EVALUATION OF MECHANICAL PROPERTIES OF 6061 ALUMINIUM BASED MMC REINFORCED WITH SiC & GRAPHITE

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ABSTRACT

I*n recent years, there has been an ever-increasing demand for enhancing evaluation of mechanical properties of Aluminum Matrix Composites (AMCs), which are finding wide applications in the field of aerospace, automobile, defence etc., Among all available aluminium alloys, Al 6061 is extensively used owing to its excellent wear resistance and ease of processing. Addition of hard reinforcements such as silicon carbide, alumina, titanium carbide, improves hardness, strength and wear resistance of the composites. AMCs reinforced with particles of Gr have been reported to be possessing better wear characteristics owing to the reduced wear because of formation of a thin layer of Gr particles, which prevents metal to metal contact of the sliding surfaces. Further, heat treatment has a profound influence on mechanical properties of heat treatable aluminium alloys and its composites. For a solutionising temperature of 550^{0}C, solutionising duration of 2hrs & 10 min, ageing temperature of 135 ^{0}C, quenching media and ageing duration significantly alters mechanical properties of both aluminium alloy and its composites. In the light of the above, the present study aims at developing aluminium based hybrid metal matrix composites containing both silicon carbide and graphite and characterize their mechanical properties by subjecting it to heat treatment. Results indicate that increase of graphite content decreases ultimate tensile strength of hybrid composites reinforced with varying SiC reinforcement. For the heat treatment processes, water quenching with ageing duration of 4hrs resulted in improved ultimate tensile strength of both the unreinforced matrix alloy and its hybrid composites.*

I INTRODUCTION

1.1 Composite Materials

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common example includes materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites which are known as

Robotic materials. Composite materials possess higher specific strength, stiffness and fatigue limit, which enable the structural design more flexible than conventional metals.

Many researches tried to study the mechanical properties of Al based alloy in which other materials are added as the reinforcement. As per Srinivasan Ekambaram & Mahendra Boopathi, the effect of alumina, SiC, Fly ash, B4C etc., as an reinforcement material to the Al 6061 alloy composites and he found that tensile strength, hardness, corrosion & wear resistance and compressive strength were increased as increase in weight % of reinforced material composites compared to the base metal but ductility and elongation of the hybrid MMC was decreased on comparision with unreinforced Al alloys.

After surveying, we clearly observe more addition of SiC & Graphite composition may reduce the ductility but improve the tensile strength, hardness, compression strength, impact strength and wear resistance. So we are decided to prepare MMC using Al 6061 using 0%, 2%, 4% & 6% of SiC & Graphite as the reinforcement materials.

II MATERIALS

2.1 Matrix Materials

The metal matrix used for the present investigation was an Al 6061 alloy whose chemical composition of the Al 6061 is as shown in the below Table 1. It therefore has a melting point 660^0c. The molten metal has high fluidity and solidifies at constant temperature.

Table 1.Composition of Al 6061 alloy

Alloy 6061	Wt%
Si	0.4-0.8
Fe	0.7
Cu	0.15-0.4
Mn	0.15
Mg	0.8-1.2
Cr	0.04-0.35
Zn	0.25
Ti	0.15
Others	0.05
Al	Remainder

Figure 1.Al alloy 6061 blocks

2.2 Reinforcement materials

Silicon carbide particulates: SiC particles are the most commonly used reinforcement materials in the discontinuously reinforced metal-matrix composite system. The SiC particles, which were used to fabricate the composite, had an average particle size of 400 grits and average density of 3.2 g/cm3. It is the second hardest material after diamond with a Mohr's hardness of 9.5. The melting point of the SiCp is 2890^0C.

- **Graphite particulates:** Graphite is the most stable form of carbon under standard conditions. Graphite particles are rarely used reinforcement materials in the discontinuously reinforced metal matrix composite system. Aluminium matrix composites reinforced with Gr particulates acts as a self-lubricating and avoid friction & increases wear resistance. Particle size and shape are important factors in determining materials properties. Fatigue strength is greatly improved with the use of fine particles. The Graphite particles, which are used to fabricate the composite, had an average particle size of 70μm and average density of 2.2 g/cm^3 density. It is having a thermal conductivity of around 190 W/m-K.

III SPECIMEN PREPARATION

3.1 Fabrication method

Stir casting:

The stir casting technique was used to fabricate the composite specimen as it ensures a more uniform distribution of the reinforcing particles. This method is most economical to fabricate composites with discontinuous fibers or particulates.

