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An Experimental Investigation on Tensile and Compression Behavior of Aluminum, Silicon Carbide, and Graphite Hybrid Composite with and without Cryogenic Treatment

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Abstract

The present investigation aims at evaluating the tensile and compression strength of aluminum-silicon carbide- graphite hybrid composite with and without cryogenic treatment. In this composite Al6061 is used as matrix material with varying SiC quantity from 2.5wt% to 10 wt% and varying graphite quantity from 1wt% to 4 wt%. The composites were fabricated by using stir casting technique. EDS and XRD tests were carried out to know the composition and phase identification of the composite sample. Microstructure analysis was carried out to study the structure of the composite with and without cryogenic treatment.

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Keywords: Al6061+SiC+Gr, Cryogenic treatment, Microstructure, EDS, XRD.

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1. INTRODUCTION

A Composite material is a combination of two or more distinct materials with a recognizable interface. The properties of a composite as a whole are enhanced as compared with the properties of its individual components. Composites are used for structural, electrical, thermal, tribological and environmental applications [1]. Panchakshari H.V *et al.*, reported that the impact of deep cryogenic treatment which improves the microstructure and mechanical

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properties of Al6061/Al_2O_3 composites at -196^{o}C [3]. G Elango *et al.*, showed that the improvement of microstructure and hardness upon cryogenic treatment on LM25 alloy and MMCs reinforced with SiC [4]. Rajender Singh *et al.,* showed that the hardness worth increments up to a constrained weight division of SiC and past this weight portion the hardness began diminishing [5]. B.M. Viswanatha *et al.*, showed that the hardness of composite increased significantly with addition of SiC while maximum hardness was obtained for 9% of SiC [6].

2. MATERIAL SELECTION

2.1. Al6061

Aluminum is the third richest component after oxygen and silicon. It is extricable in character, reveals reasonable excellence and surpassingly corrosion resistance. They have been contemplated broadly in view of their mechanical significance and due to precipitation hardening it as got their excellent increment in quality. Aluminum Al6061 grade was used as the matrix material. It was purchased as blanks and was used for casting.

2.2. Silicon carbide (SiC)

Silicon carbide (SiC) can be utilized as reinforcement in the form of particulates, whiskers or fibers to enhance the properties of the composite. SiC certainly improves the overall strength of the composite along with corrosion and wear resistance.The wear resistance of carbides is very high, therefore the wear resistance of the composite material obtained is high. Also, the hardness of the composites will increase. SiC is very hard as compared with Aluminum metals. The addition of SiC will increase the stiffness of the material. The promising features of adding hard reinforcements are to improve the resistance to wear and abrasion of the material. But at the same time care must be taken about the content of SiC in material as they will cause grain boundaries embrittlment and crack formations.

2.3. Graphite (Gr)

Graphite is a crystalline form of carbon having a layered structure with basal parts planes or sheets of close packed carbon atoms. Consequently, graphite is weak when sheared along the layers. This characteristic, in turn gives graphite its low frictional properties as a solid lubricant. However, its frictional properties are low only in an environment of air or moisture. In vacuum, graphite is abrasive and a poor lubricant. Unlike in other materials, strength and stiffness of graphite increase with temperature. Also, its small absorption cross section and elevated scattering cross section for thermal neutrons make graphite suitable for nuclear applications.

3. EXPERIMENTAL PROCEDURE

3.1Preparation of composite

Stir casting is utilized to fabricate the Al-SiC-Gr composite specimens with (2.5, 5, 7.5, 10%) weight fraction of SiC particles and (1, 2, 3, 4%) weight fraction of Gr particles. Al6061 alloy is selected as matrix material. Silicon carbide and Graphite are utilized as reinforcements. Aluminum alloy is made to a molten state in the furnace and then preheated reinforcement particles are added. The composites are prepared by using stir casting technique. The furnace used for fabrication is shown in Fig-1. The material composition for the present study is shown in Table 1. The required composition was initially obtained through raw ingots and then those ingots were melted in the furnace at 800^{o}C for two hours in stir casting machine. In stir casting process the ingots were completely melted. The stirring was continued at a speed of 400 rpm for about 5 minutes and then the molten metal were poured into the moulds and allowed to cool and then they were machined to the required standard dimensions.

