Research Article

A study on the Fatigue behavior of Heat Treated Aluminium Hybrid Metal Matrix Composites(Al6061-SiC-Gr)

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Abstract: Aluminum alloys are widely used as a choice for aerospace, automotive and structural applications due to their high strength to weight ratio and high wear resistance. This research work is aimed at investigating the impact of heat treatment and age hardenability on the fatigue behavior of Aluminum Hybrid Metal Matrix Composites(AHMMC). The composite was produced with Aluminum alloy 6061 as base material with varying reinforcement of x weight percentages (1wt% and 3wt%) of graphite and fixed value of 5wt% of Silicon Carbide. Fabrication of AHMMC was carried out using a vortex stir casting technique with a stirring speed of 400 rpm for 1 minute and a temperature of 700℃ to 800℃. Microstructure, X-ray diffraction, microhardness and fatigue strength studies were conducted for different percentages of reinforcement on the fabricated stir cast AHMMC specimen before and after the heat treatments. Fractography was also performed to study the fractured surfaces of the AHMMC. Microstructure and XRD study revealed that both SiC and Gr are uniformly distributed in the matrix alloy. The microhardness of Al-SiC was higher than that of hybrid composites and base alloys. Heat treatment increased the microhardness of base alloy and its hybrid composites while ice quenching treatment resulting in maximum value. The fatigue strength of heat-treated AHMMC was higher than that of Al-SiC composites and base alloys without heat treatment. Fractography results suggest that fatigue failures are reduced with the addition of SiC and Gr.

Keywords: Aluminium Hybrid metal matrix composite, Aluminium 6061, Heat Treatment, Microhardness, Fatigue behavior.

1. Introduction

Alloys and monolithic metals have restrictions in obtaining a high-quality combination of high-temperature performance, wear resistance, strength, corrosion resistance, and toughness. As a result, material analysts have redirected their concentration towards composite materials[1]. Different materials are blend together, called constituents, to form a material called 'composite,' which is expected to have desired properties. These constituents which form the composite are known as reinforcements and matrix[1]. The matrix is a smooth phase which has excellent thermal conductivity, ductility, and formability and in which the rigid reinforcements are bordered. The reinforcements may be steady or irregular, slanting, or mixed-up. Aluminum matrix composites (AMCs) have been preferred for advanced applications in automobiles, electronics and also in aerospace[2]–[4]. The various properties possessed by these composites, to be used in advanced applications, are high rigidity modulus, high fatigue resistance, high particulate strength, good wear resistance at high temperatures, and excellent corrosion resistance[2], [5], [6][7]. These composites can replace the long-established engineering alloys. Al6061 composites give an incredible combination of break tolerance and strength at soaring and cryogenic temperatures for applications like essential components related to structures and high-quality weldments[8]. Al6061 is utilized in light of its age hardenable nature, which is suited for high temperature and high quality. This alloy dissipates heat to a great extent because of its high heat-conducting property. The mechanical properties of Aluminium 6061 depend significantly upon heat treatments. Mixture composites strengthened with SiC and graphite (Gr) particles have pulled in impressive consideration because of their high wear resistance consolidated with a low contact coefficient. Including a specific measure of strong grease to the powder blend can diminish the thickness inclination and increment the thickness of green compacts by advancing more uniform weight transmission. AMC's mixed with graphite and SiC particles are thus a distinctive group of superior engineered materials that have been produced to make use in tribological applications[1][9], [10].

Gr is every now and again utilized as the strong material which is utilized for lubrication. However, it crumbles the mechanical properties of composites[11]–[17]. The nearness of hard SiC particles enhances the rigidity and the potential nature of Aluminium/SiC/Gr cross breed composites and adjusts for the debilitating impacts of Gr[11]–[17]. Because of the above details, the present work depicts the investigation of exhaustive conduct of the Al6061 combination and its crossbreed composites subjected to warmth treatment. From the literature review, it has been found that a large amount of research has been carried out on the study of mechanical properties and properties related to the tribology of Al6061-SiC-Gr hybrid composites[11]–[17]. However, less work is carried out on the fatigue behavior of these composites subjected to heat treatment.

