

Fracture Analysis to Determine Strength of Metal-Composite Joints

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ABSTRACT

In this thesis the effect of joining method on strength and failure mode is investigated for bolted, bonded, and hybrid (bolted/bonded) joints in single-lap joints. The metal composites considered are Steel & Kevlar 49, Steel & E glass epoxy, Aluminum alloy & Kevlar 49, Aluminum alloy & E glass epoxy. Static analysis is performed to compare the stresses and displacements for different joints and materials. Fracture analysis on joints with semi elliptical cracks investigated by determining the stress intensity factors, J - Integral.

Theoretical calculations are done to determine stress intensity factor and J – integral. Modeling is done in Pro/Engineer and Static and Fracture analysis is done in Ansys.

INTRODUCTION

Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture.

There are three ways of applying a force to enable a crack to propagate:

Mode I fracture – Opening mode (a tensile stress normal to the plane of the crack),

Mode II fracture – Sliding mode (a shear stress acting parallel to the plane of the crack and perpendicular to the crack front), and

Mode III fracture – Tearing mode (a shear stress acting parallel to the plane of the crack and parallel to the crack front).

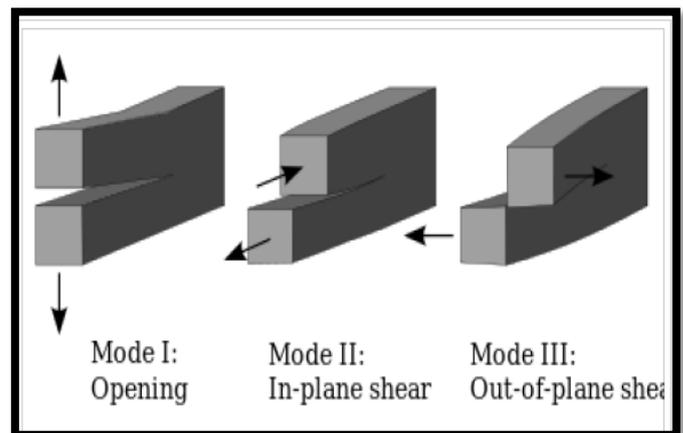


Fig – Modes of failure

LITERATURE REVIEW

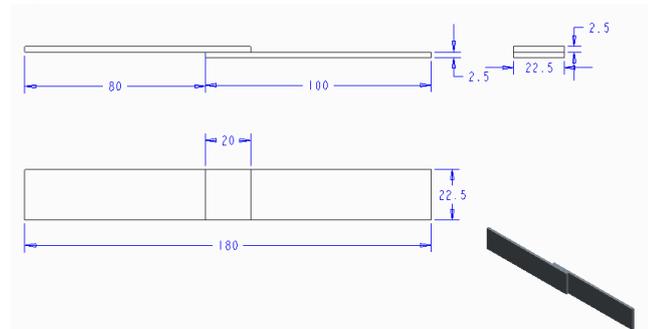
In the paper by A. R. Shahani[1], three-dimensional modeling of the fatigue crack growth profiles was performed in a simple riveted lap joint. Simulation results showed that mode I was dominated on the one side of the plates and the crack straightly grew on this side, while the other side of the plates was in a mixed-mode condition and the crack propagation path was not straight on this side. Afterward, the fracture mechanics-based life prediction of the riveted lap joint was considered using EIFS concept. In the paper by S.Venkateswarlu[2], ANSYS FEA tool has been used for stress distribution characteristics of various configurations of double riveted single lap joint with three joining methods namely bonded, riveted and hybrid. In several different applications and also for joining various composite parts together, they are fastened together using adhesives or Mechanical fasteners. Modeling and static analysis of 3D Models of joints such as bonded, riveted and hybrid were carried out and compared for two different composite materials

MODELING AND ANALYSIS

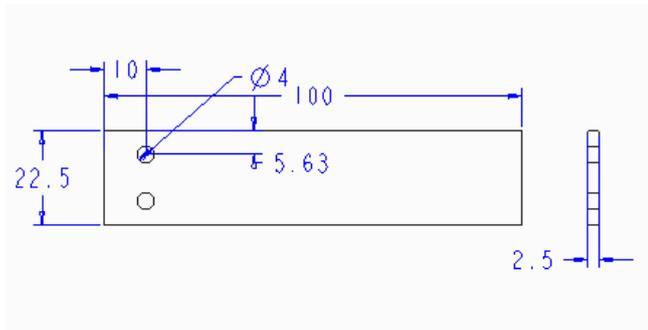
The consideration of lap joints is taken from “Study of effects of adhesive layer thickness on strength of single lap joint by using ansys and mechanical testing” By Rohan P. Chumble, Dr. S.N. Shelke[7], as specified in References chapter.