Table 1: Chemical composition of Hybrid Aluminum Metal Matrix Composites (HAMMC)

Sl. no	Composition of HAMMC
1.	Al6061
2.	Al6061+2.5% SiC+ 1% Gr
3.	Al6061+5% SiC+ 2% Gr
4.	Al6061+7.5% SiC+ 3% Gr
5.	Al6061+10% SiC+ 4% Gr

Fig.1. Furnace

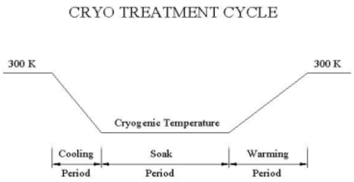

Fig. 2. Cryo treatment cycle

Fig.3. Cryo treatment setup

3.2 Cryogenic treatment

Cryo treatment cycle mainly consists of three stages, the first one is slow cooling rate stage which makes material to come down to liquid nitrogen temperature called cooling period, next one is soaking period in which samples are kept at liquid nitrogen temperature [-196 C] up to minimum of 12 hours and lastly warming period in which slowly samples get back to room temperature. The setup consists of liquid nitrogen tank, cryo processor and a computer control panel to regulate the cooling temperature. The cryo treatment cycle is shown in Fig.2.

3.3 Tensile test

Tensile test was done on electronic tensometer of capacity 20kN according to ASTM E8 standard

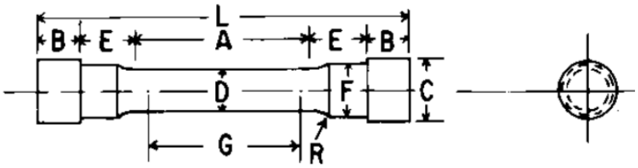

Fig.4. ASTM tensile specimen dimension

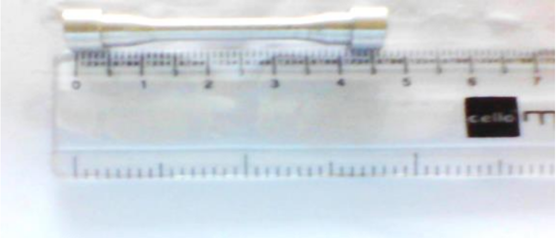

Fig.5. Tensile specimen

[R] = Radius of fillet = 6mm, [D] = Diameter= 4mm, [A] = Length of reduced section = 24mm, [B] = Length of end section= 5mm, [L] = Overall length= 46mm, [C] = Diameter of end section= 8mm, [F] = Diameter of shoulder=6mm, [E] = Length of shoulder and fillet section= 4mm, [G] = Gage length= 20mm

4. RESULTS AND DISCUSSION

4.1. Scanning Electron microstructure

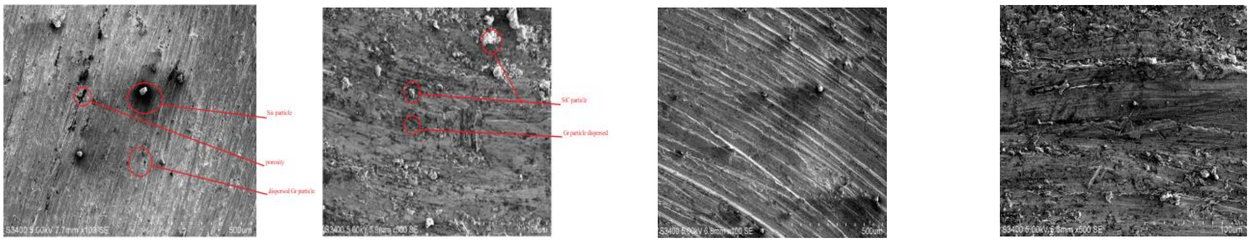

Fig.6.a. Fig.6.b. Fig.6.c. Fig.6.d.