In light of this fact, the present paper describes the fabrication of Al6061 based hybrid matrix composites by stir casting technique. Also, since the presence of hard particulate reinforcement in composite leads to poor surface finish and higher tool wear, therefore, the composites were prepared with both hard reinforcement (SiC) and soft reinforcement (Gr) [17]. Microstructure, XRD, Microhardness, and Fatigue test with respect to heat treatment along with fractography have been carried out in the present project work. Fig.1.1 gives an idea about the procedure followed in carrying out the project.

2. Materials And Methods

A. Materials

1) Matrix material

a) Aluminium 6061

Aluminium 6061 alloy is chosen as the base matrix as it is the most widely used alloy[1]. Its chemical composition is as shown in table 1 [1]. It is more qualified than other alloys for heat treatment with medium to high-quality abilities. Standard properties incorporate medium to high strength, excellent durability, great surface complete, superb erosion imperviousness to air conditions, high consumption, great weld capacity, excellent workability, and it is additionally generally accessible. Physical properties of Al6061 is given in the table.2 below[18].

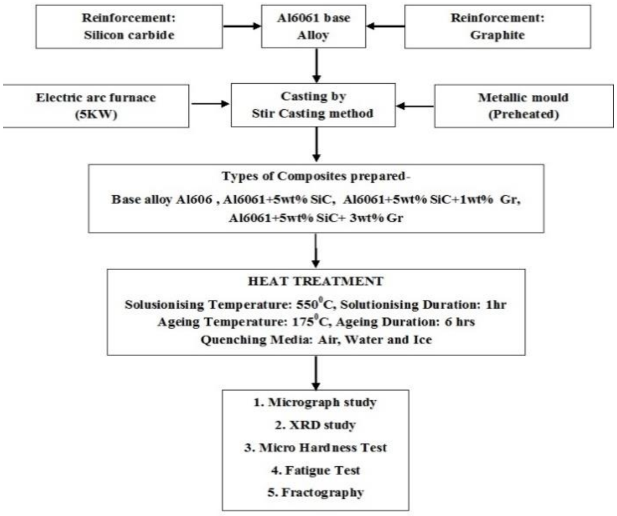


Fig.1 Systematic plan of the project

TABLE.1 Base matrix chemical composition

Elements	Fe	Mn	Cr	Si	Cu	Mg	Al
%(Max)	0.7	0.8	0.35	0.8	0.4	1.2	Balance

TABLE.2 Physical Properties of Al6061

Elongation at Break	12 %
Tensile Strength	276 MPa
UTS	310 MPa
Vickers Hardness Number	107

2) Reinforcements

a) Silicon Carbide

Silicon Carbide (SiC) powder of particle size of ten microns was used as one the reinforcement. SiC is selected as the reinforcing material of the composite under study because its density is very close to Aluminum, there will be no separation during processing, and there will not be a significant difference in the thermal expansion coefficient between Aluminum and Silicon Carbide.

b) Graphite

Graphite has been extensively used in various applications in industries due to its self-lubricating tendency. Graphite powder with the particle size of 10 microns was used as another type of reinforcement to fabricate hybrid composites.

B. Preparation of Composite

Al6061-SiC composite and Al6061-SiC-Gr hybrid composites(AHMMC) of compositions as shown in table.3 were fabricated by the vortex stir casting method using an electrical resistance furnace, as shown in fig.2[2], [9], [10], [13], [15]. The furnace temperature was set between 700℃-800℃. A vortex was formed when the alloy in the molten state was stirred at 400 rpm for up to 1 minute. For the complete mixing of particles, stirring is done continuously for three to five minutes while SiC is added along with the mixture. Graphite after weighing was added and stirred uniformly for about ten minutes.The molten composite was finally poured into a die made up of cast iron with a diameter of 25mm and length 200mm, as shown in fig.3 with the fabricated material shown in fig.4

