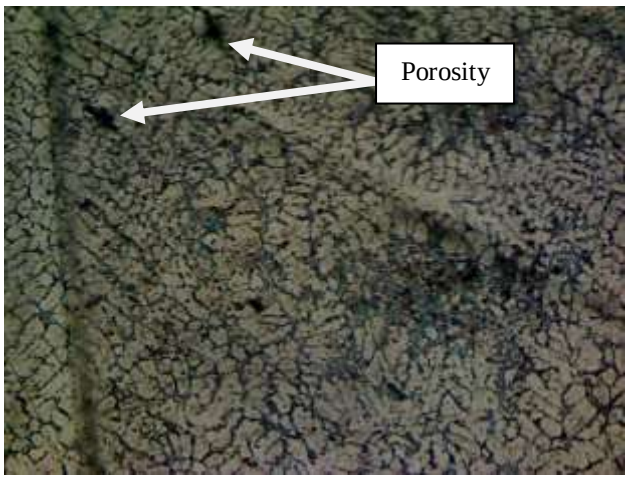


Fig. 10 Optical microstructures of unreinforced A356 alloy with 8 wt. % Silicon Carbide particles at 200X

Fig. 11 Optical microstructures of unreinforced A356 alloy with 12 wt. % Silicon Carbide particles at 200X

The main phase are primary α-Al dendrites, eutectic structure and SiC particles. Uniform distribution of reinforcement particles was observed which showed strong tendency to accumulation of SiC particles in the grain boundary which froze in the last stage of SiC increased [12]. At 8 wt. % of particles some clustering were observed. These can be due to large dendrite arm spacing (DAS) of matrix. In 8 wt. % SiC the porosities are the main defects observed since the porosities can be due to the composites slurry was not degassed effectively.

(III) Optical Microstructure of unreinforced A356 alloy with Al_2O_3 particles :

Fig. 12 Optical microstructures of unreinforced A356 alloy with 4 wt. % Al_2O_3 particles at 200X

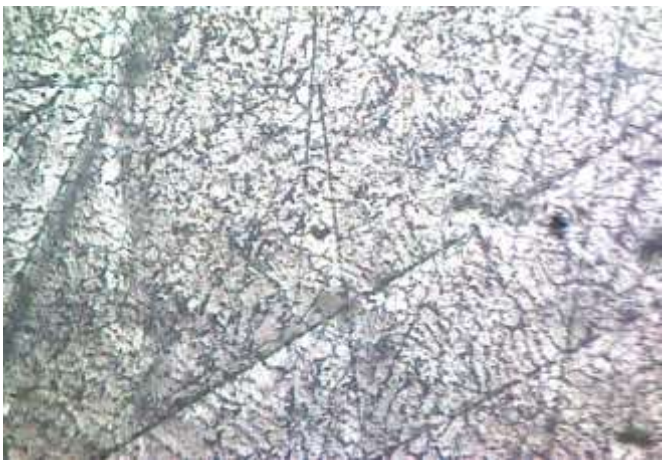


Fig. 13 Optical microstructures of unreinforced A356 alloy with 8 wt. % Al_2O_3 particles at 200X

Fig. 14 Optical microstructure of unreinforced A356 alloy with 12 wt. % Al_2O_3 particles at 200X

at lower magnification (200x) fair distribution of Al2O3 particles were observed. At 4 wt. % some segregation of

particles were observed. Segregation of particles may also occur during the solidification of the composites, when Al dendrites solidify first, thus rejecting the particles by the solid liquid interface, causing segregation of inter-dendritic region [16]. Shape of dendrites is different than shape of dendrites in SiC. Size of the dendrites is continuously decreased with increase in alumina particle.

(IV) Optical Microstructure of unreinforced A356 alloy with (SiC + Al_2O_3) particles:

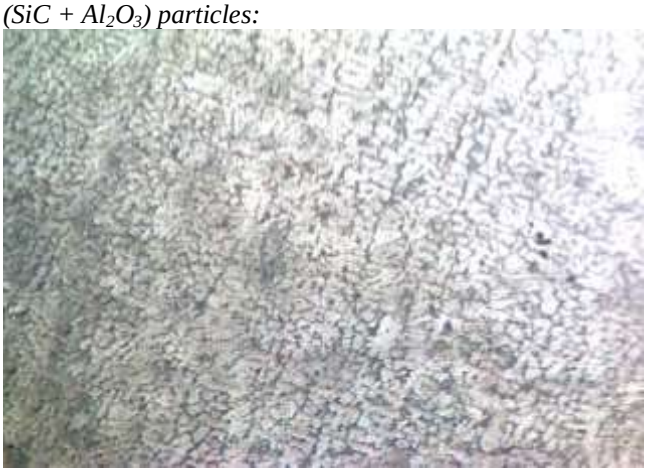


Fig. 15 Optical microstructure of unreinforced A356 alloy with 4 wt. % (SiC + Al_2O_3) particles at 200X

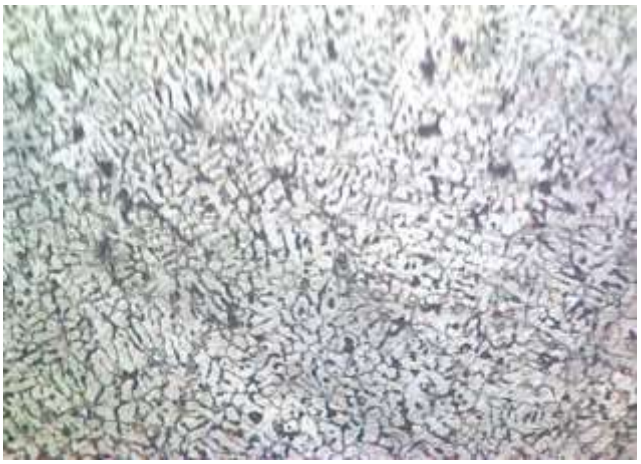


Fig. 16 Optical microstructure of unreinforced A356 alloy with 8 wt. % (SiC + Al_2O_3) particles at 200X

Fig. 17 Optical microstructure of unreinforced A356 alloy with 12 wt. % (SiC + Al_2O_3) particles at 200X

Uniform distribution of reinforcement particles were observed in case of hybrid composites. The figure revealed the homogeneity of the cast composites. The optical microstructure also showed increased filler contents in the composites. In this case hybrid composites do not act as nuclei for Aluminium and both the particulates tends to segregate in the eutectic region of the matrix. The microstructure showed both coarse and fine (SiC + Al2O3) particles in the matrix.

IV. CONCLUSIONS

1. Hybrid composites showed better tensile properties as compared to mono composites and unreinforcement alloy. Tensile strength of hybrid composites is 20.10% more than unreinforcement A356.

2. Hybrid composites have higher value of hardness than A356 alloy and mono composites.

3. More uniform distribution was observed in case of hybrid composites.

4. Porosity content of hybrid composites is quite low compared to A356. Porosity content of A356 + (6 % SiC + 6 % Al_2O_3) and 10 wt. % Al2O3 showed less porosity content than the porosity content of A356 and SiC mono composites.

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