Fig.6. SEM of a. Untreated Al6061+5%SiC+2%Gr b. untreated Al6061+10%SiC+4%Gr c. cryotreated Al6061+5%SiC+2%Gr d.Al6061+10%SiC+4%Gr

Figure 6.a. some porous with some of SiC particles completely bonded with aluminium alloy as well as dispersed Gr particles and more dispersed particles seen in Fig.6.b. Microstructure indicates good wet ability, strong bonding of SiC particle, small porosity in some cases and good strength of the MMC. But Gr particle reinforcement cannot be so much visualized because its micro grain structure is very low. There is no difference identified in the cryo treated because only TEM image can be tell us the exact reaction product occurred.

4.2. EDS Analysis

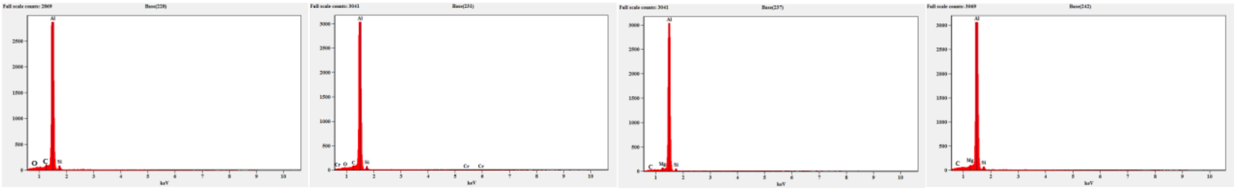

Fig.7.a. Fig.7.b. Fig.7.c. Fig.7.d.

Fig.7. EDS of a. Untreated Al6061+5%SiC+2%Gr b. untreated Al6061+10%SiC+4%Gr c. cryotreated Al6061+5%SiC+2%Gr d. cryo treatedAl6061+10%SiC+4%Gr

Energy dispersive spectroscopy analysis of the Al6061+SiC+Gr reinforced composite is present in each combination. Figures 7.a. to 7.d. shows Al, Si, O and C peaks and the EDS analysis confirms the presence of Al6061, SiC, Gr particles. The Mg_2Si (magnesium silicate) and SiO_2 (silicon oxide) are the reaction products which are represented by Mg and Si peaks in EDS graph after cryogenic treatment.

4.3 Peak and Break load

The highest peak load recorded for untreated specimen was 1618 N which was 48% higher than bare alloy. The highest peak load recorded for cryo treated specimen was 1794 N which was 52% higher than bare alloy. Compared to untreated specimen, cryotreated specimen showed higher value of peak load which indicates that cryo treatment improves the specimen load bearing capacity. Al 6061+5%SiC+2%Gr is the best among untreated and Al6061+2.5% SiC+1%Gr is best among the cryotreated. Between these two combinations Al6061+2.5% SiC+1%Gr is best one for peak load in tensile test.The variation of Peak load for untreated and cryotreated specimen is shown in figure 8.

The highest break load recorded for untreated specimen was 1255 N which was 81.7% higher than bare alloy. The highest break load recorded for cryo treated specimen was 1447.4 N which was 84% higher than bare alloy. Compared to untreated specimen, cryotreated specimen has higher value of break load which indicates that cryo treatment improves strength of the specimen. Al 6061+5%SiC+2%Gr is best among combinations. The variation of break load for untreated and cryotreated specimen is shown in figure 9.

