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Evaluation of Heat Treatment Effect on Fracture Behavior of Aluminum Silicon Carbide Graphite Hybrid Composite

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Abstract:

Aluminum Silicon Carbide Graphite hybrid composite is a potential material for automotive and aerospace applications because of its properties like enhanced hardness, solid lubrication imparted by silicon carbide and graphite respectively. In the present research ageing heat treatment influence on fracture toughness of the hybrid composite was investigated. Aluminum 6061 silicon carbide graphite hybrid composite was fabricated through liquid metallurgy route by creating a vortex in the molten slurry and compact tension specimens for fracture toughness testing were prepared by wire EDM process. Ageing heat treatment on solutionising heat treated hybrid composite compact tension specimens for fracture toughness testing was carried out using muffle furnace at 170^0 and 270^0 C. As cast and ageing heat treated hybrid composite specimens were tested for finding the fracture toughness using Nano Universal Testing Machine.

The average fracture property of the composite ageing heat treated at 170^0C was found to be superior to as cast composite and the composite ageing heat treated at 270^0C, while the composite aged at 270^0C was found to have inferior fracture toughness compared to as cast hybrid composite. Microstructure analysis of 170^0C ageing heat treated specimens revealed precipitation of fine particles which attributes to enhanced fracture toughness. Dendritic microstructure formed in 270^0 C ageing heat treated hybrid composite resulted in lower fracture toughness.

Keywords: Aluminum Hybrid Composite, Ageing Heat Treatment, Solution Heat Treatment, Fracture Toughness.

INTRODUCTION

More than one type of reinforcement in a hybrid composite facilitates tailor-making a composite material to meet specific property requirement. Hybrid aluminum composite containing soft solid lubricant like graphite and hard reinforcement like SiC is the potential material for automotive and aerospace applications because of its enhanced hardness and tribological properties. Suresh and Shridhar conducted parametric studies on tribological behavior of aluminum SiC graphite hybrid composite and their investigation revealed that graphite reinforcement volume fraction hike up to 7.5% reduces the wear and further increase in graphite percentage leads to increase in wear tendency[1]

Achutha M V et.al., conducted three stress level fatigue tests on stir cast aluminum SiC graphite hybrid composite to arrive at stress life curves. Comparison of stress life curves of hybrid composite with the base alloy concluded that fatigue resistance of hybrid composite is superior to its base alloy [2].

Experiments carried out to investigate the volume fraction, particle size and matrix strength influence on fatigue behavior of aluminum 2124 SiC composite concludes that decrease in reinforcement particle size and increased volume fraction results in enhanced yield and tensile strength. Reinforcement of SiC enhancing the tensile strength improves fatigue resistance [3].

Investigation to evaluate the effect of cold deformation and solution heat treatment on tensile and fracture behavior of AA 6063/Al_2O_3 composites suggested that solutionising heat treatment and cold deformation results in uniform distribution of alumina particles in the matrix alloy and reduced porosity.

Increasing alumina volume percent decreases the fracture toughness but increased degree of cold deformation enhances fracture toughness [4].

Experimental studies on fracture toughness of aluminum 6061 reinforced with fine SiC particles revealed that fracture toughness is influenced by reinforcement particle size and finer the reinforcement. In coarse particle reinforced composite crack initiation and fracture happens because of the void in the matrix alloy around reinforcement particles ahead of main crack. Fine particle reinforced composite fracture is associated with the boundaries between matrix alloy and the reinforcing particle clusters [5].

Experimental studies carried out to investigate the effect of ageing heat treatment on fracture behavior of aluminum (6063) silicon carbide particulate composite concluded that, ageing heat treatment performed at 180^0C for 3 hours followed by water quenching has a significant influence on improving the fracture toughness [6]. Fine needle shaped particles precipitation in the aluminum 6082 alloy ageing heat treated at 190^0C for 6 hours improves the mechanical properties with combination of good fracture toughness. Aluminum 6082 alloy ageing heat treated at temperatures 130^0 and 160^0 C for 17 hours results in under aging which leads to improved fracture toughness. Over ageing adversely affects on fracture, hardness and mechanical properties [7].