Figure 2.Stir Casting Set Up

Aluminium alloy 6061 was in large sizes we cut those large sizes into small piece of blocks. Exactly 3000 grams of blocks of aluminium alloy 6061 was placed in the mild steel crucible of electric furnace about 6 kW. The aluminium alloys 6061 blocks are shown in fig 1. The furnace temperature was raised to 790˚C. The furnace temperature maintained between 780 to 800˚C for about 120 minutes to melt aluminium alloy blocks. The scum powder in small quantity is added to the melt to remove the slag or flux which was floating on molten metal and removed by a slag cleaning tool. The total melt is then degassed by adding dry hexa-chloroethane tablet weighing 10 grams (C_2Cl_6, 0.3 % by weight). The silicon carbide particles (400 grit size) and graphite particles (70µm size) were pre heated to 400˚C for 90 minutes before adding to furnace.

After degassing, preheated silicon carbide particles with different % by weight were added to the vortex formed in the melt by stirring. A mild steel stirrer with vertical axis was used. It has been used to obtain an output of 400 rpm. The stir caster was mounted on the furnace with the help of three legs. The equipment setup for stirring is shown in the fig 2. The rpm of the stirrer was maintained at 350-400 rpm for 10 to 15 minutes and stirring is continued for about 10 minutes to allow for uniform mixing of the silicon carbide particles with the molten metal. The melt temperature was maintained at 780-800˚C during the addition of the particles.

The pouring temperature was kept at 800˚C and the time of pouring was 5 minutes. The crucible containing the melt mixture was then carefully taken out of furnace and poured into a specially designed permanent mould. The melt was poured in the grey cast iron moulds which were preheated to 300˚C using a kerosene pump burner. The mold was left to cool and castings were ejected. The aluminium-silicon carbide and Gr composites were produced by varying amount of silicon carbide & Gr 2, 4 and 6% by weight. These casting samples are now ready.

Figure 3.Alloy after casting

3.2 Preparation of samples

A number of samples will be prepared from Al-6061 matrix alloy SiC & Gr composites. The samples prepared for tensile test, compression test, wear test and impact test are according to their standards.

Tension test specimen

Tension test specimens will be prepared according to the ASTM standard E8M having diameter 12.5mm and gauge length 62.5mm. Tension test specimen geometry is shown in the fig 4.

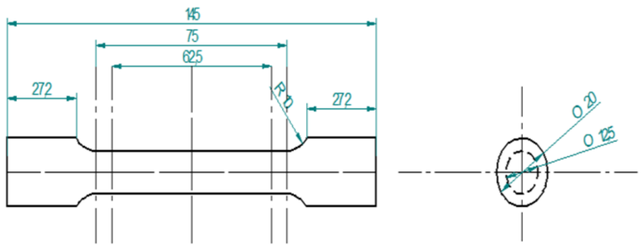


Figure 4.Tension test specimen's geometry

Compression test specimen

Compression test specimens will be prepared according to ASTM standard E9-95 having diameter 18mm and length 25mm. Compression test specimen geometry is shown in fig 5.

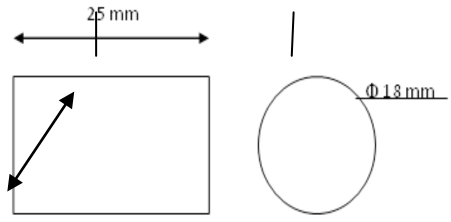


Figure 5.Compression test specimen's geometry

Wear test specimen

Wear test specimens will be prepared according to the ASTM standard E10 having diameter 10mm and length 25mm. Wear test specimen geometry is as shown in the below fig 6.

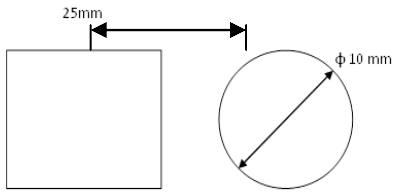


Figure 6.Wear test specimen's geometry

Impact test specimen

Impact test specimens will be prepared according to the ASTM standard E23 of 10mm square rod and length of 55mm. Impact test specimen geometry is shown in fig 7.