The model dimensions are taken from “Experimental and Numerical Failure Analysis of Adhesive Composite Joints” By Farhad Asgari Mehrabadi[4], as specified in References chapter.

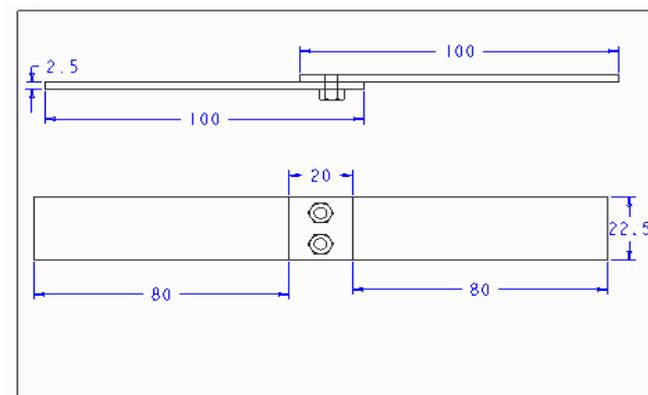
Lap Joint



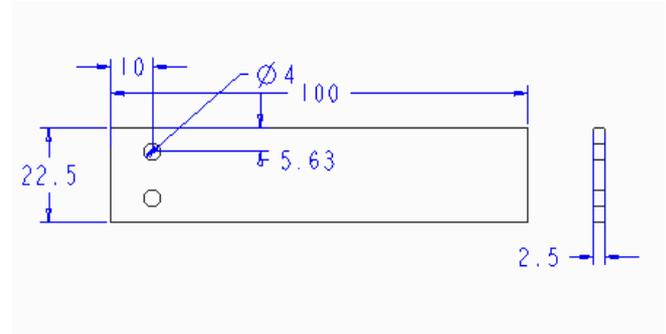
Bolted joint



Lap Joint with bolted



Hybrid Joint



BOUNDARY CONDITIONS

The boundary conditions (i.e) fixing and applying load is taken from the journal “Design and Analysis of Hybrid Composite Lap Joint Using Finite Element Methods” By S.Venkateswarlu, K.Rajasekhar[2], Page 4212 as specified in References chapter.