Aging heat treatment on aluminum 7090 SiC particulate composite enhances the fracture toughness. The fracture toughness first decreases and then increases with elongation of aging time [8].

Adnan et al.[9], studies on the influence of annealing, natural ageing and artificial ageing on strain life of aluminum alloy 6061 revealed that annealing heat treated alloy specimens exhibit higher value of transition fatigue life followed by naturally aged and artificially aged specimens.

Aluminum SiC Graphite hybrid composite could be the potential automotive material because of its enhanced strength, hardness and solid lubrication properties. Though the literature suggests that hardness and strength of the hybrid composite can be further improved by ageing heat treatments, work related to influence of ageing heat treatment on fracture toughness property of the composite is limited. Fracture toughness being essential property of the automotive material there is scope for investigating the heat treatment influence on fracture behavior of aluminum SiC graphite hybrid composite.

MATERIALS AND METHODS

Materials

Matrix material chosen for the hybrid composite is aluminum 6061 alloy which is age hardenable. Silicon carbide of particle size 50µm (2%wt) and graphite of particle size 70µm (3%wt) were used as reinforcements.

Fabrication of Hybrid Composite by Stir Casting Process

The graphite crucible in the muffle furnace was heated to 500°C initially and then temperature was gradually increased up to 900°C. Elevated temperature of the muffle facilitates quick alloy melting, reduced oxidation level and the reinforcement particle wettability improvement in the matrix alloy. Known weight of Al6061 which is free from dust particles was then poured in the crucible for melting. Stirrer was switched on once alloy is converted to molten state. With the help of speed controller stirrer rpm was gradually increased from 0 to 400 rpm. Temperature of the heater was set to 630°C which is below the melting temperature of the matrix. Stirring at 630°C resulted in a uniform semisolid stage of the matrix alloy. Reinforcing materials silicon carbide (2%wt) and graphite (3%wt) which were preheated to 500°C for half an hour, poured in semi solid matrix. Pouring of preheated reinforcements at the semisolid stage of the matrix reduces the particle settling at the bottom of the crucible improves the wettability of the reinforcement. Stirrer was turned off and and then molten composite slurry was poured in the metallic mould preheated to 500^0C. Preheating the mould ensures molten condition of the slurry throughout the pouring. While pouring the slurry in the mould the flow of the slurry was kept uniform to avoid trapping of gas. After cooling hybrid composite castings were removed from the mould.

Compact Tension Fracture Toughness Testing Specimen

Hybrid composite compact tension specimens for fracture toughness testing were prepared by wire EDM process. Dimensions of the ASTME399 standard compact tension specimen are as shown in Fig.1.

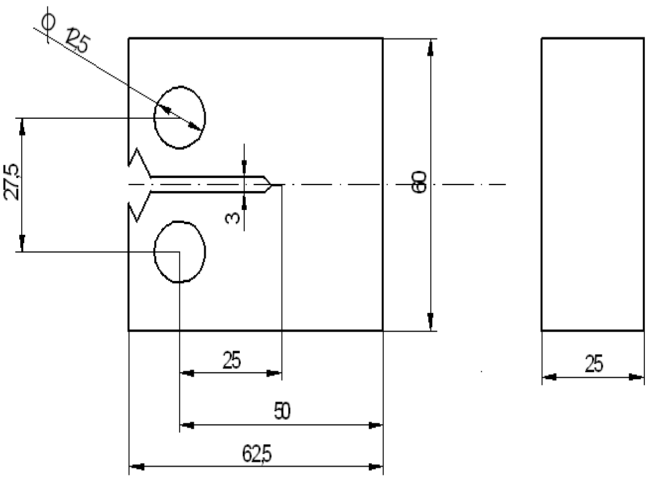

Figure 1. Compact tension fracture toughness specimen

Tensile Test Specimen

Dimensions of ASTME08 tensile test specimens used to determine the yield strength of as cast and ageing heat treated hybrid composite are as shown in Fig.2.