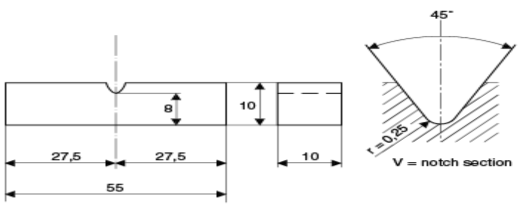


Figure 7.Impact test specimen's geometry

3.3 Machining

The casted composite materials are machined using conventional machining process like turning, milling, shaping. The machining is done using Lathe, Milling machine, Shaping machine as per above dimensions. The below figure shows the prepared samples of composite material as per ASTM standards by using Lathe, Milling machine in machine shop.

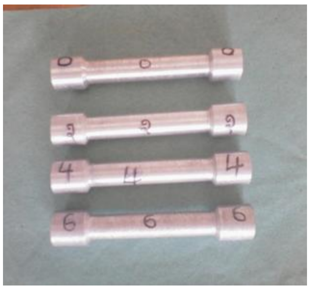
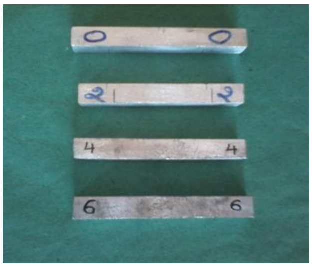



Figure 8.a)Tensile test specimen b)Compression test specimen

c) Wear test specimens   d) Impact test specimens

IV HEAT TREATMENT

Heat treatment is an operation in the fabrication of an engineering materials system. The main objective of heat treatment is to make the material system structurally and physically fit for engineering application. Once the alloy has been heated to the recommended solutionizing temperature, it is quenched at a rapid rate such that the solute atoms don’t have enough time to precipitate out of the solution. As a result of the quench, a super saturated solution now exists between solute and aluminium matrix. Quenching is the process of rapid cooling of material systems to room temperature to preserve the solute in solution.

Heat treatment was carried out in an electric furnace as shown in fig 9. The specimens were heat treated for a solutionising temperature of 550 0C, for duration of 2 hrs & 10 min. After that they were cooled in water medium for 1 hr. They were further subjected to secondary heat treatment at ageing temperature of 135 0C for duration of 4 hrs & about 30 min for air quenching of the specimen. They were further cooled in air under normal room temperature.

Figure 9. Electric Furnace

V EXPERIMENTATION

5.1 Results and Discussions

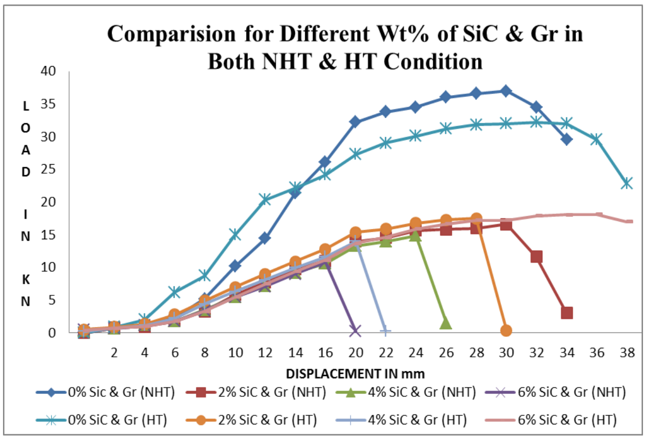
Tensile test results

Tensile strength of a material is the tension stress at which a material breaks or permanently deforms (changes shape). Toughness, Resilience, Poisson's ratio can also be found by the use of this testing technique. Figure 10 shows Universal Testing Machine [UTM] in which tensile specimen of composite ends are gripped into machine with a capacity of 40KN. The sample is loaded gradually and at regular intervals of load extension is measured by digital load indicator on UTM. After certain load extension increases at faster rate the material is failure. It is removed and then the extension is measured from scale. Load is increased gradually till the specimen breaks.

This tensile test data obtained is in the form of graphs which are plotted as load v/s elongation or displacement. Comparision for tensile test of different wt% SiC & Gr in both Non-heat treated [NHT] condition as well as in Heat treated [HT] condition are shown in below figures.

Figure 10.Universal testing machine

Comparision for Line and Column Diagram of Tensile Test both in Non Heat Treated [NHT] & Heat Treated Condition [HT] of all combination like 0%, 2%, 4% & 6% of SiC & Gr.