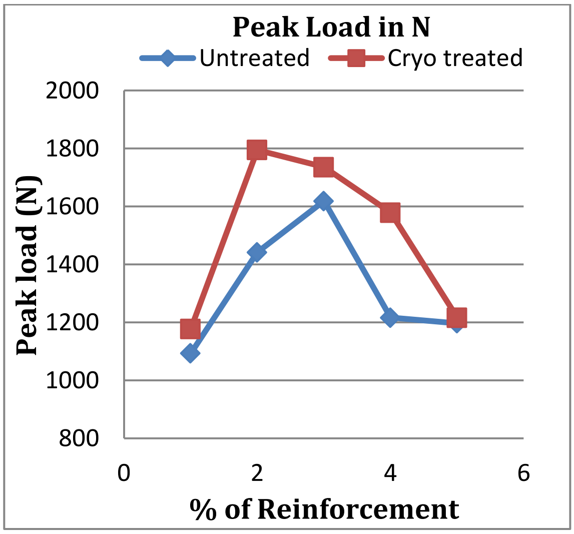

Fig.8. Comparison of peak load

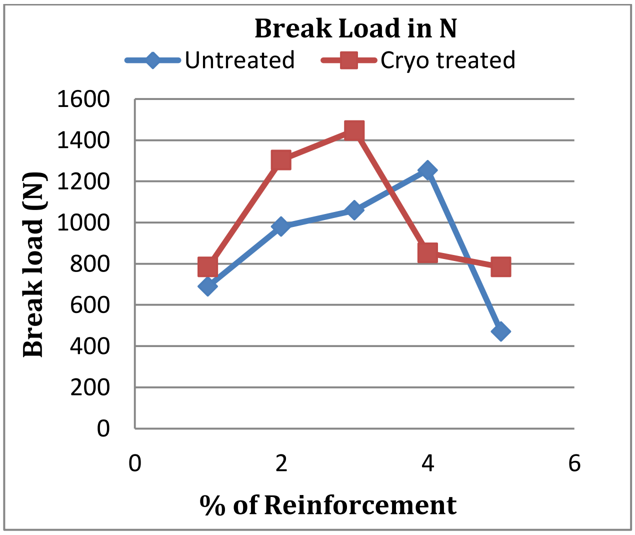

Fig.9. Comparison of break load

4.4 Engineering and True ultimate tensile strength

The highest Engineering ultimate tensile strength (UTS) recorded for untreated specimen was 128.7N/mm^2 which was 48.09% higher than bare alloy. The highest Engineering UTS recorded for cryo treated specimen was 142.89 N/mm^2 which was 64.26% higher than bare alloy. Compared to untreated specimen, cryotreated specimen has higher value of Engineering UTS which indicates that cryo treatment improves strength of the specimen. Al 6061+5%SiC+2%Gr is best among combinations.

The highest True UTS recorded for untreated specimen was137.4 N/mm^2 which was 14% higher than bare alloy. The highest Engineering UTS recorded for cryo treated specimen was 153.7 N/mm^2 which was 27% higher than bare alloy. Compared to untreated specimen, cryotreated specimen has higher value of Engineering UTS which indicates that cryo treatment improves strength of the specimen. Al 6061+5%SiC+2%Gr is best among combinations. The results of ultimate and true tensile strength for tensile test are represented by graph which is shown in figure 10 and 11 respectively.

