Microstructural Analysis of Aluminum MMCs fabricated by Stir Casting

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Abstract - Present industrial revolution is focusing on performance of the composite materials with better performance even at an elevated temperature. The materials are used in many applications like automobile sector, marine, sports, aerospace and medical applications. In order to enhance the performance, the materials will be subjected to various heat treatment processes. Irrespective of the materials, the heat treatment relay on changing the microstructure of the materials which leads to changes in the wear resistance and mechanical properties. Micro Structural analysis has been carried out and following results are observed that the particles are having irregular grain structure with sharp corners. SEM images also indicate that the presence of SiC is being increased; Formation of SiC clusters at some locations is also being identified in few of the SEM images. X- Ray Diffraction analysis of Composite material with 6% SiC powders indicate the peaks related to aluminium and carbon which are present in the processed composite. High and narrow peaks are obtained for the carbon materials and the composite containing 6% SiC has higher peaks compared to others. Similar peaks are also seen in other compositions.

***Key Words*:** Microstructure; SEM; XRD

1. INTRODUCTION

Metal Matrix Composites (MMCs) have gained widespread attention in recent years due to their excellent mechanical and physical properties. They are fabricated by reinforcing a metal matrix with a second material, often a ceramic or a polymer, to improve the overall performance of the composite. Stir casting is a commonly used process for the fabrication of MMCs, using a stirring device the reinforcement agent is mixed with the liquid metal matrix using. In this process, the reinforcing material is evenly dispersed throughout the matrix, resulting in improved properties such as increased strength, stiffness, and wear resistance. Aluminium alloys have been commonly used as the matrix material in MMCs for the area of research production and application in industries. Composites of aluminium metal matrix are highly engineered materials with high modulus strength, improved hardness & tensile strength, high elevated temperature and higher resistance and consequently lower thermal expansion coefficient [1]. Moreover, when evaluated with other materials such as Ti or Mg, these materials are low cost. This material is well understood from the other point of observation in corrosion, ductility and strength and can be easily adjusted for the necessary application like automobile sector, aerospace and medical applications [2]. Y.U. Ishii et al [3] have used Al6061 with different propositions of SiC particles by high pressure infiltration process and the processed composites are subjected to wear study with varying parameters like speed and load conditions. Results obtained from the present study indicate that the presence of the reinforcement material has helped in reducing the wear rate even at increased load conditions. Davis Joseph et al [4] Studied on Reinforcement materials like Silicon carbide (SiC), Aluminium oxide (Al2O3) and Boron carbide (B4C) are normally used in particulate form in order to enhance the mechanical and thermal properties of Aluminium alloy matrix phase in the composite structure. SiC is one of the most widely used reinforcement materials in the aluminium based MMCs because it is very compatible with aluminium matrix. Singla et al [5] Studied on the Aluminium alloys which are relatively striking because of their light weight, their ability to have good mechanical property and better anti- corrosion property. They are typically reinforced by SiC, Al2O3, B4C, BN, graphite, SiO2 etc. Many of the transportation industries have been using discontinuously reinforced aluminium matrix composites for their structural components. They are extremely attractive due to their isotropic mechanical characteristics with lower price. Composites reinforced with particulates offer enhancements over the matrix alloys in all aspects and a greater resistance to wear and an enhancement in rupture stress. Ye Haizhi et al [6] Studied on Al-SiC alloys, these materials find wide-ranging applications in the mechanical and tribological components of internal combustion engines, including pistons, cylinder blocks, and cylinder heads. Because of their good cast ability, good formability, resistance against corrosion and light weight. However, the poor seizure resistance property of the materials restricts their use for the tribological application, addition of strengthening materials leads to enhancement in the tribological characteristics of the materials. T Jong et al [7] showed that Particulates of Silicon carbide are reinforced in the MMCs due to their enhanced specific properties which are of most important in the applications of automotive components. T.P.D. Rajan et al [8] Studies on Fabrication and characterization of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes where in two stage of particle distribution is being carried out. The temperature of the melt is being reduced slightly to have better bonding of matrix and reinforcement material followed by addition of reinforcement particles. This two stage processing as helped in reducing the agglomerates and led to the improvement of the composites with uniform distribution. Ravi Raj et al [9] Studied on certain other process optimizing techniques that are used in the stir casting process to obtain a sound casting. One of them is the pre- heating of the reinforcement particles before its being immersed into the liquid melt. Pre-heating helps to avoid the thermal mismatch and enhances then wettability of the particles. K Raj Kumar et al [10] Studies have shown that even with at most care there is a possibility to have a porous structure inside the cast composite which are normally termed as porosity. The porosity in cast materials is generated due to entrapment of the gases (Oxygen, Hydrogen and Nitrogen) that are trapped inside the metal which reduces the strength of the material in that vicinity. This study is primarily concerned with the microstructural analysis of Aluminium Metal Matrix