Fig.2 Stir Casting furnace

Fig.3 Cast iron moulds

Fig 4 Fabricated samples

TABLE.3 Composition of hybrid composite in wt%

Specimen	Al6061	SiC	Gr
I	100	-	-
II	95	5	-
III	94	5	1
IV	92	5	3

C. Characterization

1) Microstructure Study

The specimens were successively ground with finer abrasive media. Silicon carbide abrasive papers with variable grade numbers were used for grinding. The polishing of the specimen is performed after the grinding operation. Ordinarily, the sample is cleaned with a slurry of alumina, silica, or jewel velvet material to deliver without a scratch[2], [12], [19]. In the wake of cleaning, certain small scale basic constituents can be seen with the magnifying lens, e.g., considerations and nitrides. If the precious stone structure is non-cubic (e.g., a metal with a hexagonal-shut pressed gem structure, for example, Ti or Zr), the microstructure can be uncovered without scratching utilizing crossed enraptured (light microscopy) [20], [21]. Something else, the microstructural constituents of the example, are uncovered by utilizing a reasonable synthetic or electrolytic etchant. The samples of the specimen are shown in fig.5

Fig.5 Microstructure samples

2) X-Ray Diffraction (XRD) Analysis

XRD analysis (XRDA) was performed to investigate the presence of SiC and Gr reinforcement particles in aluminium hybrid composites. XRD is a method used in the science of materials to determine the atomic and molecular structure of the material. It is achieved by irradiating a sample of the material with incident X-rays and then calculating the intensity and scattering angles of the X-rays that are scattered by the substance.

3) Micro Hardness Test

The micro hardness (VHN) for Al6061, Al6061-SiC and Al6061-SiC-Gr composites was carried by using Shimadzo micro hardness tester. The high mirror-polished samples before and after the heat treatment were put under a load of 100 gms for 30 seconds. Three trials were conducted on three different locations, and the average diagonal of indentation was measured. Vickers Hardness Number (VHN) was calculated by using formula.

$$VHN = (1854.4 \times P)/d^2$$

where,

P- Load, gms

d- Mean diagonal of indentation, µm

4) Fatigue Test

It has been estimated that fatigue leads to nearly 90% of all mechanical service failures. Fatigue affects any part or component that has relative motion with the other part. Fatigue failures are found in road vehicles, aircraft wings and fuselages, ships at sea, nuclear plants, jet engines and land-based turbines. The fatigue test was conducted on all the composites prepared using the fatigue machine shown in fig.6

and speicifications shown in table.4.The specimen geometry as per ASTM standard is shown in fig.7.The specimen, both before and after heat treatment were tested for fatigue behavior with a load of 1 kg. The number of cycles for failure for each specimen was noted down.

Fig.6 Fatigue testing machine

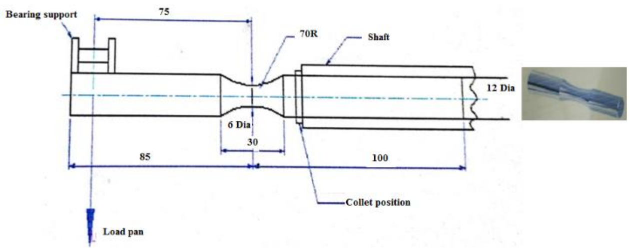


Fig.7 ASTM specification for fatigue test

TABLE.4 Fatigue machine specifications

Horse Power Of Motor	1492 W (2HP), 2800 rpm
Electrical power	3ph, 10A, 440V, AC with neutral connection
Digital rpm indicators	2 ns (counter will be in thousands)
Set of weights for loading	Total 10 Kgs
Indicator	Sound hooter for indicating both specimen failures
Loading lever ratio	2
Maximum number of counts	10^8
Specimen size	12mm dia*170mm length with contoured shape at centre of dia 6/8mm

5) Heat Treatment

Heat treatment was carried out in an electric resistance furnace, as shown in fig.8 and technical specification is given in table.5. The specimen were heat treated at a temperature of 5500C for a duration of one hour followed by quenching media such as air, water and ice. They were further heat treated at a temperature of 1750C for a duration of 6 hrs followed by air cooling under normal room temperature.