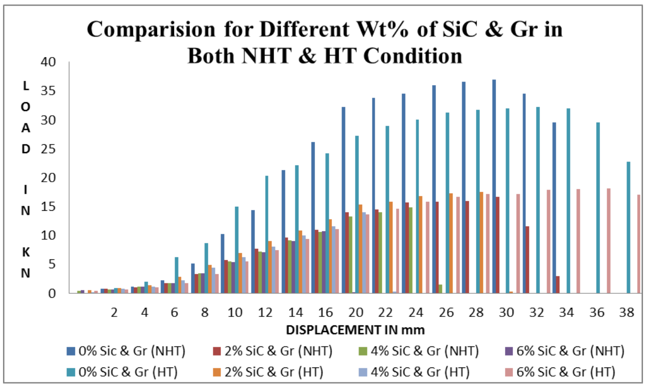


Figure 11.Sows Load v/s Displacement for comparision of different wt% of SiC & Gr in both NHT & HT condition.

Column diagram of Tensile strength for different Wt% of SiC & Gr in both Non Heat Treated and Heat Treated Condition.

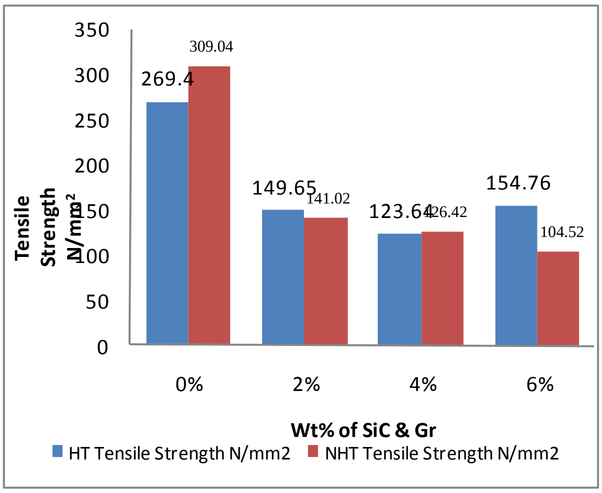


Figure 12.Shows Tensile strength V/s Wt% of SiC & Gr.

Discussion

Experiments are conducted by varying weight fraction of SiC & Gr (0%, 2%, 4% and 6%) both in Non-heat treated [NHT] and Heat treated [HT] conditions. Tensile test is conducted in Universal Testing Machine [Fig 10]. The Tensile strength of aluminium alloy 6061 is highest for 0% of SiC & Gr composite and lowest for 6% of SiC & Gr composite in NHT condition but when Tensile strength of HT condition is observed, the Tensile strength is reduced for 0% of SiC & Gr composite and maximum increment in Tensile strength for 6% of Sic & Gr composite was seen. The increase in combined % of SiC & Gr reinforcement particles reduces the ductility of AL-SiC-Gr hybrid composites. Generally the brittle material having less Tensile strength compare to ductile material. So we can conclude that addition of Sic & Gr to the base alloy increases brittleness due to their low density and self-lubricating property and also profound in heat treatment, hence tensile strength is reduced. The highest value of Tensile strength shows the maximum capacity of aluminium alloy composite material to withstand loads while being stretched or pulled before failure.

Figure 13.Fractured tensile specimens

5.2 Compression Test Results

A compression test is any test in which a material experiences opposing forces that push inward upon the specimen from opposite sides or is otherwise compressed or flattened. The compression test specimens is generally placed in between two plates that distribute the applied load across the entire surface area of two opposite faces of the test specimens and then the plates are pushed together by a Universal Testing Machine [UTM] causing the sample to flatten. A compressed sample is usually shortened in the direction of the applied forces and expands in the direction to the force. Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size, as opposed to tensile strength, which withstands loads tending to elongate.

This compression test data obtained is in the form of graphs which are plotted as load v/s elongation or displacement. Comparision for compression test of different wt% SiC & Gr in both Non-heat treated [NHT] condition as well as in Heat treated [HT] condition are shown in below figures.

Comparision for Line and Column Diagram of Compression Test both in Non Heat Treated [NHT] & Heat Treated Condition [HT] for all combination like 0%, 2%, 4% & 6% of SiC & Gr.

