Finite Element Simulation of Fracture Toughness of Al6061 Reinforced with Silicon Carbide

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Abstract. The main objective of the work is to study the fracture behaviour of AA6061-Silicon Carbide material using finite element method. Fracture toughness analysis of AA6061-Silicon Carbide composite has been carried out using finite element methods. Modelling of compact tension specimens was utilized to analyze the fracture toughness using the ANSYS tool. From the results of the comparison, it is recommended that AA6061-9 wt% silicon carbide particulate composite material can be potentially utilized as a replacement of AA6061 in the aerospace application such as helicopter rotor blades.

Keywords: Aluminium alloy, Metal matrix composite, AA6061-Silicon Carbide, FEM, Fracture toughness, compact tension specimens.

1. Introduction

Many two dimensional, three dimensional tutorials ware also available to evaluate the fracture toughness [1-4] using finite element methods, most of them ware used ANSYS tool for the same. While simulating the fracture related issues, it requires the use of PLANE182, which will fit the crack tip section. PLANE182, as shown in figure 1, is a higher order form of the 2-D, eight-node component. It gives more exact outcomes to blended (quadrilateral-triangular) automatic meshes and can hold up under sporadic shapes without as much loss of accuracy. The 8-node components have ideal displacement shapes and are appropriate to model curved boundaries.

The 8-node component is characterized by eight nodes having two degrees of freedom at every node: interpretations in the nodal x and y directions. The component might be utilized as a plane component or as an axis-symmetric component. The component has stress stiffening, large deflection, plasticity, creep, swelling, and extensive strain abilities. The stress intensity factors at a crack for a linear elastic fracture mechanics analysis may be computed. The analysis uses a fit of the nodal displacements in the vicinity of the crack.

Literature shows that failure of helicopter occurred is at the threaded hole region of rotor blade. Many helicopter rotor blades are failed due to the fatigue loading, corrosion of threaded holes [7-8].
Literatures also shows that many helicopter failures occurred in air i.e in the operational conditions [7-9]. Crack developed and propagated, in the rotor blade fittings i.e., bolt hole [8,10], edge spar [9] without giving any prior indication. Many researchers reported that main rotor blades are made of aluminum 6061-T6 alloy [7-11].

![Figure 1. PLANE182 Geometry](image)

Yasmin Begum et al [12], Saleemsab Doddamani et al [13] worked on aluminum matrix reinforced with graphite particles has been studied for the mechanical and fracture characteristics of the composite respectively. ASTM has prescribed compact tension specimen for the fracture toughness testing [14]. Saleemsab Doddamani et al [15] uses compact tension specimen to study the fracture toughness of Al6061-graphite MMC at varied weight fractions. S Doddamani et al [13] utilizes ANSYS software to study the fracture toughness of Al6061-graphite. K.K. Alaneme et al [16] studied the fracture toughness of Al6063-SiC particulate MMC. It is observed from the results of the fracture toughness testing of Al6061-graphite [15] and Al6063-SiC [16] that Al6061-graphite composite has more fracture toughness values.

From the literature it is identified the helicopter rotor blade, made of AA6061, was failed at the threaded portion of the rotor blade. The main objective of the work is to study the fracture behavior of AA6061-SiC material using finite element method [18-20]. The finite element model is built for the AA6061 and AA6061-SiC composite. Through this work an attempt has been made to compare the existing use of material with the composite material to prepare the helicopter rotor blade so as to enhance its fatigue crack resistance property.

2. Materials Selection
In the present work aluminium 6061 is utilized as a matrix and silicon carbide particles are used as reinforcement. A precipitation-hardened aluminium (AA6061) alloy has its main alloying elements as magnesium (0.81 wt%) and silicon (0.70 wt%). Hardness of 95 BHN, E=68.9 GPa, $\sigma_y = 275$ MPa, $\sigma_{ut} = 315$ MPa and elongation 17% were the some of its mechanical properties.

Silicon carbide (SiC), a form of carborundum, is a ceramic material. It is a combination of silicon and carbon. SiC is one of exceptional abrasive materials used to manufacture abrasive wheels. Now a day, the SiC available is of high quality technical grade ceramic with excellent physical properties. Some of the properties of the SiC are Density = 3.1 g/cc, melting point – 2730°C, Appearance –Black in color, Hardness = 45.8 GPa.

3. Model Generation
Using ANSYS, the geometric model was created. A finite element model was constructed utilizing PLANE182 and SOLID185 components shown in figure 2. The nodes around the crack tip appear in figure 3. The finite element model was built using PLANE182 element, for the crack analysis of the aluminum-graphite alloy.
4. Results and Discussion
The crack analysis was carried out and the resulting analysis is shown in Table 1.

| Sl No | Composite       | Fracture load (Pf) kN | $K_{IC}$ MPa $\sqrt{m}$ |
|-------|-----------------|-----------------------|--------------------------|
| 1     | AA6061          | 2.183                 | 0.936                    |
| 2     | AA6061-6%SiC    | 2.260                 | 1.04                     |
| 3     | AA6061-9%SiC    | 2.367                 | 1.051                    |
| 4     | AA6061-12%SiC   | 2.148                 | 0.954                    |

From the fracture toughness analysis using ANSYS software, it is clear that fracture toughness increases with the increase of SiC content. For the AA6061 value of fracture toughness is 0.936 MPa $\sqrt{m}$, whereas for AA6061-9%SiC it is 1.051 MPa $\sqrt{m}$, which is slightly higher than the 6wt% and 12 wt% compositions and also with the base metal. From the fracture toughness analysis using ANSYS software, it is clear that fracture toughness increases with the increase of SiC content. Up to 9 wt% and at 12 wt% it decreases. The fracture toughness values were additionally observed to be in close concurrence with data got from standard $K_{IC}$ testing (as shown in figure 4).
Figure 4(a). $K_{IC}$ of AA6061-6wt% SiC – a/W ratio = 0.45

Figure 4(b). $K_{IC}$ of AA6061-9wt% SiC – a/W ratio = 0.45

Figure 4(c). $K_{IC}$ of AA6061-12wt% SiC – a/W ratio = 0.45

Figure 5(a) shows the theoretical stress distribution of the plain strain and plane stress approach [1]. Figure 5(b) shows the stress distribution at the crack tip of the AA6061-6wt% SiC. The shown stress distribution resembles the Von-mises stress distribution of metallic materials [1] for the plain strain condition. This validates the simulations results. The fracture toughness at that condition is referred as the plain strain fracture toughness. As per the requirements of the plain strain fracture toughness, the model generated using finite element simulation software is satisfying the required condition. Hence the results obtained through finite element simulation are validating with the available theoretical geometrical conditions.
Due to the improved fracture toughness of the AA6061-SiC composite, as compared to the AA6061, the composite can be the potential material utilized for the aerospace application. AA6061-SiC composite can be used as a replacement material for the use of the Helicopter rotor blade.

5. Conclusion
The finite element model of the compact tension specimen was successfully modelled using the ANSYS. The fracture toughness values obtained from the ANSYS are in close agreement with data obtained from standard $K_{IC}$ testing. From the comparison, it is recommended that AA6061-9%SiC composite material can be considered as a potential rotor blade material as a replacement of AA6061 in the application of main rotor blades of the helicopter. The result obtained through the finite element simulation validates with the geometrical conditions. Thus the $K_{IC}$ values obtained can be considered as the plain strain fracture toughness.

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