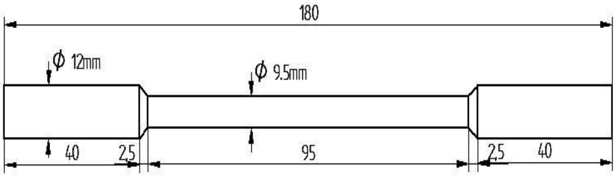

Figure 2. Tensile test specimen

Solutionising and Ageing Heat Treatments

The as cast Al6061-SiC-Gr hybrid composites were subjected to solutionizing heat treatment by placing the standard specimens in muffle furnace at a temperature 500^0C for a period of 90 minutes, followed by quenching in water

Artificial aging heat treatment was carried out by placing the solution heat treated specimens in muffle furnace for duration of about 2 hours at a temperature of 170^0 C, followed by air cooling. Over aging heat treatment was carried out by placing the solution heat treated specimens in muffle furnace for duration of about 2 hours at a temperature of 270^0 C, followed by air cooling

Fracture Toughness Testing

The fracture toughness testing was carried out on a Nano Universal Testing Machine. The CT specimens were loaded in the tensile testing clevis (with circular loading pins) of the machine and a clip gauge was fixed to the knife-edge of the specimen to measure the crack mouth opening displacement (COD). Initially, the specimens were subjected to fatigue loading to induce the fatigue pre cracks. Fatigue pre crack of 1.3 mm was induced in the CT specimen by applying 5 kN maximum load and 0.5 kN minimum load at 100 Hz for 10^5 cycles of fatigue loading. Fatigue pre cracked specimens were subjected to tensile loading to find the maximum fracture load that the specimen can withstand. The loading was carried out in such a way that during the initial elastic displacement the stress-intensity factor increase rate is between 0.55 and 2.75MPa√m. The plot of load against crack mouth opening displacement (COD) was used to determine the fracture toughness of the hybrid composite specimen.

Microstructure-Observation

Fine grinding and then polishing are performed on as cast and ageing heat treated hybrid composite specimens. Polished specimens are immersed in Keller's etch for 10 seconds. Microstructure analysis is carried out using optical metallurgical microscope.

RESULTS AND DISCUSSIONS

Fracture Toughness

The yield strengths of as cast, 170^0C ageing heat treated and 270^0C ageing heat treated hybrid composite specimens determined by tensile testing were found to be 86MPa, 80MPa and 91Mpa respectively.

Load versus crack opening displacement (COD) plotted for as cast and ageing heat treated hybrid composite compact tension specimens are as shown in figures 3,4,5,6 and 7.