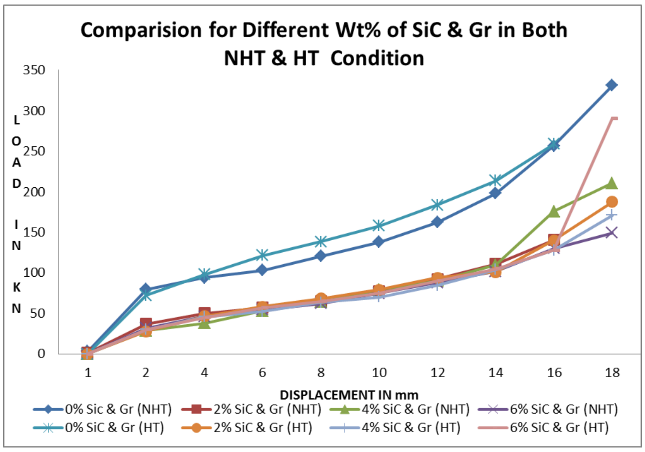
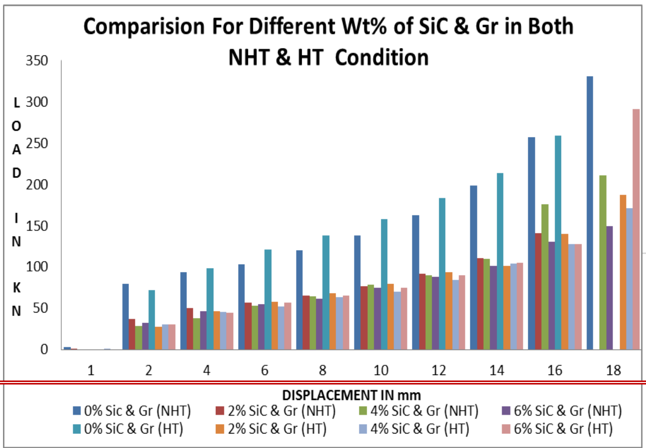


Figure 14.shows Load v/s Displacement for comparision of different wt% of SiC & Gr in both NHT & HT condition

Comparision for Column diagram of compression test in both Non-heat treated and Heat Treated Condition.



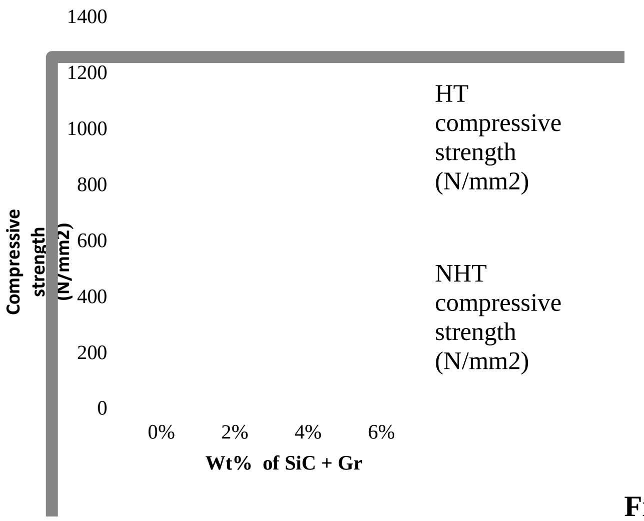


Figure 15. Shows compressive strength V/s Wt% of SiC & Gr.

Discussion

Experiment is conducted by varying weight fraction of SiC & Gr (0%, 2%, 4% and 6%). Compression strength are recorded and tabulated. The test is conducted on a universal testing machine. The Compressive strength of aluminium alloy 6061 is highest for 0% of SiC & Gr composite and lowest for 2% of SiC & Gr composite in NHT condition but when Compressive strength of heat treated condition was observed, the Compressive strength is reduced for 0% of SiC & Gr composite but there is an increment of Compressive strength for 2%, 4% & 6% of Sic & Gr composite than the NHT condition and also large increment of Compressive strength for 6% in HT condition was clearly observed. Hence as increase in wt% of Sic & Gr, increases Compressive strength in HT condition. This is because in SiC is known to have better chemical compatability with aluminium because it doesn't form any inter-metallic phases during its interaction with the Al matrix. The highest value of compressive strength shows the maximum capacity of aluminium alloy composite material to withstand loads tending to reduce size.

Figure 16.Tested compressive specimens

Impact test

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. The impact test is used to measure the materials ability to withstand shock load. This absorbed energy is a measure of a given materials notch toughness and acts as a tool to study temperature-dependent ductile-brittle transistion. Test results are shown in below table 2.