TABLE.5 Electric resistance furnace specifications

Max. temperature	1000℃
Heating rate	10℃ per minute
Dimensions of heating chamber	60mm × 60mm × 300mm

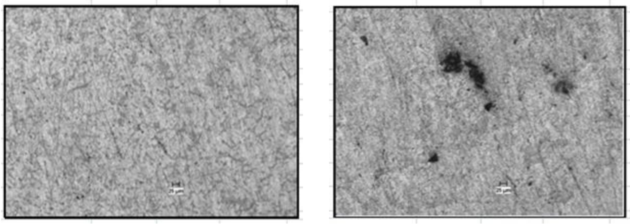
Fig.8 Heat treatment furnace

3. Results and Discussion

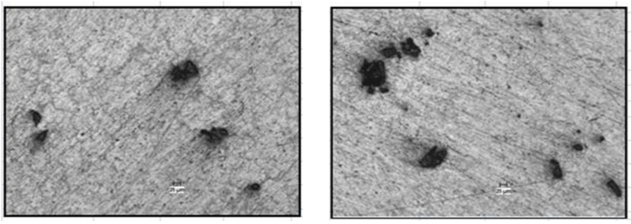
A. Microstructure Study

1) Before Heat treatment(bht)

The microstructure of Al6061 and its composites before heat treatment in the etched condition is shown in fig.9



(a) Al6061 (b) Al6061+5%wt SiC



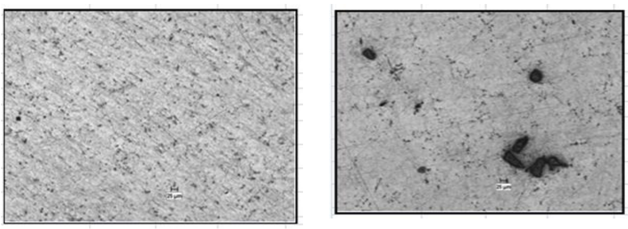
(c) Al6061 + 5%wtSiC + 1%wtGr (d) Al6061 5%wt SiC + 3%wtGr

Fig.9 Microstructure study of Al6061 and its composites before heat treatment

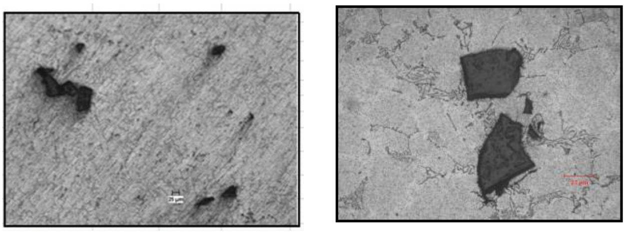
From the fig.9, it is observed that both SiC and Gr are fairly uniformly distributed in the matrix alloy with minimal porosity. There is an excellent bonding of reinforcement with matrix alloy.

2) After heat treatment(aht) (Ice quenching)

The microstructure of Al6061 and its composites after heat treatment (ice quenched) in the etched condition is shown in fig.10



(a) Al6061 (b) Al6061+5%wt SiC



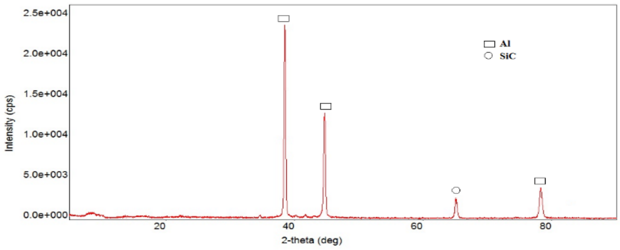
(c) Al6061 +5%wt SiC +1%wt Gr (d) Al6061 +5%wt SiC +3%wt Gr

Fig.10 Microstructure study of Al6061 and its composites after heat treatment

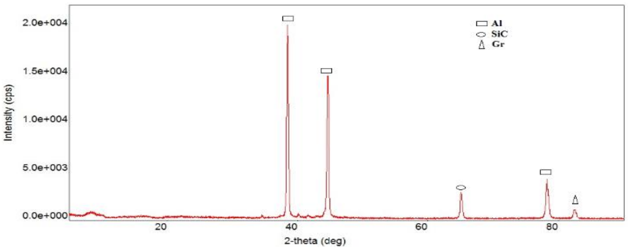
With heat treatment (ice quenching), the finer grain structure of Al6061 and its composites is observed, as evident from fig.10. Also, both SiC and Gr are uniformly distributed in the matrix alloy. The level of porosity is also less, and there is an excellent bonding of reinforcement with matrix alloy.