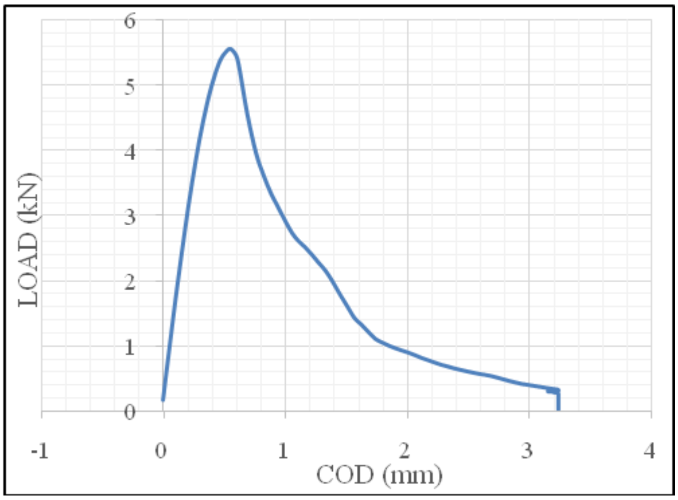

Figure 3. Load vs crack opening displacement of as cast specimen

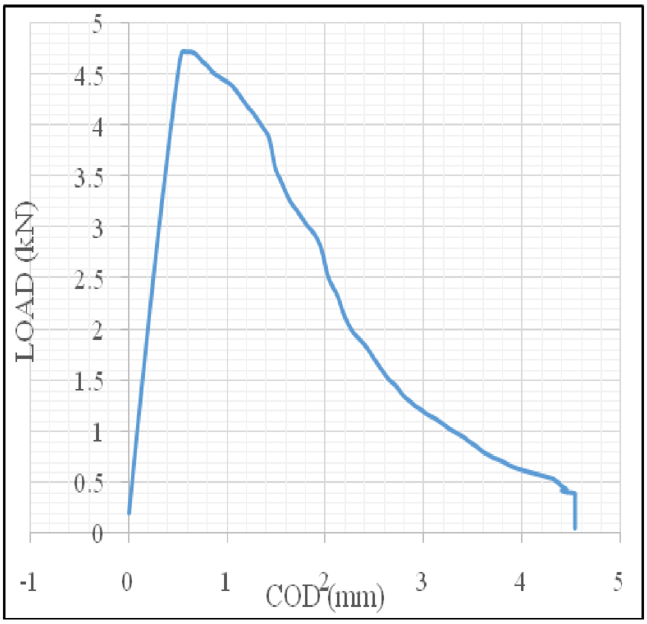

Figure 4. Load vs crack opening displacement of 170^0C ageing heat treated specimen-I

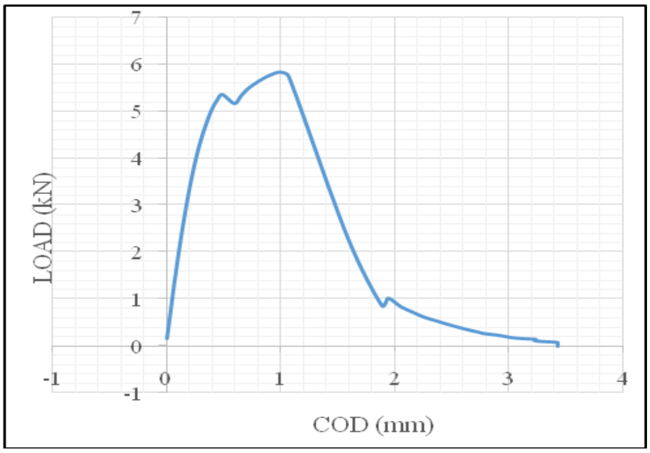

Figure 5. Load vs crack opening displacement of 170^{0}C ageing heat treated specimen-II

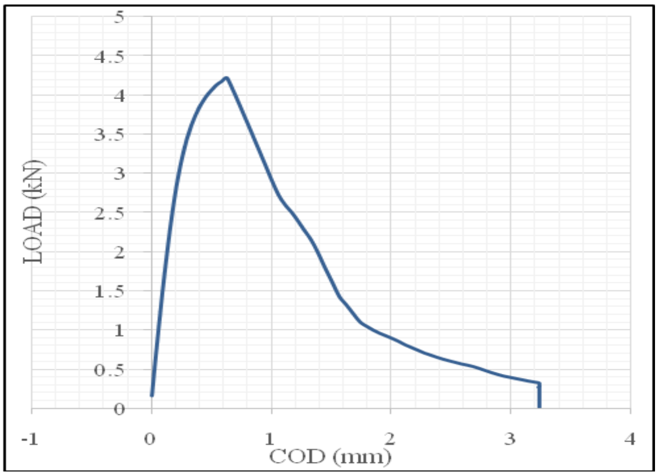

Figure 6. Load vs crack opening displacement of 270^{0}C ageing heat treated specimen-I

