Estimation of fracture parameters for Al-SiC and Al-Fe$_2$O$_3$ metal matrix composites

S Jacob$^1$, R Sridhar$^2$ and S Joseph Irudaya Raja$^3$
$^1$Assistant professor, Department of Automobile Engineering, Vels University, Chennai, Tamilnadu, India
$^2$Assistant professor, Department of Mechanical Engineering, Vels University, Chennai, Tamilnadu, India
$^3$Assistant professor, Department of Mechanical Engineering, Vels University, Chennai, Tamilnadu, India

E-mail: jacobthermal@gmail.com

Abstract. In this paper silicon carbide and iron oxide is reinforced with aluminum matrix. The prepared composite provide high strength than the commercial composite. It provides high elastic properties and high service temperature. Since this material have great scope in space application it has been chosen for estimation of fracture toughness. Hence grain size of the samples increased this is due to the effect of reinforcement bonding with aluminum matrix. The CMOD test has been carried out for this Purpose. Microscopic examination has shown that with increase in of reinforcement test confirmed that with increase in reinforcement ratio the fracture toughness also increased. In this work specimens have been preferred with and without addition of SiC and Fe$_2$O$_3$ to compare the influence. The results are compared and it has been studied that Fracture Toughness increased significantly by addition of inclusions.

1. Introduction

Metal matrix composites offer the ameliorated concrete properties as well as incremented elevated temperature performance relative to their unreinforced alloys. These are critical impute for many aero engine applications, making composites alluring contempt their higher cost. For brittle matrix systems such as inter-metallic, reinforcement can withal be utilized as an expedient of ameliorating toughness. In this paper, a wide range of long fiber and discontinuously reinforced composite systems are considered from an aero engine perspective predicated on Aluminium, titanium, and inter-metallic matrices peregrinating from moderate-temperature systems towards sultry ones. Processing methods felicitous to each type are described [2]. Properties such as concrete stiffness, strength, creep, and fatigue performance are considered. Another paramount aspect is the predisposition to engender residual stresses as a function of the discrepancy in thermal expansion between the phases [3]. In the final section a range of potential aero engine applications is examined. In this paper, stir casting process was adopted for preparing Aluminum matrix composite which is reinforced with various weight fractions (1\% and 3\%) and investigations are carried out by using SEM, EDAX, and CMOD [4].
2. Methodology

In this work stir casting is been followed for preparing the composites. In stir casting process uniform distribution of reinforcing particles is ensured by adding 5gms of reinforcement with 1 kg of Aluminum. The Aluminum is melted in a crucible by heating it in a muffle furnace at 800°C for one hour. The grain size of the Aluminum oxide particles used is 150 µm. The furnace temperature was first raised above the liquidus temperature of Aluminum near about 950 °C to melt the Al alloy thoroughly [6]. A pink colored powder (Scum powder) Hexachloroethane is added to the melted Aluminum to remove the Slag from the melt. A degassing flux is added to remove the bubbles from the melt. Then the melted Aluminum is cooled down just below the liquidus to keep the slurry in Semi solid state. Automatic stirring was carried out with the avail of radial stirrer operated for about 10 minutes at stirring rate of 125 rpm. In order to minimize gas stored in the molten matrix during stirring, the stirring speed and the stirrer location was placed at a concrete location [7]. At this stage, the preheated SiC and Fe₂O₃ particles were integrated manually to the vortex. In the final commixing processes the furnace temperature was controlled within 700 ± 10°C. After stirring process the melt was poured in the sand mould to get desired shape of specimen in Figure 1.

![Fabrication of composites](image)

Figure 1. Fabrication of composites

3. Results and Discussion

3.1. Optical Microscopic Examinations

Sample: 1 Al

Imported model in ANSYS workbench

Magnification: 100X  Etchant: H.F. soln
The metal matrix shows fine grains of Al-Si eutectic in aluminium solid solution. The constituents of phases present in the matrix are Mg$_2$Si and some Cu-Al$_2$ phases that are present in random distribution. As it is chill cast, the dendritic pattern of the grains is cored towards the direction of the chilled plate. No directional orientation could be seen in castings. The scanning of the plate in cross-section shows freedom from casting defects like shrinkage and micro porosities. The grains are finer due to the additives used and being a small area/volume casting.

Sample: 2 Al-SiC (1%)
used and being a small area /volume casting. The presence of Fe\textsubscript{2}O\textsubscript{3} could be seen but cannot be confirmed. The microstructure by using SEM followed by EDAX can give the composition of the particles.

3.2. Crack mouth opening displacement test
In the CMOD test the specimens are proportional. If the thickness is represented by ‘A’, then the depth will either be ‘A’, for a square cross section, or, ‘2A’ for a rectangular cross section with the standard length being ‘4.6A’. To prepare a specimen for a CMOD test, a incision on the surface is machined in the centre of the specimen and then an authentic fatigue crack is conscientiously induced at the base of the notch. The crack must be long enough to pass through any area showing plastic deformity caused by the machining process.