B. XRD Study Result

XRDA, as shown in fig.11, clearly indicates the presence of SiC in Al6061-SiC composite, and SiC and Gr in Al6061-SiC-Gr hybrid composite. The X-ray diffraction shows the peaks of aluminum and silicon carbide. The X-ray diffraction consists of the dominant aluminum and silicon carbide peaks and the patterns are identical to each other, albeit with different particle sizes. The same is the case of Aluminium hybrid composite with peak for Graphite[22], [23].



(a) Al6061 + 5wt% SiC



(b) Al6061 +5wt% SiC +3wt% Gr

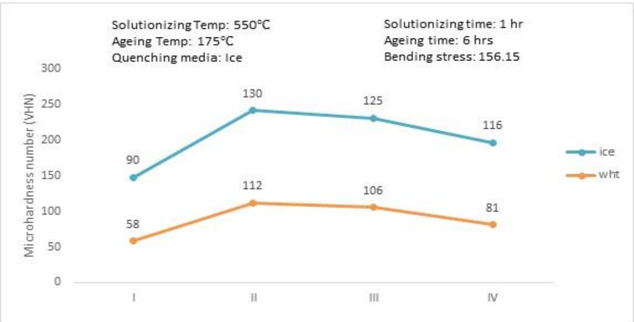
Fig.11 XRD analysis of SiC and Gr

C. Micro Hardness

1) Before heat treatment

The microhardness (VHN) of the Al6061 alloy & its composites before and after the heat treatment is indicated in fig.12

From the fig.12 we can see that there is an increase in microhardness as there is addition of SiC but decreases with addition of Gr. SiC is hard reinforcement and it makes the material harder and stronger while Gr is soft reinforcement which increases ductility while reduces strength of the material.



I- Al6061 II- Al6061+5%wt SiC

III-Al6061+5%wtSiC+1%wtGr IV-Al6061+5%wtSiC+3%wtGr

Fig.12 Microhardness after heat treatment.

From fig.13, an observation can be made that there is an increase in microhardness number with the addition of SiC but a decrease in microhardness number due to the addition of the Gr. The heat treatment process increases the microhardness number of the composite compared to the process without heat treatment. Heat treatment results in the development of bonding, which is intermetallic during hardening, resulting in stronger & harder material. Microhardness of the composites before & after heat treatment is shown in fig.13

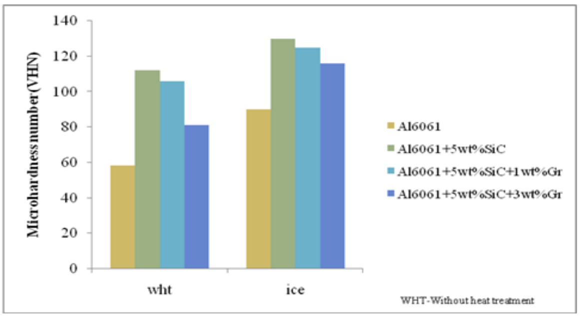


Fig.13 Microhardness of the alloy & composite-before & after heat treatment

D. Fatigue Strength

1) Before heat treatment

The number of cycles for fatigue failure for this hybrid composite before heat treatment is shown in fig.14

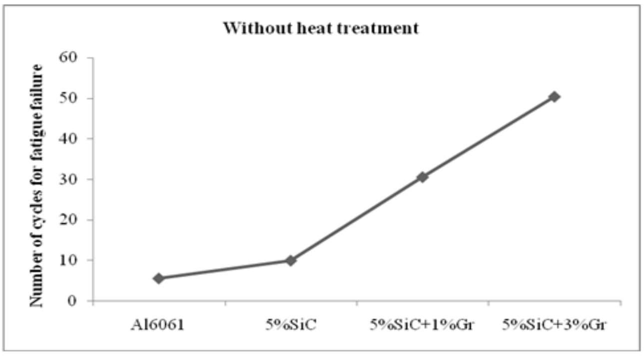
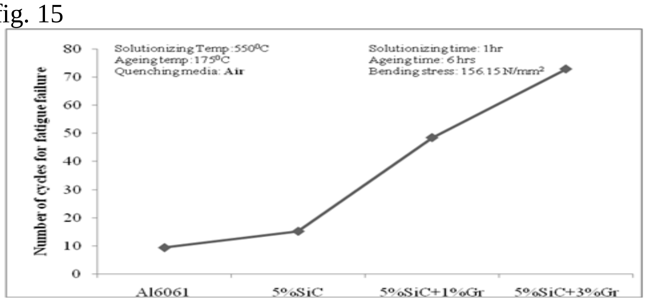