STRUCTURAL ANALYSIS OF BONDED AND BOLTED JOINTS

BONDED LAP JOINT

MATERIALS – STEEL & KELVAR 49

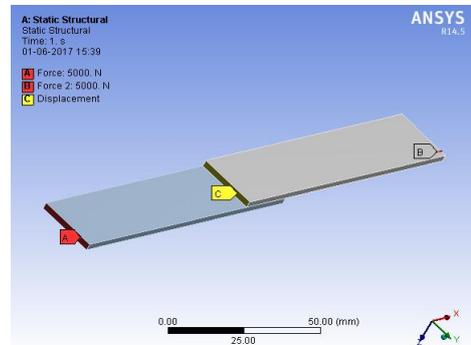


Fig – Forces and Displacement Applied on bonded joint

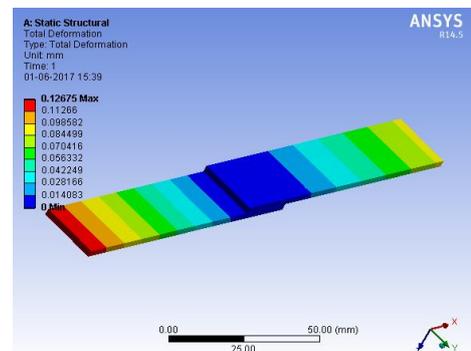


Fig - Total deformation of bonded joint using Steel & Kelvar 49

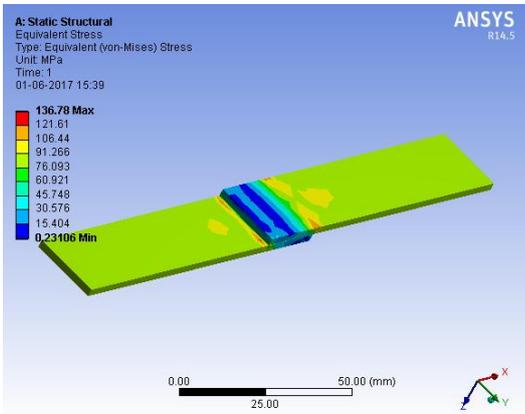


Fig – Equivalent Von-Mises Stress of bonded joint using Steel & Kelvar 49

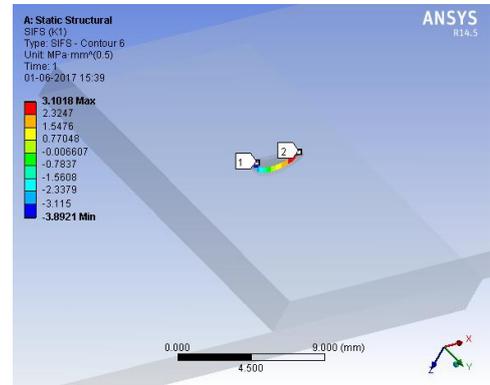


Fig - Stress intensity factor on bonded plate using Steel & S-Glass

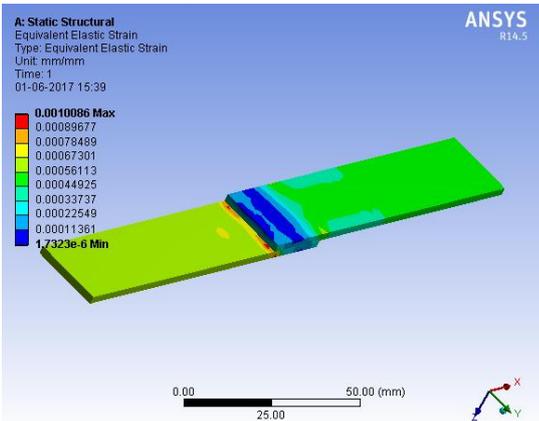


Fig – Equivalent Von-Mises Strain of bonded joint using Steel & Kelvar 49

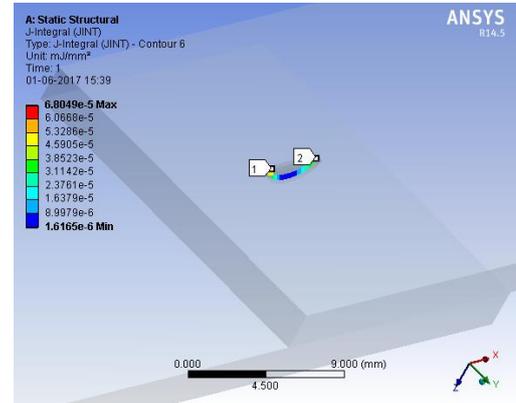


Fig - J - Integral on bonded plate using Steel & S-Glass

FRACTURE ANALYSIS OF LAP JOINT BONDED JOINT

Select Crack Shape – Semi Elliptical (first plate), Enter major radius →10mm, Enter minor radius→3mm, Enter Fracture affected zone Height – 1.9511mm, Enter largest contour radius – 0.75mm