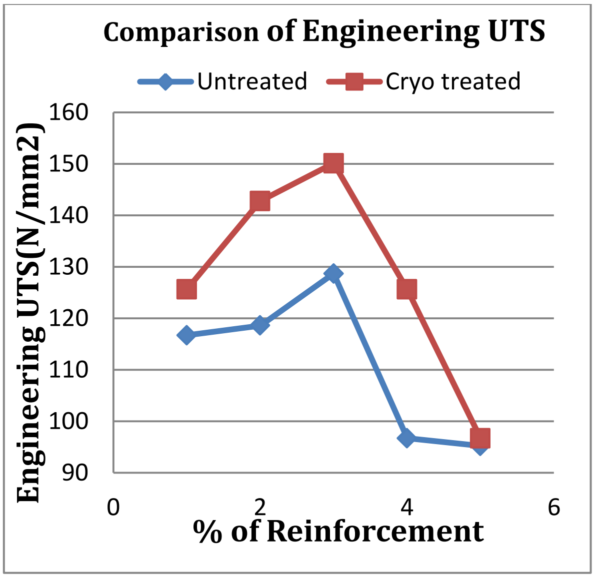

Fig.10. Comparison of Engineering UTS

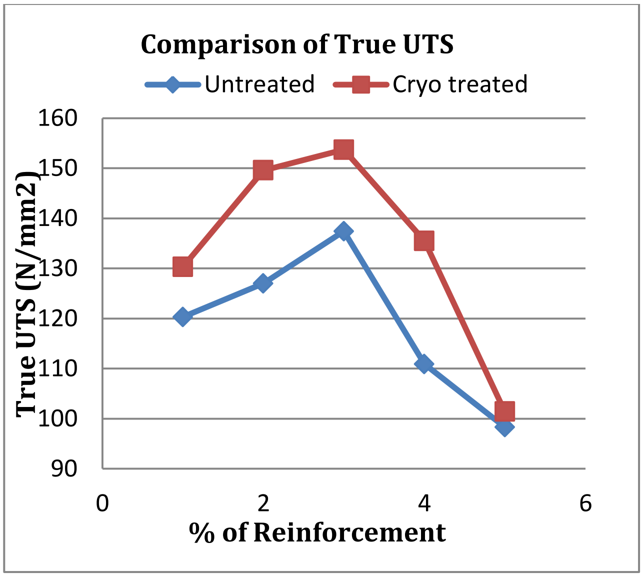

Fig.11. Comparison of True UTS

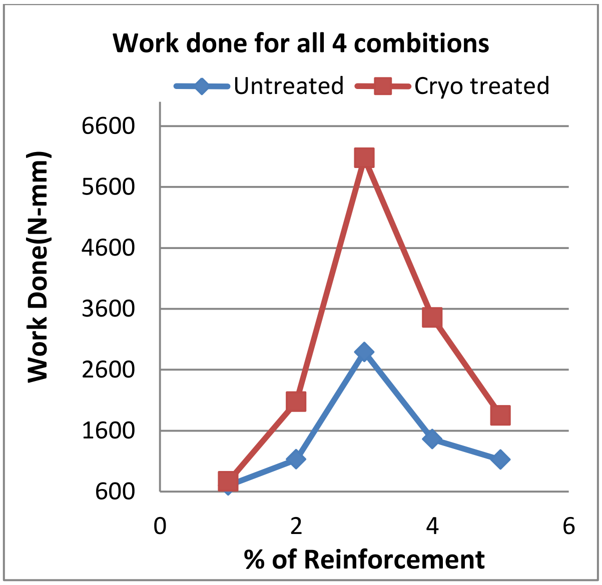

Fig.12. Comparison of work done

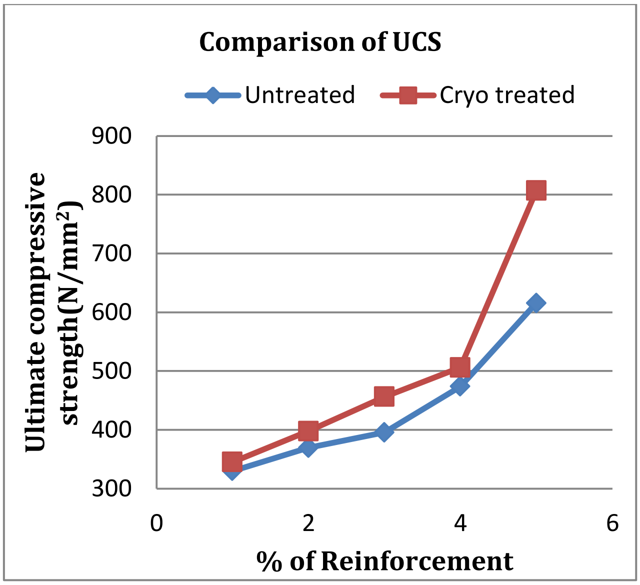

Fig.13.Comparison of UCS

4.5 Work Done

In case of untreated and cryo treated specimen, work done was increased as the % SiC increased upto 5% but suddenly drops as the % of Gr increases more than 2%. The highest work done recorded for untreated specimen was 2890.2 N-mm which was 75% higher than bare alloy. The highest work done recorded for cryo treated specimen was 6074.7 N-mm which was 87.4% higher than bare alloy. The work done for all the 4 combinations with and without cryogenic treatment is shown in figure 12.

4.6. Ultimate Compressive Strength

The highest Ultimate Compressive Strength (UCS) recorded for untreated specimen is 615.45 N/mm^2 which is 86.5% higher than bare alloy. The highest UCS recorded for cryo treated specimen is 806.78 N/mm^2 which is very higher than bare alloy. Compared to untreated specimen, cryotreated specimen has higher value of UCS which indicates that cryo treatment improves the compressive strength of the specimen. Al 6061+10%SiC+4%Gr is best among combinations. The results of ultimate compressive strength are represented by graph which is shown in figure 13.