The impact test is carried out on pendulum type testing machines which consist of a moving mass whose kinetic energy is great enough to cause rupture of the test specimen. It also has an anvil and a support on which the specimen is placed to receive the blow. It also has a means for measuring the fracture energy of the specimen after it has been broken.

Figure 17.Impact Test Pendulum

Table 2. Test results of Impact test at Non-heat treated and heat treated condition

Sl. no	Composition	Impact energy (J)NHT	Impact energy (J) HT
01	Aluminium alloy 6061 + 0% SiC + 0% Gr	82	106
02	Aluminium alloy 6061 + 2% SiC + 2% Gr	22	28
03	Aluminium alloy 6061 + 4% SiC + 4% Gr	10	22
04	Aluminium alloy 6061 + 6% SiC + 6% Gr	12	28

Column diagram of Impact test in NHT & HT Condition.

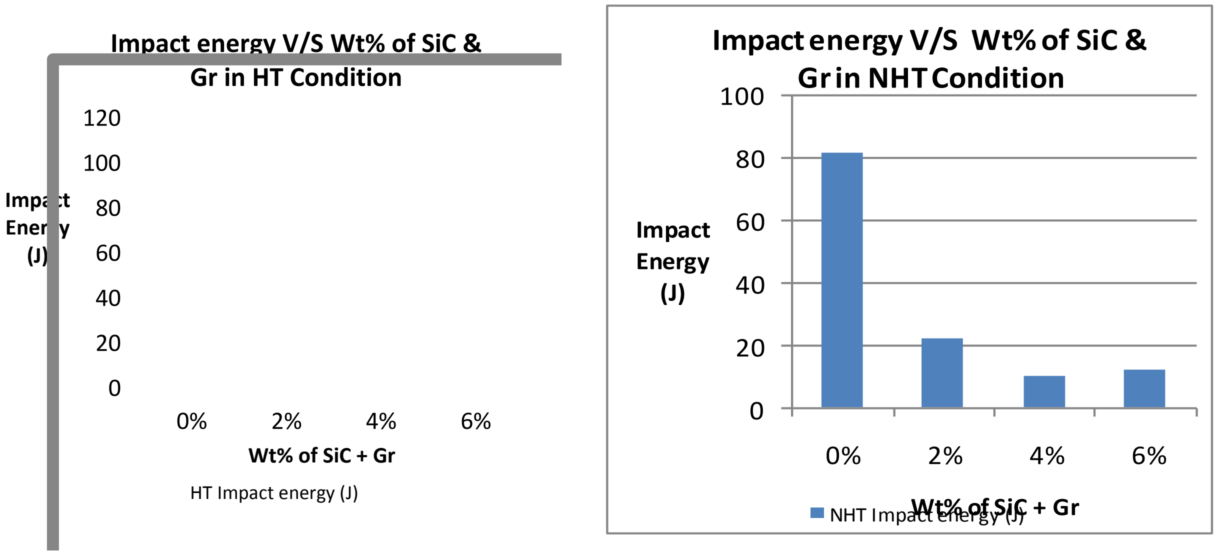
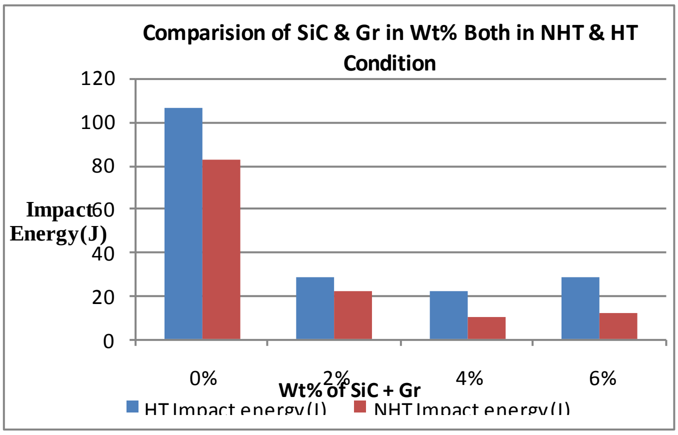


Figure 18. Shows Impact energy(J) V/S Wt% of SiC & Gr

Comparision for Column diagram of Impact test in both Non Heat Treated [NHT] and Heat Treated [HT] Condition.