Composites (AMMCs) produced using the stir casting technique. The objective is to understand the effect of the process parameters on the microstructure of the composite and to identify the optimal processing conditions for maximum reinforcement dispersion and improvement in the composite's mechanical properties. The study will provide valuable insights into the fundamental aspects of AMMCs and will pave the way for the development of high-performance AMMCs with tailored properties.

The objectives of the present research work which are drawn from the literature study are discussed below:

1. Processing of composite materials by stir casting process with Al 6061 has base material, SiC particles of 30µm are reinforced with varying percentage of reinforcements of 2%, 4%, 6% & 8%.
2. Microstructural study of processed composite materials.

2. EXPERIMENTAL METHOD

The experimental procedures used in the present investigation for processing of composites and their characterization with respect to microstructure are discussed in detail.

2.1Selection of Matrix Material (Aluminium 6061)

It's the predominant material in the series which consist of SiC as an alloying element and Magnesium of higher percentage. This material is widely used due to its superior benefits ranging from its strength to thermal conductivity. The presence of SiC makes the material harder compared to other series of the materials. When the present grade material is reinforced with additional amount of SiC, the strength will be further enhanced but care should be taken such that the brittleness phenomenon is not being incorporated due to higher percentage of SiC. Table 2.1 shows the Physical properties of Al6061 used in the present work.

Table 2.1: Physical properties of Al 6061

Properties	Values
Young's Modulus (E) GPa	68.9
Density (g/cc)	2.70
Poisson's ratio	0.33
Tensile strength (MPa)	120-290
Melting temperature(°C)	6500C
Linear thermal expansion coefficient (α)	2.32*10-5K-1
Thermal conductivity(k) W/(m-k)	151-202

2.2 Selection of Reinforcement Silicon Carbide

In the present work SiC particle (30µm) is added as reinforcement material along with Al 6061 matrix material for a weight percentage of 2%, 4% 6% and 8%, processed by liquid stir processing technique which is normally termed as Stir casting process. Table 2.2 shows the physical parameters of the reinforcement material used in the present work.

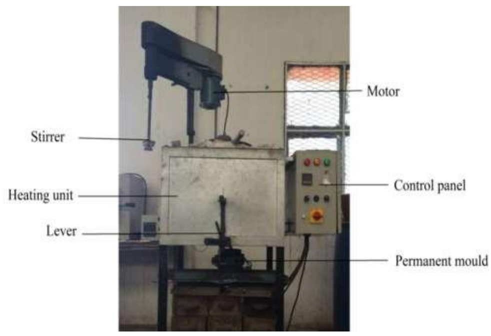
Table 2.2: Physical parameters of Silicon Carbide

Properties	Values
Density (g/cc)	3.1
Color	Black
Elastic modulus(MPa)	410
Poisson's ratio	0.14
Compressive strength(MPa)	3900
Maximum use temperature (°C)	1650
Linear thermal expansion coefficient(α)	4
Thermal conductivity(k) W/(m-k)	120

2.3Liquid Processing Technique

Stir casting process is selected to process the composite material. Furnace consists of graphite crucible (Fig 2.3 (a)) for melting the aluminum material, once the liquid state is obtained the SiC powders particles of 30 µm size will be added as the reinforcement for the Al 6061 matrix material. In order to obtain a better reinforcement stirrer is used; this facilitates the vortex formation and helps the reinforcement particle to get bonded with the matrix material. The impeller forces the particles towards the matrix material at greater force which helps the materials to get adhered to each other. A medium speed of 300-500rpm will be employed to carry out the process. Along with the speed the shape of the impeller also has a high impact, blades with curved shape has higher impact on the vortex formation. Round shaped mould (Fig 2.3 (b)) made of mild steel will be utilized to obtain the composite material with a dimension of 40 mm diameter and length 180 mm.