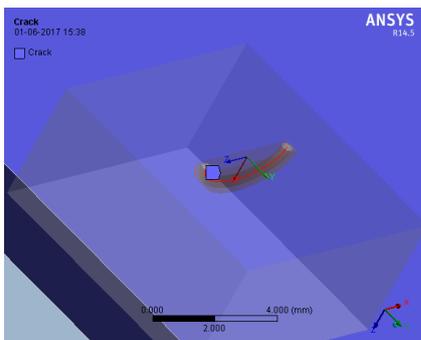


Fig – Crack on bonded first plate

BOLTED JOINT

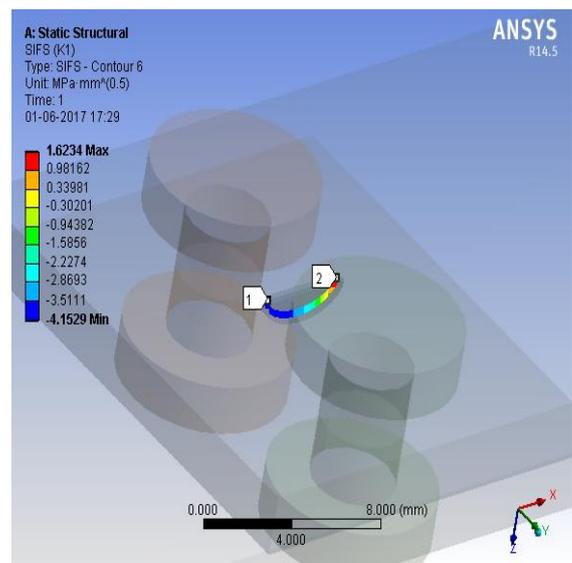


Fig - Stress intensity factor on bolted plate using Steel & Kevlar 49

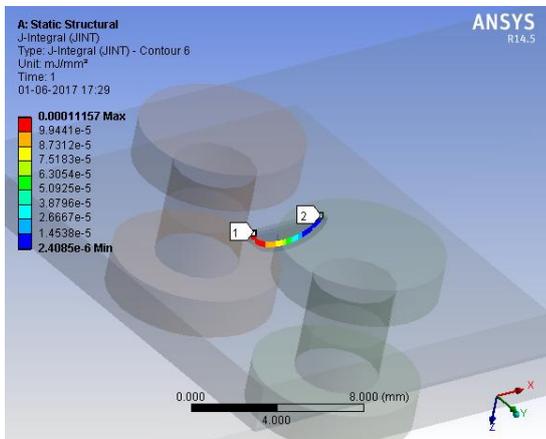


Fig –J - Integral on bolted plate using Steel &Kevlar 49

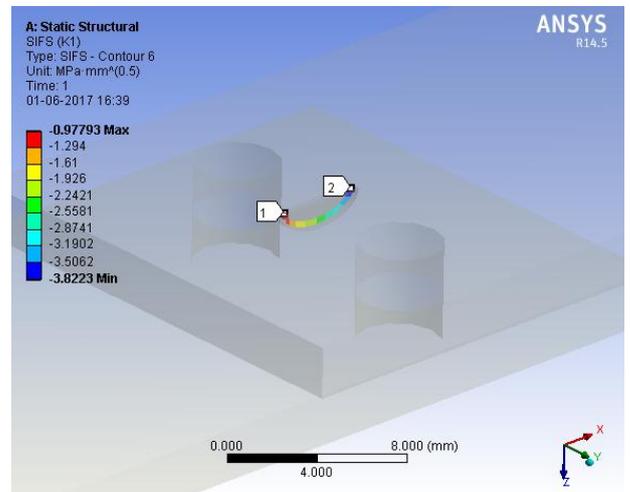


Fig - Stress intensity factor on hybrid plate using Steel
E-Glass epoxy

HYBRID JOINT

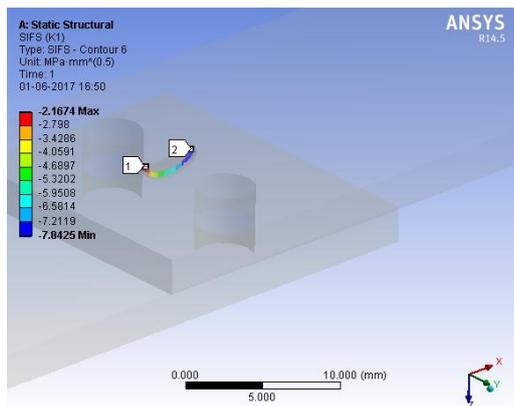