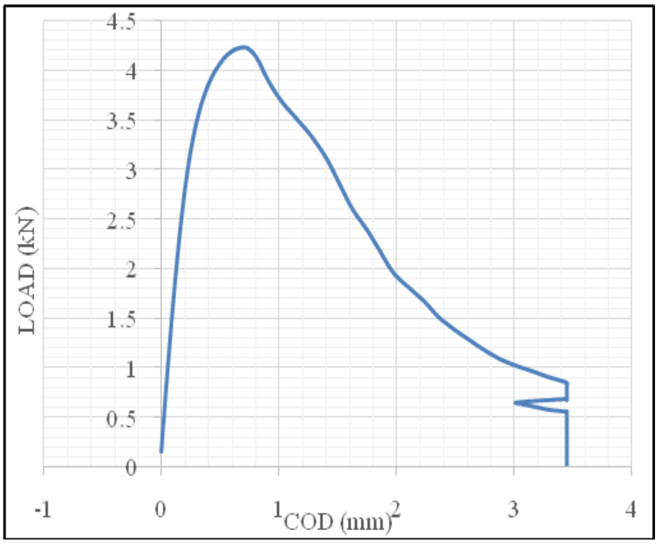

Figure 7. Load vs crack opening displacement of 270^{0}Cageing heat treated specimen-II

The force P_Q at a 5 % secant offset from the initial slope is established by a specified deviation from the linear portion of the record. The value of K_Q is calculated from this force using equation $KQ = \frac{PQ}{B\sqrt{W}} f\left(\frac{a}{w}\right)$ where

$$f\left(\frac{a}{w}\right) = \frac{\left(2+\frac{a}{w}\right)}{\left(1-\frac{a}{w}\right)^{\frac{3}{2}}}\left[0.886+4.64\frac{a}{w}-13.32\left(\frac{a}{w}\right)^2+14.72\left(\frac{a}{w}\right)^3-5.6\left(\frac{a}{w}\right)^4\right]$$

Compact tension fracture toughness specimens used have a/W = 0.5, B = 25 mm, W =50 mm. Using the above data and formulae, the values of fracture toughness (K_Q) obtained are tabulated in Table 1.

Table 1. Results of fracture toughness testing

Specimen	P_{MAX} (kN)	P_Q (kN)	K_Q MPa√m)	K_{1C} MPa√m)
As-cast	5.565	3.833	6.771	6.771
170^{0}C Ageing Heat treated Specimen-I	4.718	4.258	7.521	7.521
170^{0}C Ageing Heat treated Specimen-II	5.84	4.5	7.949	7.949
270^{0}C Ageing Heat treated Specimen-I	4.25	2.52	4.451	4.451
270^{0}C Ageing Heat treated Specimen-II	4.23	2.53	4.469	4.469

Criteria for validating plane strain fracture toughness (K_{1C}) test, crack length $a \geq \left[\frac{KQ}{\sigma y}\right]^2$ or thickness $B \geq \left[\frac{KQ}{\sigma y}\right]^2$ is satisfied for all the K_Q values determined. Hence fracture toughness results are validated and K_Q is equal to plane strain fracture toughness (K_{1C}).

Fracture toughness and yield strength of the hybrid composite as shown in Fig.8 reveals that as the yield strength decreases, fracture toughness enhances.

Microstructure Analysis

Optical metallurgical microscopic image of as-cast composite specimen as shown in Fig.9 reveals that second phase particles are fully dissolved in the aluminum solid solution and are not visible as precipitates. Microstructure of the composite 170^{0}C ageing heat treated as shown in Fig.10 consists of fine precipitates in the aluminum solid solution. Coarse dendritic precipitated particles are observed in the microstructure 270^{0}C ageing heat treated hybrid composite specimen as shown in Fig.11.

