Influence of Heat Treatment on Stress Intensity Factor of Nano Boron Carbide Hybrid Al2219 Composites with MoS2

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Abstract. The current work emphasizes on study of influence of heat treatment on Stress Intensity factor (K_{IC}) of Al alloy matrix hybrid composites. Hybrid composites with a constant Nano B4C content of 3 weight % and MoS2 of 4 weight % as reinforcements to Al2219 alloy matrix are fabricated by using two step stir casting technique and tested for Stress Intensity factor and fracture toughness as per ASTM standards. One set of composites are subjected to T6 type heat treatment. Compact Tension (CT) Specimen were prepared using wire EDM process and tested in BISS Axial Universal Testing Machine to find Stress Intensity factor (K_{IC}). From this study stability of crack propagation under mode-I failure is analyzed. Results show generous increment in energy required to open the crack and crack propagation is delayed in heat treated composites when compared to non-heat treated composites and furthermore improvement in fracture toughness of the heat treated specimen over non-heat treated specimen.

1. Introduction
Aluminium hybrid alloys are being the predominant material used in high temperature applications using nano boron carbide with molybdenum Disulphide as filler material. Greater part of engineering machine parts and structures are failed by fatigue and fracture cause issues [1]. Biggest challenge is to understand how materials fail and how crack begin and propagate, how it can be controlled and how to prevent such failures. Aluminium composites have most advantages in aircrafts, rockets and submarines. In aluminium metal matrix composites, ceramic materials are added as a reinforcing material which imparts better physical and mechanical properties which are impossible to get with monolithic alloys [2]. Usually researchers adopt molten metal stir casting technique or powder metallurgy for fabrication of ceramic-reinforced aluminium matrix composites [3]. Composite with B4C content of 3 weight % and MoS2 of 4 weight % as reinforcements to Al2219 alloy matrix yielded best results [4]. Al 2219 matrix composite is very suitable to age hardening irrespective of lower or
higher aging temperature. Clearly the composites show accelerated rate of aging kinetics as compared to unreinforced matrix alloy [5].

Sufficient investigation has not been accounted to come across the fracture toughness of heat treated nano B₄C hybrid composites. In the present work, the nano B₄C hybrid composite was fabricated by using two step stir casting technique. The aim of this study is to evaluate the influence of heat treatment on Stress intensity factor (Fracture toughness) of the nano B₄C hybrid composites. In this study, hard particle nano B₄C and dry solid lubricant MoS₂ are used as reinforcement for matrix material Al2219 to investigate the stress intensity factor of heat treated hybrid composites on Mode-I failure.

2. Synthesis of Hybrid Composite

2.1. Matrix and Reinforcement material

Table 1 shows the nominal composition of matrix material (Al 2219) and Table 2 shows the reinforcements used.

| Element | Mg | Si | Cu | Zr | Fe | Zn | Ti | V | Mn | Al |
|---------|----|----|----|----|----|----|----|---|----|----|
| % by Wt | 0.02 | 0.2 | 6.3 | 0.18 | 0.3 | 0.1 | 0.06 | 0.1 | 0.3 | Base |

Table 1: Composition (Wt. %) of Al2219 alloy

| Reinforcement | Wt% |
|---------------|-----|
| Nano B₄C     | 3 Wt% |
| MoS₂         | 4 Wt% |

Table 2: Composition (Wt. %) of Reinforcement

2.2. Stir casting technique

Stir casting technique is the Liquid Metallurgical Technique used to synthesis the hybrid aluminium composites with two step addition of reinforcement. Resistance furnace used for stir casting process is shown in figure 1. Matrix material Al2219 alloy was melted in graphite crucible, the mixture of Nano B₄C with MoS₂ were preheated at the temperature of 300°C before adding to melt. In order to eliminate absorbed gases present in melt a tablet of degassing agent is introduced into the melt and K₂TiF₅ is added with reinforcement as wetting agent. At the melt temperature of 750°C the preheated mixture of reinforcement were added into the Al2219 melt in step of two, because to avoid agglomeration. Zirconia coated stainless steel stirrer is used for stirring the melt, stirring is done for 5-6 min at 600 rpm spindle speed. The melt was poured into the preheated die and the obtained cast product is shown in figure 2.
2.3. T6 Heat Treatment (Age hardening treatment)
Heat treatment of selected samples of the composites produced was carried out using Muffle furnace as shown in figure 3. The samples were first solution-treated in the furnace at 530°C for duration of 2 hrs, followed by water quenching. Then, ageing was carried out at 180 °C for a period of 6 hrs, followed by water quenching.