Ceramic-coated impeller (Fig 2.3 (c)) is been immersed up to 3/4 of molten metal from melt top and a speed of 500 rpm will be maintained to create the vortex in the molten metal. Curved shaped blade/impeller is used in the present investigation, the shape of the blade facilitate in forming the vortex in the molten metal which aids in better mixing of reinforcement particle with the matrix.



(a) Stir casting furnace

(b) Mould boxes with casting (c) Rotating impeller
Fig. 2.3(a)-(c) Stir casting process setup.

2.4 Percentage of compositions of the composites

Composites specimens were casted by adding reinforcements with 2, 4, 6 and 8% by weight. Figure 3.4 indicates the raw material in the form of blocks which is being used as the base material; the required weight composition of the base material is being weighed and selected with respect to the reinforcement percentage.

Fig 2.4 Aluminum 6061 blocks

2.5 Micro structural Analysis

Structural analysis has been carried out to know the behaviour of different percentage of silicon carbide in aluminium matrix by using SEM/TEM analysis. Samples with identical sizes are cut from various sections having flat surfaces. These samples will be grinded with emery papers of 300, 600, 800 and 1000 grit sizes followed by fine polishing with velvet cloth using polishing grade II alumina suspension by using a polishing machine and then etching done by adding few drops of 40% concentrated Hydro Fluoric (HF) acid. Figure 3.5 indicates the JSM F100 SEM equipment used for the microstructural analysis of the processed composite material and the specification of the equipment is listed.

Resolution (1 kV)	1.3 nm
Resolution (20 kV)	0.9 nm
Magnification	Photo magnification : X 10 to X 1,000,000 (128 mm X 96 mm) Display magnification : X 27 to X 2,740,000 (1,280 X 960 pixels)
Accelerating voltage	0.01 to 30 kV
Specimen size (Draw out)	Maximum diameter: 170 mm Maximum height: 45 mm (WD 5 mm)

Fig 2.5 SEM Machine and specifications

3. RESULTS AND DISCUSSION:

3.1Metallurgical test results

Structural analysis has been carried out to know the behaviour of different percentage of Silicon Carbide reinforcement in Aluminium matrix by using SEM/TEM analysis. The Scanning Electron Microscope (SEM) is a type of electron microscope that uses a high-energy beam of electrons to scan the sample surface in a raster pattern. The interaction between the electrons and the atoms in the sample produces signals that contain valuable information about the Surface Topography, Composition, and other characteristics.SEM can generate images of a sample surface with exceptional resolution, uncovering details as small as 1 to 5 nanometers. With its narrow electron beam, SEM micrographs have an extensive depth of field that creates a unique 3D appearance, ideal for comprehending the surface structure of a sample. SEM can offer magnifications ranging from about 10 to over 500,000 times, providing more than 250 times the magnification limit of light microscopes. Optical microscopes analysis can also be made to identify the dispersion reinforcing particles, and to check the formation of agglomeration. The analysis is performed on JSM F100 equipment operating at an accelerating voltage of 15 kV. The standard metallography procedure followed by cloth polishing using emery sheets and a polishing machine were carried out to prepare the specimens.