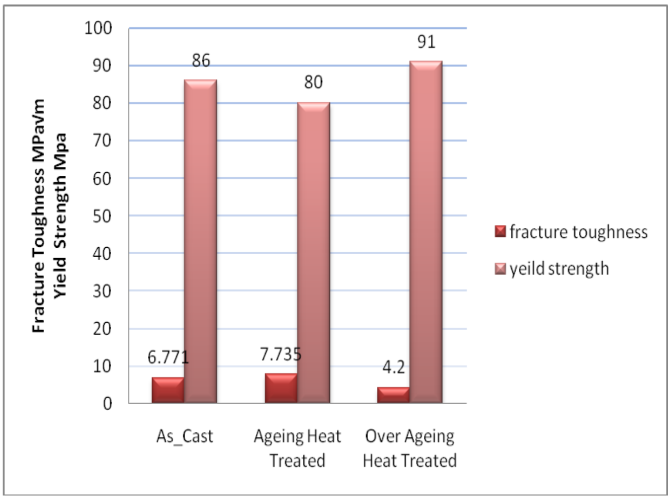

Figure 8. Fracture toughness and yield strength of hybrid composite

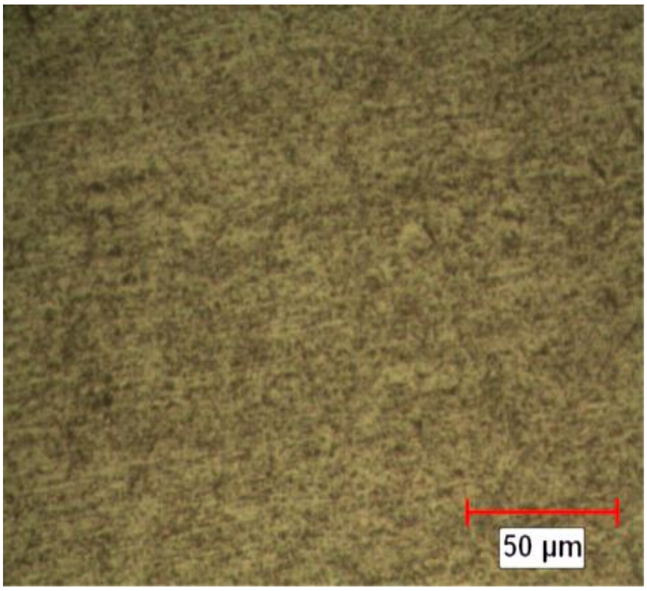

Figure 9. Micrograph of as-cast hybrid composite

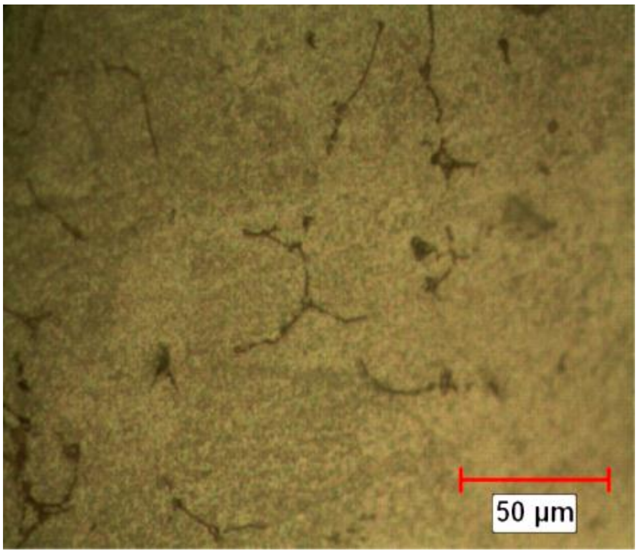

Figure 10. Micrograph of 170^{0}C ageing heat treated hybrid composite

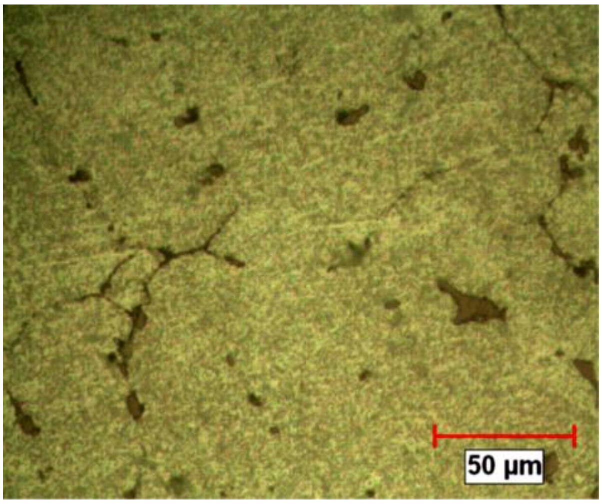

Figure 11. Micrograph of 270^{0}C ageing heat treated hybrid composite.