Fig - Stress intensity factor on hybrid plate using Steel
&Kevlar 49

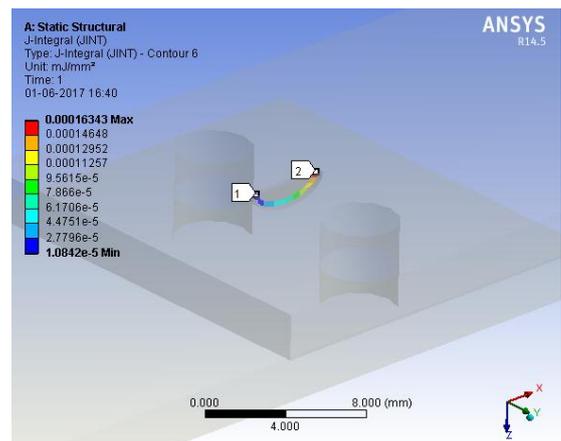


Fig –J - Integral on hybrid plate using Steel E-Glass
epoxy

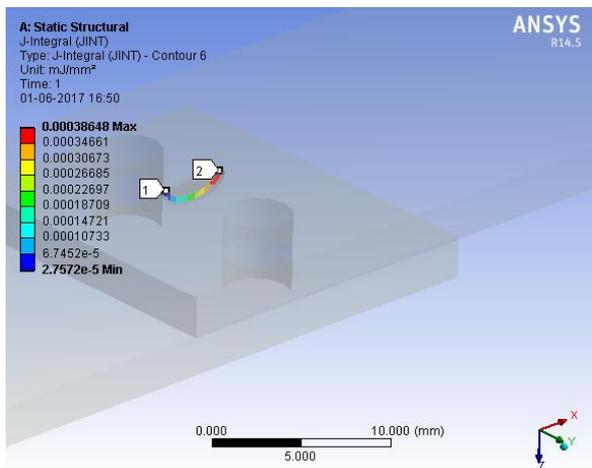
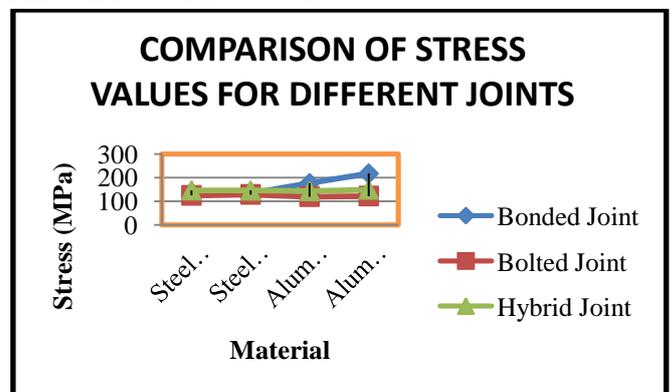
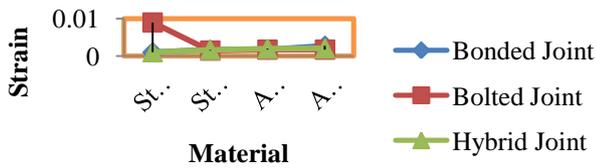


Fig –J – Integral on hybrid plate using Steel &Kevlar
49

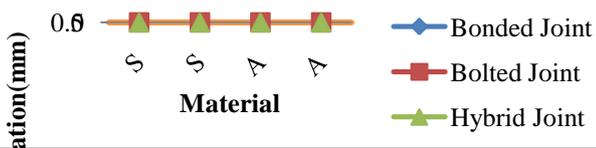
RESULTS & DISCUSSION



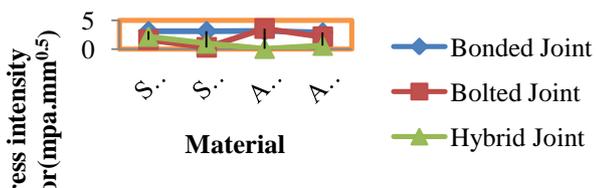
COMPARISON OF STRAIN VALUES FOR DIFFERENT JOINTS