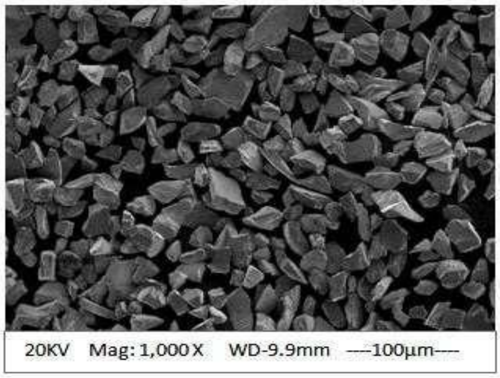


Fig 3.1 SEM image of SiC particulates

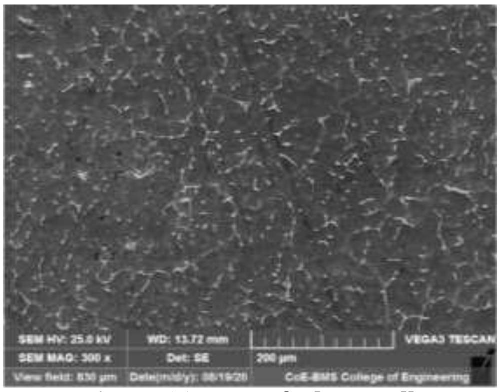


Fig. 3.2(a) SEM of Al6061 Alloy

Figure 3.1 indicates the SEM images of the SiC particles; it can be noted from the figure that the particles are having irregular grain structure with sharp corners. This sharp corners helps in getting the reinforcement particles embedded into the matrix material. The average particle size is found to be 30µm which can be evidenced from the above SEM analysis. SEM images of the composite materials reinforced with varying percentages of SiC are discussed below. For the micro structural studies, specimens were cut from cast bars and ground with grit paper of various size. The mounted samples were then mechanically polished with a 1µm alumina-powder and fine polishing to near mirror like finish was achieved using 0.5µm diamond paste and etched with Keller's reagent. Fig.3.2 (a) indicates the SEM image of Aluminium Al6061 alloy, Figure 3.2 (b)-(e) indicates the SEM images of the composite material reinforced with 2% and 4% SiC at 1500X magnification. It can be observed form the images that as the percentage of reinforcement are being increased, the reinforcement particles will be more which leads to higher load carrying capacity of the material when subjected to hardness test. It can be observed that the reinforcement particles are embedded within the matrix material and share a good bonding between them. It is also observed that Aluminium Silicon Carbide composite having cluster particles which is found to be more with with a rise in the proportion of reinforcement, and some places are identified without SiC inclusions.