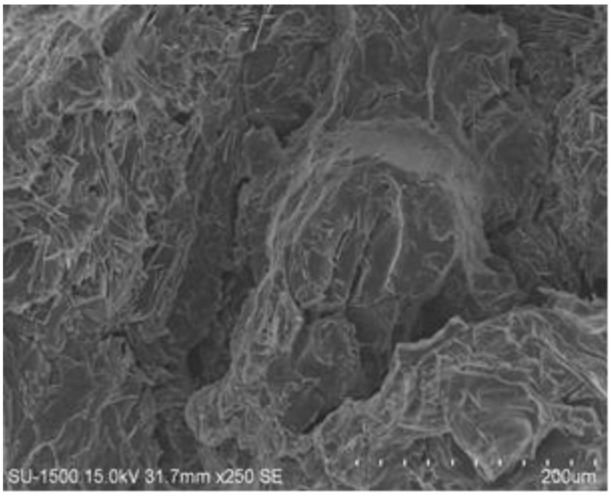

Figure 12. Fractured surface SEM image of as cast specimen

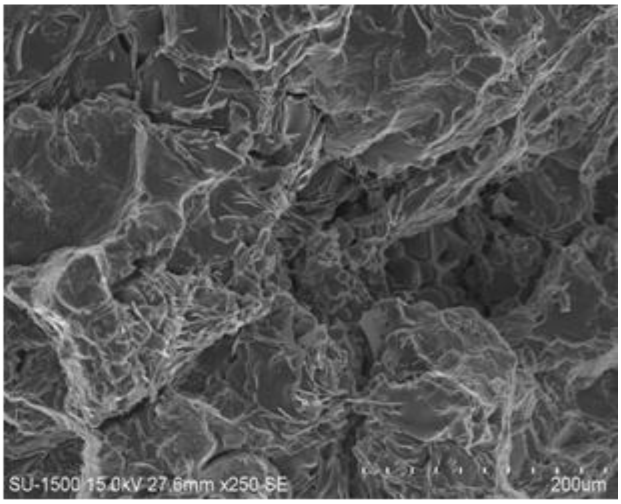

Figure 13. Fractured surface SEM image 170^0 C ageing heat treated specimen

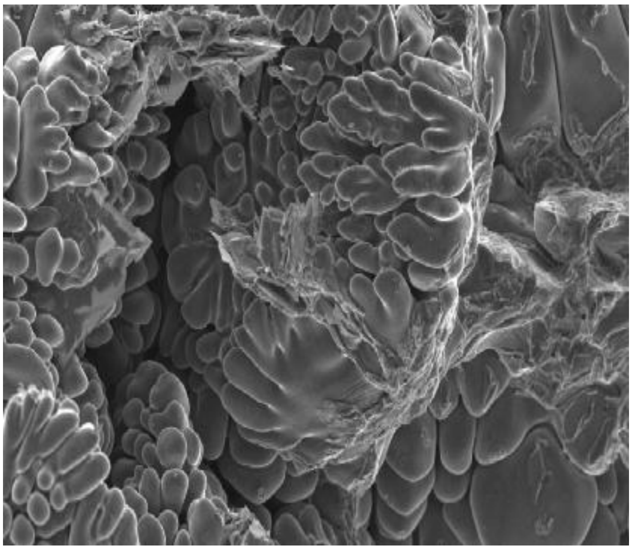

Figure 14. Fractured surface SEM image of 270^0 C ageing heat treated specimen

Comparison of SEM images of fracture failed specimens as shown in figures 12,13 and 14 confirms formation of coarse dendritic microstructure in 270^0 C ageing heat treated hybrid composite. Microstructure of 170^0 C ageing heat treated hybrid composite is finer than 270^0 C ageing heat treated hybrid composite and coarser than as cast specimen. Precipitation of fine second phase particles in hybrid composite aging heat treated at 170^0 C enhances the fracture toughness

CONCLUSIONS

1. Ageing heat treatment at 170^0C results in precipitation of fine particles in the matrix. Ageing heat treatment at 270^0C causes precipitation of coarse dendritic particles.
2. Fracture toughness of the hybrid composite ageing heat treated at 170^0C is superior to as cast and 270^0C ageing heat treated hybrid composite. Precipitation of fine particles attributes to enhancement in fracture toughness and decreased yield strength.
3. Fracture toughness of 270^0C ageing heat treated hybrid composite is inferior to as cast hybrid composite. Coarse dendritic particles precipitated result in decreased fracture toughness and enhanced yield strength.

REFERENCES

[1] Suresha S and Sridhara B K, “Parametric studies on the tribological behaviour of aluminum matrix hybrid composites”, International Journal on Design and Manufactring Technologies, 4, pp.15-20, 2010