Discussion

Experiment was conducted by varying weight fraction of SiC & Gr (0%, 2%, 4% and 6%). Impact strength are recorded and tabulated. The test conducted is Charpy impact test. The room temperature was 250C while conducting the test. At the beginning the impact strength decreased with increase in wt% of SiC & Gr in NHT condition. There was slight increment in impact energy for aluminium alloy 6061 with 2%, 4% & 6% of SiC & Gr composite in HT condition than in the NHT condition. Maximum impact energy was seen for 0% of SiC & Gr composite for heat treated condition shows maximum amount of energy absorbed by aluminium composite material during fracture.

Hence we can conclude that if increasing the wt% of SiC & Gr the impact energy decreases as the fracture toughness also decreases. The composite becomes harder due to heat treatment so the impact strength increases than in the NHT condition. It meant that this composite reduces toughness and become more brittle.

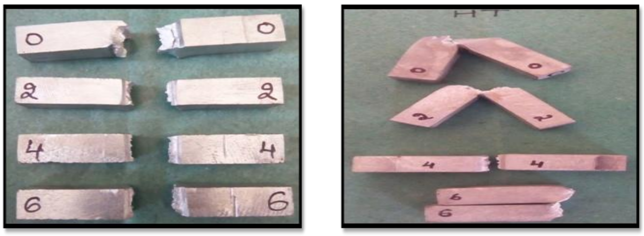
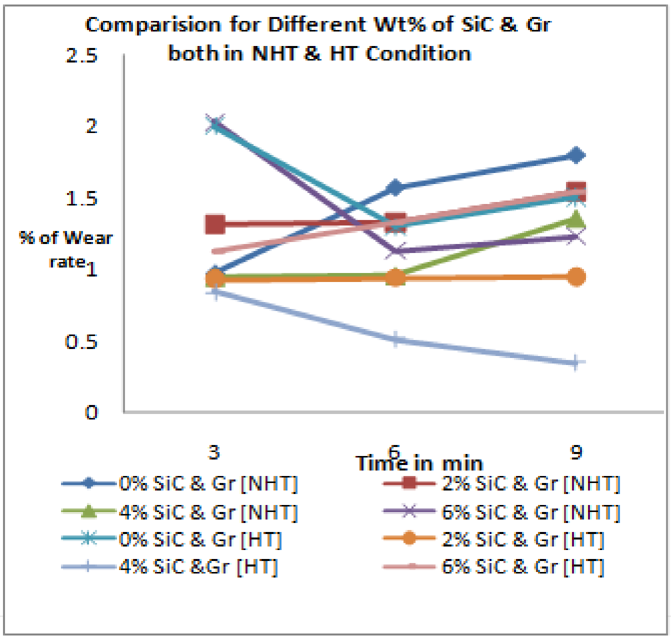


Figure 19. Fractured Impact Specimens

Wear Test

Wear can be defined as “the process of removal of material from one or both surfaces when two surfaces are in relative motion with each other”. Wear test was conducted using digitalized pin-on-disc apparatus [figure 20] by varying time and at constant load of 3kg and speed of 1000 rpm in NHT as well as HT conditions

Figure 20. Wear Testing Machine



Comparision for Line and Column Diagram of Wear Test both in Non Heat Treated [NHT] & Heat Treated Condition [HT] for all combination like 0%, 2%, 4% & 6% of SiC & Gr.

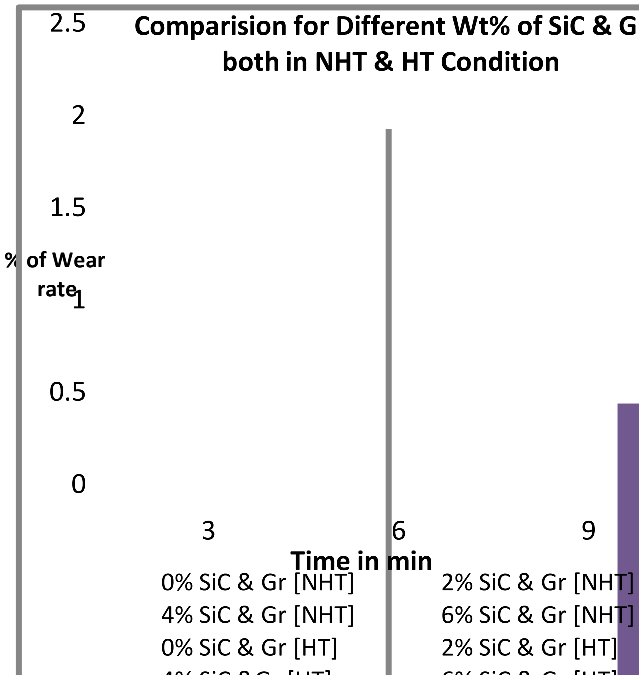


Fig.21 shows % of Wear rate v/s Time for comparision of different wt% of SiC & Gr in both NHT & HT condition.