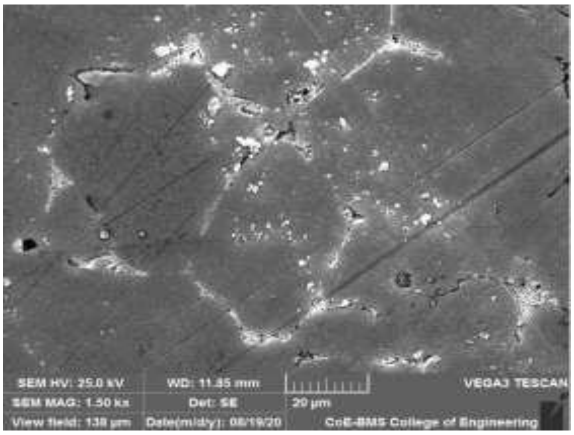


Fig 3.2 (b) Al6061 with 2% SiC Normal

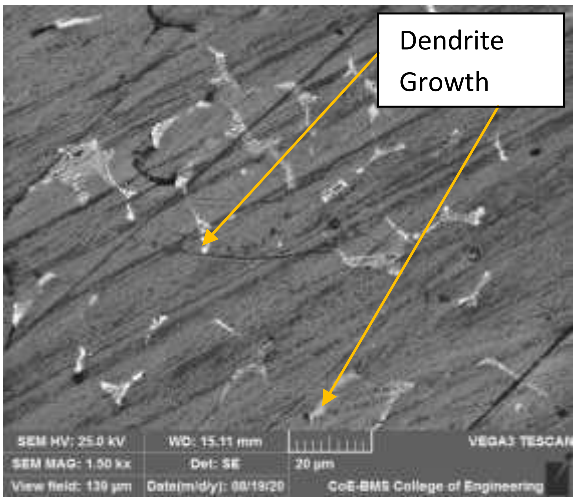


Fig 3.2 (c) Al6061 with 2% SiC Cryo Treated

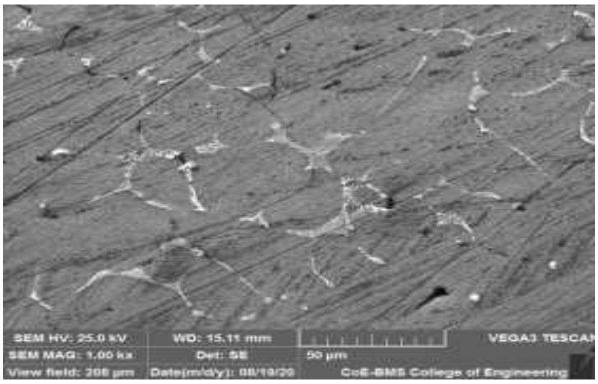


Fig 3.2 (d) Al6061 with 4% SiC Normal

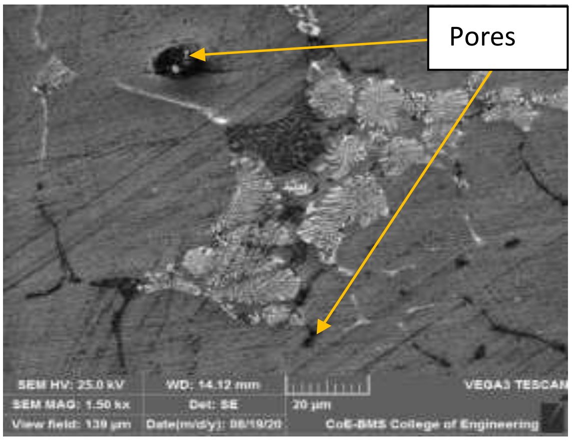


Fig 3.2 (e) Al6061 with 4% SiC Cryo Treated

Fig 4.2(b)-(e) SEM Images of Al 6061 Reinforced with SiC

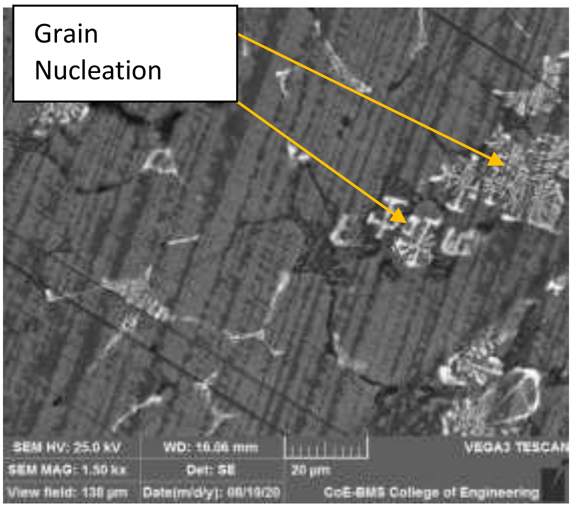


Fig. 3.3 (a) Al6061 with 6% SiC Normal

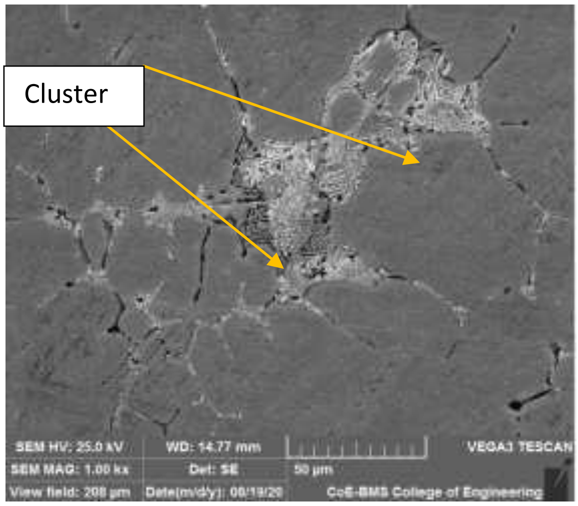


Fig.3.3 (b) Al6061 with 6% SiC Cryo Treated

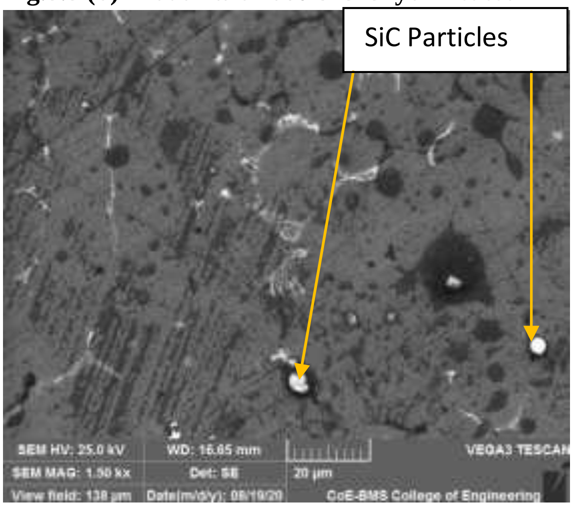


Fig. 3.3 (c) Al6061 with 8% SiC Normal

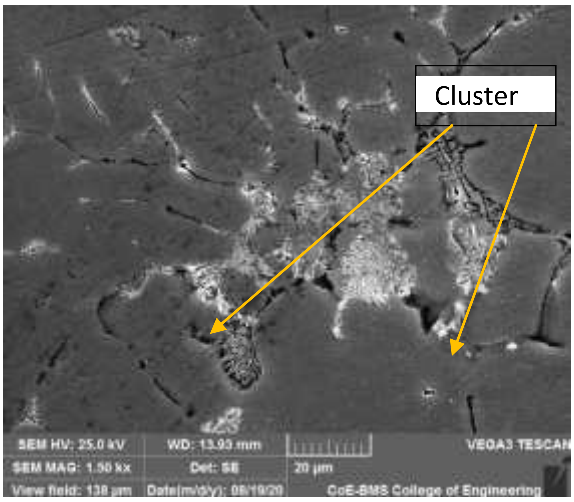


Fig. 3.3 (d) Al6061 with 8% SiC Cryo Treated
Fig. 4.3(a-d) SEM Images of Al 6061 Reinforced with SiC