[2] Achutha M V, Sridhara B K and Abdul Budan, “Fatigue life estimation of hybrid aluminum matrix composites”, International Journal on Design and Manufactring Technologies 2, pp.14-21, 2008

[3] Jody N Hall, J Wayne Jones and Anil K Sachdev, “Particle size, volume farction and matrix strength effects on fatigue behavior and particle fracture in 2124 aluminum-SiCp composites”, Materials Since and Engineering, A(183), pp. 69-80, 1994

[4] K.K Alaneme, “Mechanical behaviour of cold deformed solution heat treated alumina reinforced AA6063 metal matrix composites”, West Indian Journal of Engineering, Vol. 35, No.2, pp 31-35, 2013

[5] Lihe Qian, Toshiro Kobayashi, Hiroyuki Toda, Takashi Goda and Zhong-guang Wang, “Fracture toughness of a 6061 Al matrix composite reinforced with fine SiC particles”, Materials Transactions, Vol. 43, No. 11. pp 2838 to 2842, 2002

[6] K.K. Alaneme and A.O.Aluko, “Fracture toughness (K1C) and tensile properties of as-cast and age-hardened aluminum (6063)-silicon carbide particulate composites”, Scientia Iranica A, 19(4), pp.992-996, 2012. Vol. 35, No.2, pp 31-35, 2013

[7] G Mowka-Nowotnik, J Sieniawski and A Nowotnik, “Effect of heat treatment on tensile and fracture toughness properties of 6082 alloy”, Journal of Achievements in Materials and Manufacturing

[8] Engineering, 32, pp.162-170, 2009.

[9] Yuan Wu-hua and A N Bai-ling, “Effect of heat treatment on microstructure and mechanical property of extruded 7090/SiCp composite”, Trans. Nonferrous Met. Soc. China 22, pp.2080-2086, 2012.

[10] Adnan N Abood, Ali H Saleh and Zainab W Abdullah, “Effect of heat treatment on strain life of aluminum alloy AA 6061”, Journal of Materials Science Research, 2, pp.51-59, 2013.