Fig.14 No. of cycles for fatigue failure of Al alloy and its composites before heat treatment

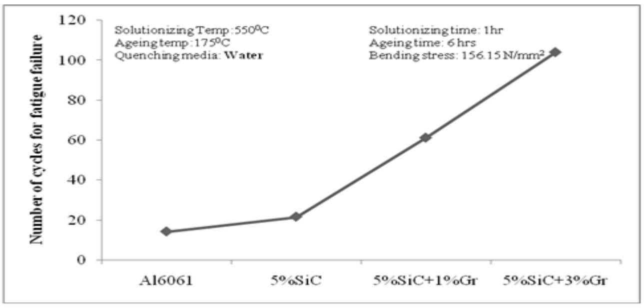
From the fig.14 it is observed that the number of cycles for fatigue failure increases with the addition of SiC and Gr. The fatigue behavior of Aluminium hybrid composite is superior to its base alloy Al 6061 as a result of adding up of SiC & Gr. It results in better grain structure and higher stiffness of the composites.

2) After heat treatment

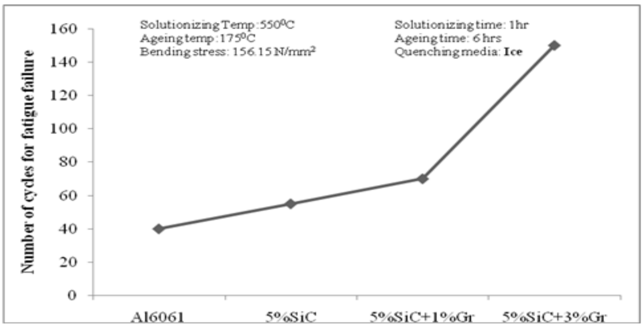
The number of cycles for fatigue failure of Al alloy and its composites after heat treatment with air, water, and ice quenching is shown in fig. 15



(a) Air



(b) Water



(c) Ice

Fig.15 No. of cycles for fatigue failure of Al alloy and its composites after heat treatment

From fig.15, it is observed that with heat treatment, the number of cycles for fatigue failure increases with the addition of SiC and Gr in Al alloy. Aging heat treatment performed at 1750C for 6 hours, followed by air, water, and ice quenching, has a significant influence on improving the fracture toughness of Al-SiC-Gr composites. The precipitation of fine particles results in improving the fatigue behavior of this composite. Considerable improvements in microstructure and precipitation of second-phase particles are due to the superior fatigue resistance of the age of heat-treated hybrid composite. Fatigue behavior of age heat-treated hybrid composite is found to be superior to cast hybrid composite. Among all the quenched composites, ice quenched composites appear to show better results. Fig.16 shows a comparison of the number of cycles for fatigue failure of Al alloy & its related composites before & after heat treatment.

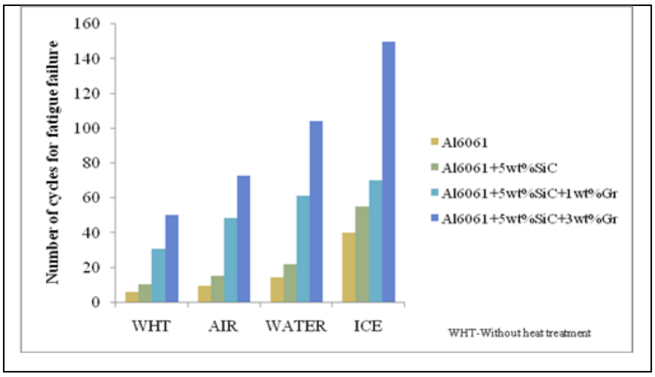
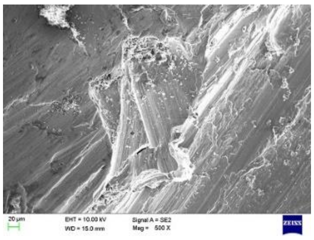