It can be seen from the Figures 3.3 (c) & (d) that there is an increase the particles cluster corresponding to an increase in the percentage of SiC and the composite material with 8% SiC has an irregular grain structure. It can be observed in the images of 3.3 (a) & (b) that the particles have formed a clusters in the matrix material and there is uneven distribution in the matrix material which has led to decrease in the mechanical properties of the material, Whereas the composite material reinforced with 6% SiC better results compared to other percentages of reinforcements which has fetched good bonding with matrix material and enhances the mechanical properties of it. It was observed that the tendency for formation of particle cluster was greater in the higher percentage even after stirring the molten metal completely until the casting process is being carried out. During the stirring time, the geometry of the blades has helped in a clear vortex formation and has led to the uniform distribution whereas for the composite with 8% SiC, particles were found to be more and lead to formation of cluster which initiates the porosity with prolonged contact between matrix and reinforcement. Processing of composites comes along with the challenge of homogeneous distribution of the reinforcement phases into the matrix for a defect- free microstructure was possible for the material with 6% SiC, other percentages also showed similar distribution but with more amount of agglomerates. The segregation of reinforcing particles within the matrix during melting and casting is a significant concern. However, by implementing optimized process parameters, the microstructure of 6% reinforced SiC in an Al alloy matrix exhibited an evenly distributed activated carbon with no cracks or porosity present in the castings. Similar results are also obtained in the Cryo Treated composites, where in some amount of porous nature and clusters is visualized in some images. Some of the images of cryotreated also shows the grain growth which has helped in improving the properties.

3.4.XRD Analysis of SiC Powders

X-Ray Diffraction (XRD) analysis of Composite material with 6% SiC powders is shown in Figure 3.4(a), Fig 3.4(b) indicates the HKL Values, The graph analysis verified the presence of both activated carbon and aluminium peaks in all materials, with activated carbon peaks observed exclusively in the Al 6061 composites. Furthermore, no reaction peaks were observed, confirming the absence of any chemical reaction between activated carbon and aluminium. XRD peak intensity analysis revealed that as the amount of activated carbon in the materials increased, peak intensity increased, with the Al6061 composite with 6% activated carbon showing the highest gross intensity. XRD results for all four compositions indicated no formation of other compounds, thus indicating a homogeneous mixture. The largest peak corresponded to aluminium, while the second-largest peak was attributed to activated carbon. In the Al 6061 composite, a distinct activated carbon peak was evident, with an increase in the intensity of activated carbon peaks with increasing aluminum content in the composite.