![CMOD Test Specimen](image)

**Figure 2. CMOD Test Specimen**

![CMOD Testing Sample](image)

**Figure 3. CMOD Testing Sample**

3.3. EDAX Test

![Quantitative Results for: Base(793)](image)

**Figure 4. Quantitative Results for: Base(793)**
EDAX Test Results For Fe$_2$O$_3$

Figure. 5. Quantitative Results for Base(792)

Table 1. Quantitative Results for Base(792)

| Element | Net Counts | Weight % | Atom % |
|---------|------------|----------|--------|
| O       | 10354      | 14.66    | 37.49  |
| Fe      | 35993      | 85.34    | 62.51  |
| Fe      | 6387       | ---      | ---    |
| Total   |            | 100.00   | 100.00 |

Table 2. J Integral test values for Al

| Rec No | Max Load | Max Disp | Compliance | Crack Length | Kmax | Jmax | Jel | Jpl | Area Total | Area Elastic | Area Plastic |
|--------|----------|----------|------------|--------------|------|------|-----|-----|-------------|--------------|--------------|
|        | kN       | mm/kN    | mm         | MPa/m        | kJ/sq-m | kJ/sq-m | kJ/sq-m | kN-mm | kN-mm | kN-mm |
| 1      | 0.278    | 0.089    | 0.220259   | 14.526       | 6.244 | 0.632 | 0.504 | 0.008 | 0.014 | 0.012 | 0.017 |
| 2      | 0.283    | 0.164    | 0.227537   | 14.684       | 9.256 | 1.935 | 1.256 | 0.666 | 0.034 | 0.034 | 0    |
| 3      | 0.256    | 0.242    | 0.254812   | 14.793       | 10.254 | 3.985 | 1.778 | 2.256 | 0.076 | 0.036 | 0.052 |
| 4      | 0.267    | 0.344    | 0.288645   | 15.251       | 11.235 | 5.325 | 1.987 | 4.985 | 0.112 | 0.054 | 0.089 |
| 5      | 0.281    | 0.432    | 0.342564   | 15.625       | 11.48  | 7.325 | 1.856 | 5.652 | 0.165 | 0.014 | 0.145 |
| 6      | 0.279    | 0.534    | 0.234561   | 16.234       | 10.825 | 9.365 | 1.652 | 7.562 | 0.152 | 0.016 | 0.15  |
| 7      | 0.269    | 0.634    | 0.477352   | 16.256       | 8.852  | 9.256 | 0.787 | 7.652 | 0.952 | 0.017 | 0.195 |
| 8      | 0.280    | 0.614    | 0.692652   | 17.679       | 7.765  | 10.462 | 0.658 | 9.762 | 0.298 | 0.013 | 0.215 |
| 9      | 0.258    | 0.802    | 0.820123   | 18.065       | 5.984  | 10.658 | 0.985 | 10.225 | 0.478 | 0.008 | 0.225 |
Figure 6. J integral vs Crack increment

Figure 7. Load VS Displacement
Validation condition
1. Thickness, $B>25*JQ/Yield\ stresses$
2. Initial ligament, $b_0>25*JQ/Yield\ stresses$
3. Slope of power law regression line, $dJ/da$, evaluated at $\Delta aQ$ is less than the yield stress.

Stress Intensity Factor
The stress intensity factor, $K$, is calculated to estimate the “stress intensity” near the tip of a crack generated by a distant load or leftover stresses. It is a theoretical construct conventionally applied to a homogenous, linear elastic material and is peripheral for providing a failure criterion for brittle materials. The concept can withal be applied to materials that exhibit minute scale yielding at a crack tip. The magnitude depends on sample geometry, the size and location of the crack and magnitude and modal distribution of loads on the material. Linear theory presages that the stress distribution ($\sigma_{ij}$) near the crack tip, in polar co-ordinates ($r, \Theta$) with origin at the crack tip, has the form. It is denoted $K_{IC}$ and has the units of $K_{IC} = Y (3PS\sqrt{a}) / 2TW^2$

$$Y= 1.9-3.07 \ (a/w) +14.53 \ (a/w) 2-25.11 \ (a/w) 3+25.80 \ (a/w) 4$$

Where

$P=$ Critical load for crack propagation $S=$ Length of the span

$a=$ Crack length $T=$ Thickness , $W=$ Width

$Y=$ Non dimensional shear factor

J- Integral
The J integral is a line integral (path-independent) around the crack tip. It has huge consequentiality in elastic-plastic fracture mechanics. In materials science, fracture toughness is a property which describes the facility of a material containing a crack to resist fracture, and is one of the most paramount properties of any material for many design applications. The linear-elastic fracture toughness of a material is resolute from the stress intensity factor ($K$) at which a thin crack in the material commences to grow. Plastic-elastic fracture toughness is denoted by JIC, with the unit of...
J/cm² or lbf-in/in², and is an expression of the energy required to grow a thin crack.

\[ J_{IC} = \frac{K_{IC}^2}{E} \]

Where

- \( K_{IC} \) = Stress intensity factor
- \( E \) = Young’s modulus of the material

### Table: 3 Stress intensity factor and J- Integral value of specimen

| S. No | Samples         | \( K_{IC} \) (MPa m) | \( J_{IC} \) (Pa m) |
|-------|-----------------|-----------------------|---------------------|
| 1     | Al (pure)       | 4.18                  | 249.61              |
| 2     | Al+ 3%SiC       | 6.931                 | 686.23              |
| 3     | Al+3%Fe\(_2\)O\(_3\) | 9.932               | 1409.23             |

### 4. Conclusion

The following are concluded from the above analysis:

- It has been studied that Fracture Toughness increased significantly by addition of reinforcements.
- The addition of Fe\(_2\)O\(_3\) has more significant fracture toughness when compared to SiC.

So by all the tests carried out, it has been concluded that the specimen with 3% reinforcement is having superior properties.

### 5. References

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