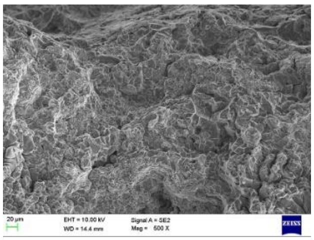
Fig.16 No. of cycles for fatigue failure of Al alloy & its related composites-before & after heat treatment

E. Fractography

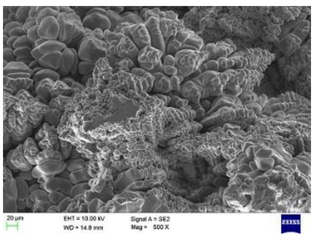
1) Before heat treatment

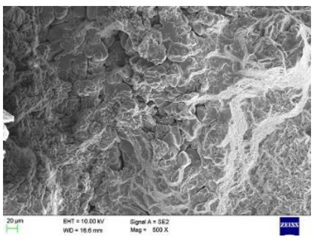
SEM of Al alloy and its composites after fatigue failure before heat treatment is shown in fig.17





(a) Al 6061 alloy **(b) Al6061+5wt%SiC**





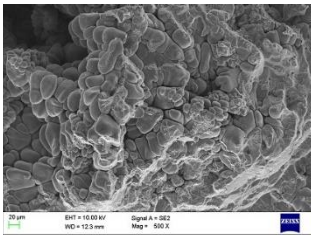
(c) Al6061+5wt%SiC+1wt%Gr **(d) Al6061+5wt%SiC+3wt%Gr**

Fig.17 SEM fractured surface of Al alloy and its composites before heat treatment

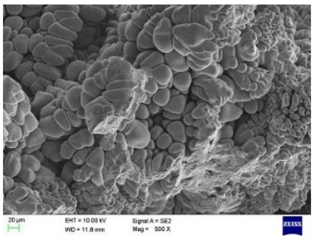
From fig.17, it can be seen that the presence of voids that act as crack initiation sites for fatigue failure is reduced with the addition of SiC and Gr. Further, SiC acts as a barrier to the dislocation motion by reducing the average distance in the composite. SEM gives a clear identification of change in grain structure due to the addition of SiC & Gr.

2) After heat treatment

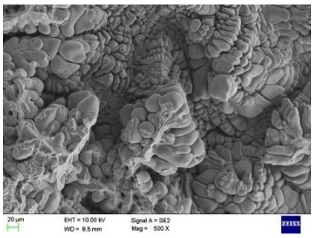
SEM of Al alloy and its composites after fatigue failure after heat treatment (ice quenched) is as shown in fig.18



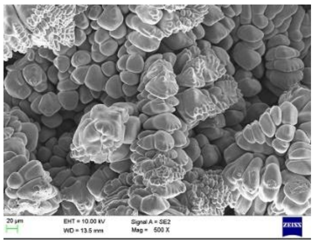
(a) Al 6061 alloy



(b) Al6061+5wt%SiC



(c) Al6061+5wt%SiC+1wt%Gr



(d) Al6061+5wt%SiC+3wt%Gr

Fig.18 SEM fractured surface of Al alloy and its composites after heat treatment.

From fig.18, it is observed that significant changes in microstructure have taken place because of heat treatment. Precipitation of the second phase particles in the hybrid composite subjected aging heat treatment results in enhanced fatigue behavior of the hybrid composite.

4. Conclusion

- By vortex stir casting method, Al 6061 alloy, Al 6061-SiC, and Al 6061- SiC-Gr composites were successfully fabricated.
- Microstructure and XRD studies indicated uniform distribution and occurrence of graphite and silicon carbide particles in the alloy used.
- Aluminum-silicon carbide composite microhardness was higher than hybrid composites and base alloys.
- Heat treatment enhances the microhardness of Al6061 (base alloy) and its composites. Also, among the heat treatments, ice quenching results in maximum hardness.
- The fatigue strength of the Al6061-SiC-Gr hybrid composite was higher than that of the Al6061-SiC composites and the base alloy.

Heat treatment enhances the fatigue strength of the Al6061 (base alloy) and its composites. Moreover, among the heat treatments, ice quenching results in maximum strength.

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