3. Experimentation

3.1. Specimen preparation
For fracture toughness (KIC) test, Compact Tension (CT) specimen is prepared as dimensions are conformity to ASTM E-647 standard. The CT specimen prepared is shown in figure 4. A 7.6 mm of notch length is cut for pre-crack by using wire EDM shown in figure 5, so as to obtain a/w ratio of 0.3. Hole of 6.35 mm diameter is drilled by drilling process. Dimensions of CT specimen are shown in table 3.
Table 3: Dimensions of CT specimen

| Factor       | Dimension (mm) |
|--------------|----------------|
| Total length | 31.75          |
| Total width  | 30.48          |
| W            | 25.5           |
| Thickness    | 6.35           |
| Hole diameter| 6.35           |
| a(initial)   | 7.6            |

3.2. Experimental Procedure

The compact tension (CT) specimen is positioned in fixture in Axial universal testing machine as shown in figure 6. Fatigue crack growth according to ASTM-E-1820 standard following the equation (1) for fatigue loading.

\[
P_f = \frac{4.6Bb_o\sigma_y}{(2W+a_o)} \quad (1)
\]

\[
\sigma_y = \frac{\sigma_{YS} + \sigma_{TS}}{2} \quad (2)
\]

\[
b_o = W - a_o \quad (3)
\]

where \(a_o\) is initial crack length, \(W\) is the length from centre of hole grove to initial notch length, \(B\) is thickness of material. \(\sigma_y\) and \(b_o\) are obtained as shown in equation (2) and (3). All the inputs are given at the beginning of test such as standard dimension of specimen, properties of the material and fatigue pre-cracking load \(P_f\) is applied to produce pre-crack, then from this point material is loaded for \(K_iC\) test condition i.e., tension fatigue load is applied until the fracture occurs as shown in figure 7 and all the results and load v/s COD graph is formed and same procedure is repeated for different specimen.
4. Results and discussion
The Load v/s COD graphs clearly show the load required to open the crack. In figure 8(a), non-heat treated Al2219 as cast requires 2.01 KN of load to open up the crack. From figure 8(b), the heat treated Al2219 requires little more load to open up the crack than non-heat treated alloy. From figure 8(c), non-heat treated composite of Al2219-3Wt% B4C and MoS₂ of 4Wt% requires more load than as cast alloy due to the addition of B₄C and MoS₂ to Al2219 alloy. In the figure 8(d) heat treated composite of Al2219-3Wt% B₄C and MoS₂ of 4Wt% requires higher load than non-heat treated composite. Thus heat treated composite specimen requires higher load to open up the crack compared to other specimen prepared. Comparison of Stress Intensity Factor of various samples indicated in the figure 9. The results clearly indicates that heat treated hybrid alloy possess higher stress intensity factor.
Table 4: Validation of $K_{IC}$

| Material                             | $P_{max}/P_Q$ | $K_{IC}$ (MPa m$^{0.5}$) | % increase in $K_{IC}$ |
|--------------------------------------|---------------|---------------------------|------------------------|
| Al2219                               | 1.051         | 21.62                     | -                      |
| Al2219-Heat treated                  | 1.059         | 23.56                     | 8.9                    |
| Al2219-3%B$_4$C-4%MoS$_2$            | 1.073         | 26.01                     | 20.3                   |
| Al2219-3%B$_4$C-4%MoS$_2$ - Heat treated | 1.093     | 28.12                     | 30                     |
The addition of reinforcement to hybrid composite reduces the inter-particle arrangements and thus creating obstacle to the movement of dislocation and thus addition of B₄C and MoS₂ to aluminium matrix creates higher resistance to open up the crack front thereby increasing the load bearing capacity and also increase in stress intensity factor. Further the load bearing capacity and stress intensity factor of heat treated cast alloy and composites is much more than the non-heat treated as shown in table 4.

5. Conclusion
This work makes an attempt to find the Stress Intensity Factor of heat treated and non-heat treated Nano Boron Carbide Hybrid Composites under mode I failure. The composites were prepared with uniform distribution of B₄C and MoS₂ which resulted in increase in bearing load to open the crack front. When compared to as-cast alloy and non-heat treated composites, the heat treated composite Al2219- 3wt%B₄C- 4wt%MoS₂ has higher Stress intensity factor. Thus the heat treatment of composites resulted in better fracture toughness.

6. References
[1] N. G. Siddesh Kumar, G. S. Shiva Shankar, S. Basavarajappa “Some studies on mechanical and machining characteristics of Al2219/n-B4C/MoS2 nano-hybrid metal matrix composites” Elsevier Journal of Measurement 107 (2017) 1–11
[2] A.K.M. Asif Iqbal, Dewan Muhammad Nuruzzaman, Effect of the Reinforcement on the Mechanical Properties of Aluminium Matrix Composite: A Review by, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 11, Number 21 (2016)
[3] Dipti Kanta Das, Purna Chandra Mishra, Saranjit Singh, Swati Pattanaik Fabrication and heat treatment of ceramic reinforced aluminium matrix composites – a review by, International Journal of Mechanical and Materials Engineering( 2014), 1:6
[4] Niranjan D. B., G. S. Shiva Shankar and Latha B. Shankar - Study on fracture behaviour of Hybrid Aluminium Composite - MATEC Web of Conferences 144, 02012 (2018)

[5] Gowrishankar.M.C, Sathyashankara Sharma, B.K.Pavan, „Mechanical characterization of heat treated Al2219 hybrid composites, Journal of Mechanical Engineering and Sciences ISSN (Print): 2289-4659; e-ISSN: 2231-8380 Volume 13, Issue 1, pp. 4380-4389, March (2019)