Comparision for Column diagram of Wear test in both NHT and HT Condition.

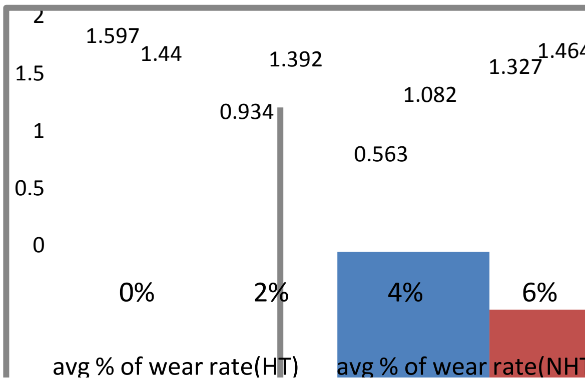


Figure 22.shows avg % of wear rate V/s % of composition of SiC & Gr.

Discussion

Experiment was conducted by varying weight fraction of SiC & Gr (0%, 2%, 4% and 6%). Average percentage of wear rate are recorded and tabulated. The wear test was conducted using digital pin on disc wear test apparatus under constant load and speed of 3kg and 1000 rpm respectively by varying time of 3, 6 & 9 min.

From the results, the composite having 4% composition shows a greater wear resistance compared with other composite material and the base alloy. This is because the graphite content in the composite will increases the Van-der wall force between the reinforcement material but in the 6% of composition shows the high tendency to grooving owing to the less resistance offered by the high volume fraction of hard particles. So that the 4% composition shows the greater wear resistance compared with other composition for both in NHT & HT conditions but the heat treated composites exhibits a high wear resistance with addition of SiC & Gr, SiC has high tendency to resist the wear because of its abrasive in nature and wear rate of the Gr particulate composite is better among the other ceramic particles reinforcement.

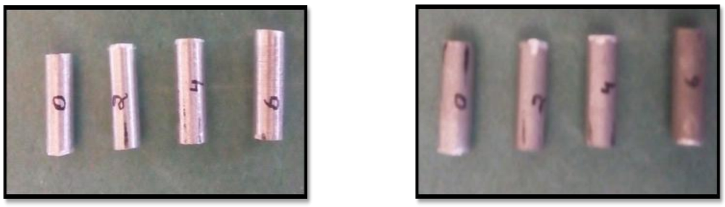


Figure 23. Tested Wear Specimens

VI. CONCLUSION

It has been observed that among all the fabrication techniques considered, stir casting stands out as the most economical method. SiC & Gr/Al hybrid composites can be made in an open atmosphere by stir casting using fabrication scheme derived from the literature review and mentioned in the experimental. Heat treatment can be achieved using electric furnace.

Composites based on Aluminium alloy 6061 reinforced with varying weight fraction of SiC & Gr particulates were prepared through stir casting. It has been inferred from the tensile test that the strength of the composite decreases with increase in volume of SiC & Gr particulates for heat treated condition except base alloy. Here the camparision is made between non-heat treated and heat treated condition. The tensile strength of aluminium alloy 6061 composite is increased maximum for 6% of SiC & Gr composite for heat treated condition.

Composite material having SiC & Gr with aluminium alloy 6061, the compressive strength in heat treated condition is reduced for 0% of SiC & Gr composite but there is an increment of compressive strength for 2%, 4% & 6% composites than in the non-heat treated condition and also large increment of compressive strength of 6% in HT condition was clearly observed.

The impact strength decreases with increase in percentage of SiC & Gr. When comparision is made between non-heat treated and heat treated condition, the impact energy increases with the increase in the % of SiC & Gr in the heat treated condition than in the non-heat treated condition.

From the Wear test results, it is found that the composite material having SiC & Gr content 4% shows a greater wear resistance compared with other composite materials. Heat treated composites exhibits a high wear resistance with the addition of reinforcement materials. The increase in graphite content results in decreased hardness and fracture toughness of Al-SiC-Gr hybrid composites.

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