4.7. Fractrographic Observations

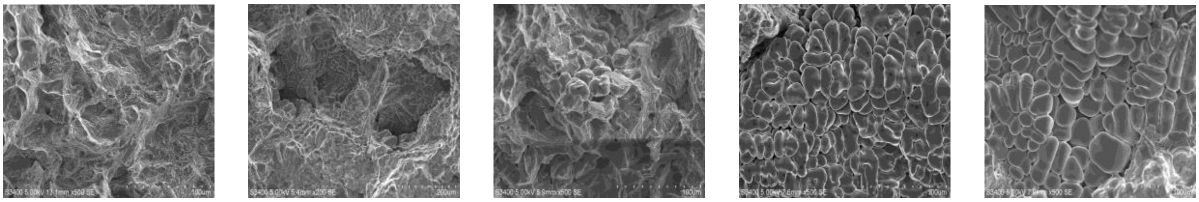

Fig.14.a. Fig.14.b. Fig.14.c. Fig.14.d. Fig.14.e.

Fig.14. Fractrography of untreated specimens a.Al6061 b. Al6061+2.5%SiC+1%Gr c. Al6061+5%SiC+2%Gr d. Al6061+7.5%SiC+3%Gr e. Al6061+10%SiC+4%Gr

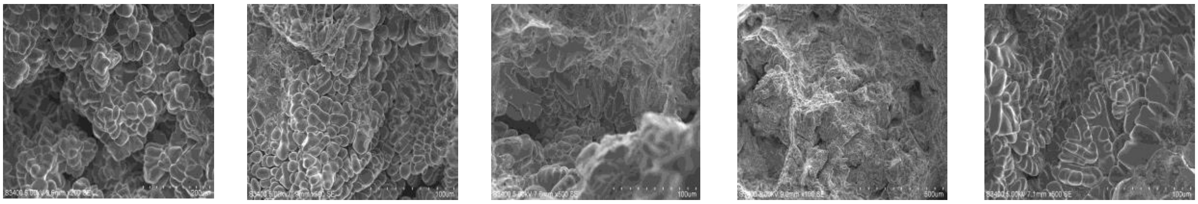

Fig.15.a. Fig.15.b. Fig.15.c. Fig.15.d. Fig.15.e.

Fig.14. Fractrography of cryo treated specimen a.Al6061 b. Al6061+2.5%SiC+1%Gr c. Al6061+5%SiC+2%Gr d. Al6061+7.5%SiC+3%Gr e. Al6061+10%SiC+4%Gr

The fracture surfaces after tensile testing with the pure Al6061 and various weight proportions of SiC and Gr particles of Al6061/SiC/Gr composite were investigated for recognizing the micro mechanisms of failure. The fractured surface of the specimens cut to a specified dimensions and ultrasonically cleaned in acetone then examined in SEM. Figure.14 and 15 shows the SEM fractographs for pure Al and various weight proportions SiC and Gr particles of Al/SiC/Gr composites. The numerous dimples, peak and voids were observed over the fracture surface for pure Al, indicating ductile fracture behaviour. As the SiC and Gr reinforced increases for Al composites the dimples should be a result of the void nucleation intergranular fracture of the Sic and Gr reinforcement and ductile rupture of the Al6061 alloy matrix

5. CONCLUSIONS

1. Al_4C_3 and Mg_2Si are the precipitating compounds after cryogenic treatment which are in brittle phase, which helps the composite to improve their characteristics. This is shown by EDS report by indicating their elements peak.
2. As the SiC percentage increases, characteristics of hybrid MMC have improved after the cryogenic treatment. But as the percentage of Gr increases above 2% decrease in mechanical properties are observed after cryogenic treatment.
3. Cryogenic treatment improves the crystalline structure of the hybrid MMC which is shown by XRD report.

4. Tensile properties improvement has been observed for cryo treated specimens. The cryotreated Al 6061+5%SiC+2%Gr composite has shown optimum value. As the percentage of Gr increases above 2% decrease in tensile strength has been observed.
5. Compressive strength increases as the percentage of reinforcement increases. Cryo treated specimens have shown higher values compared to untreated specimens. The cryotreated Al6061+10%SiC+4% composite have shown optimum value.
6. The failure of the composites was shown to consist of intergranular fracture of the Sic and Gr reinforcement and ductile rupture of the Al6061 alloy matrix

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