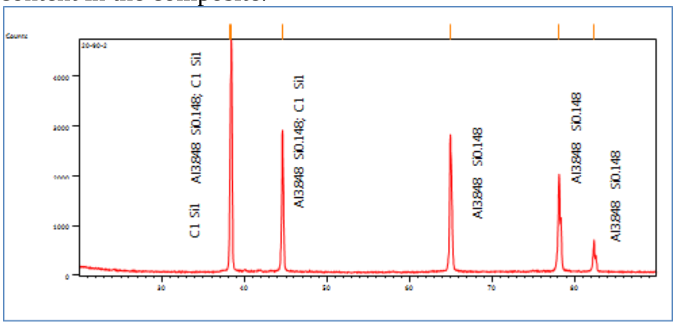


Fig 3.4(a) XRD Analysis of Al 6061 with 6% Silicon Carbide Powders

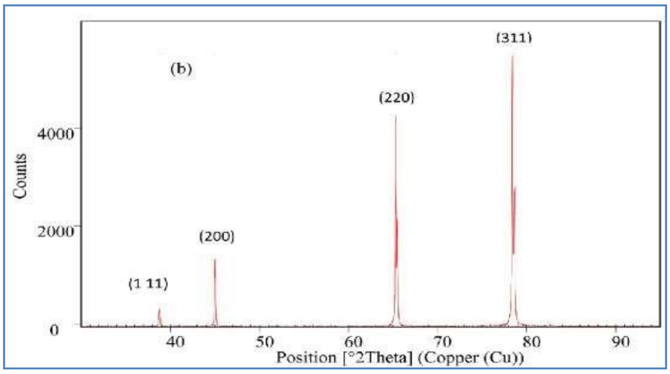


Fig 3.4(b) XRD Analysis of Al 6061 with 6% SiC Powders with HKL Values

3.5 EDAX Analysis of SiC Powders

Fig 3.5(a) EDAX of Silicon Carbide Powders

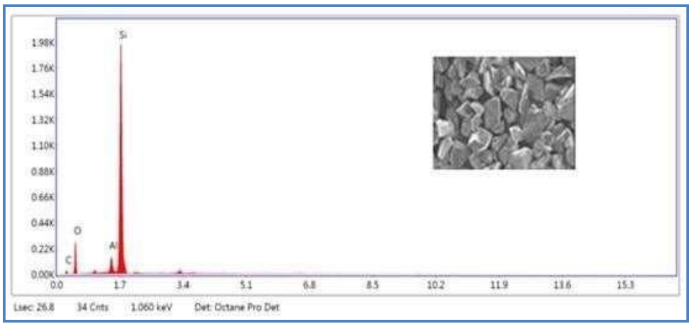


Table 3.5(a): Elemental Analysis of Si Powders

Element	Weight %
Si	80.12
O	9.34
Al	6.14
C	4.4
Total	**100.00**

Fig 3.5(a) indicates the EDAX analysis of SiC powders, The major element composition of the particles is Si (Silicon), C (Carbide), Al (Aluminium), and O (Oxide), as shown in Table 3.5(a). Indicates that the powders consists of higher amount of Silicon and few amount Carbide elements, other compositions includes Aluminium and few traces of oxides.

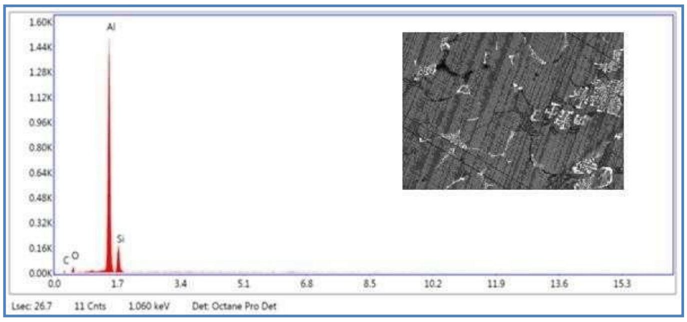


Fig 3.5(b): EDAX of Aluminium Silicon Carbide (6%) composite.

Table 3.5(b): Elemental Analysis of Composite (6% SiC)

Element	Weight %
Al	85.45
Si	10.03
O	2.54
C	1.98
Total	**100.00**

Figure 3.5(b) shows the EDAX of Composite with Al and SiC (6%), Table 4.5(b) shows the elemental composition of the material. Major element is found to be aluminium and Si which is being reinforced. Other elements are present in the material are at smaller ratio compared to the major elements. Similar result is also obtained for material reinforced with other percentages of SiC into Al 6061.

4. CONCLUSIONS

Structural analysis has been carried out to know the behaviour of different percentage of Silicon Carbide reinforcement in Aluminium matrix by using SEM/TEM analysis. From the SEM images of the SiC particles, it can be observed from the figure that the particles are having irregular grain structure with sharp corners. SEM images also indicate that as the presence of SiC is being increased, the SiC particles will be more which leads to higher load carrying capacity of the material when subjected to hardness test. Formation of SiC clusters at some locations is also being identified in few of the SEM images. These clusters increase with corresponding to a SiC addition. Composite material with 8% SiC has an irregular grain structure and the composite material reinforced with 6% SiC showed better results compared to other percentages of reinforcements which has fetched good bonding with matrix material and enhances the mechanical properties of it.

X- Ray Diffraction (XRD) analysis of Composite material with 6% SiC powders indicate the peaks related to aluminium and carbon which are present in the processed composite. High and narrow peaks are obtained for the carbon materials and the composite containing 6% SiC has higher peaks compared to others. Similar peaks are also seen in other compositions.

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