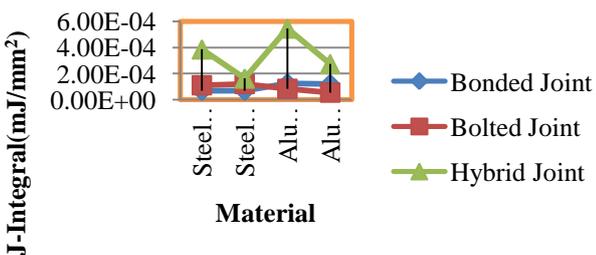
COMPARISON OF DEFORMATION VALUES FOR DIFFERENT JOINTS



COMPARISON OF SIF FOR DIFFERENT JOINTS AND MATERIALS ON PLATE



COMPARISON OF J-INTEGRAL FOR DIFFERENT JOINTS AND MATERIALS ON PLATE



For Bonded joint, observing the static analysis results, the stresses and displacements are more for the Aluminum (Metal) E-Glass epoxy (Composite) joint than other materials. By observing the stress intensity factors, the SIF values are more on the plates of material with more elastic modulus. (i.e) In case of Steel & Kelvar 49, SIF is more for Steel, since its elastic modulus is more. The SIF is increasing with increase of stresses. In this joint, the value is for Aluminum and Carbon Fiber. The calculation of J – integral values are dependent on the fracture toughness, Poisson’s ratio and Elastic modulus of material. For bolted joint, observing the static analysis results, the stresses are more for the Steel (Metal) & Kelvar 49 (Composite) joint than other materials. By observing the stress intensity factors, the SIF values are more on the plates of material with more elastic modulus. (i.e) In case of Steel & Kelvar 49, SIF is more for Steel, since its elastic modulus is more. The SIF is increasing with increase of stresses. In this joint, the value is for Steel and Kelvar 49. For Hybrid joint, observing the static analysis results, the stresses are more for the Steel (Metal) & Kelvar 49 (Composite) joint than other materials. By observing the stress intensity factors, the SIF values are more on the plates of material with more elastic modulus. (i.e) In case of Steel & Kelvar 49, SIF is more for Steel, since its elastic modulus is more. The SIF is increasing with increase of stresses. In this joint, the value is for Steel and Kelvar 49.

CALCULATIONS FOR STRESS INTENSITY FACTORS

The stress intensity factor for a through crack of length 2a, at right angles, in an infinite plane, to a uniform stress field σ is

$$K = S \sqrt{\Pi (a/Q) F (a/t, a/c, \phi)} \text{MPa mm}^{0.5}$$

Where S = stress (considered from analysis results)

a = crack depth = 0.5mm

t = plate thickness = 2.5mm

c = crack length = 10mm

Q = shape factor for an ellipse = $\Pi^2/4 = 2.467$

Φ = parametric angle of the ellipse = $\Pi/2 = 1.57$

F = Boundary correction factors = 1.851 for $a/c = 0.05$ and $a/t = 0.2$

CONCLUSION

For bonded joint, the stresses and displacements are less for the Steel (Metal) & Kelvar 49 (Composite) joint than other materials. By observing the stress intensity factors, the SIF values are less on the plates of material with more elastic modulus. (i.e) In case of Steel & Kelvar 49, SIF is more for Steel, since its elastic modulus is more. The SIF is increasing with increase of stresses. In this joint, the value is for Steel and Kelvar 49. For bolted joint, the stresses and displacements are less for the Steel (Metal) & Kelvar 49 (Composite) joint than other materials. By observing the stress intensity factors, the SIF values are less on the plates of material with more elastic modulus. (i.e) In case of Steel & Kelvar 49, SIF is more for Steel, since its elastic modulus is more. The SIF is increasing with increase of stresses. In this joint, the value is for Steel and Kelvar 49. For Hybrid joint, the stresses are less for the Steel (Metal) & Kelvar 49 (Composite) joint than other materials. By observing the stress intensity factors, the SIF values are more on the plates of material with less elastic modulus. (i.e) In case of Steel & Kelvar 49, SIF is more for Steel, since its elastic modulus is more. The SIF is increasing with increase of stresses.

In this joint, the value is for Steel and Kelvar 49. The calculation of J – integral values are dependent on the fracture toughness, Poisson's ratio and Elastic modulus of material. By observing theoretical calculations, the SIF's are more for Aluminum E-Glass epoxy for Bonded Joint, for Steel & Kelvar 49 for Bolted Joint and for Steel & Kelvar 49 for Hybrid Joint.

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