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Structural Analysis of Glass Fiber / Epoxy and Basalt Fiber / Epoxy Lap Joint Specimens Using FEA

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Abstract: The aim of this work is to predict the crack initiation and failure based on the Von Mises stress distributions at the edge of the overlap region. Finite Element Analysis (FEA) software is used to investigate the stress distribution under tensile loading on composite lap joints. From the Von Mises stresses results, the bonded joint and hybrid joint of basalt-fiber reinforced plastic (BFRP) specimen's produces higher results than bonded joint and hybrid joint of glass-fiber reinforced plastic (GFRP) specimens due to higher interfacial bonding strength. A well-designed bonded joint of BFRP laminates is very efficient for composite lap joint structures compared to hybrid (boned/riveted) joints. It is suggested that the application of basalt/epoxy laminate as a strengthening material is useful for joining of composite structural members in the engineering fields.

Keywords: Composite Lap Joints, FEA Ansys, Stress Distribution, Displacement

1. Introduction

Static stress analysis has been carried out for single bonded and hybrid lap joints with different material properties. The composite lap joints are designed to minimize the stress concentrations such as peel and Von Mises stresses, these stresses are ultimately responsible for the failure of the joints. They have studied a double lap joints with the adherends made of orthotropic laminates for the evaluation of the peel and shear stresses filed using FEA [1-2]. In this study, we make simplifying assumptions which still allow us to capture the essential features of the response. It was assumed that (1) Each layer is considered as an individual three-dimensional (3D) structure under a state of plane stress. (2) Individual layers can be connected with adhesive bonds. (3) Adhesive layer is homogeneous, anisotropic and linear elastic material. (4) The adhesive deforms under shear and peel stresses. The stress concentration is minimized with a larger bonded area, and the stress distribution becomes uniform in the overlap region [3-4]. The FEA ANSYS is used to obtain the local stress states at the interface between the adhesive and the adherend. Failure may occur due to stress concentrations, peeling stresses, shear stresses and combination of both and considered to correlate with them [5-6]. The maximum deformations of lap joints may result in relatively higher stresses on overlap region and initiate the local cracking and delamination failures. The present work explains how FEA software has been utilized to investigate the stress distribution on composite lap joints under tensile loading. The purpose of this work is to investigate the load distribution in hybrid (bonded–riveted) composite single lap joints using FEA.

2. Modelling of Single Bonded and Hybrid Joints

The laminates (adherend) were made of glass/epoxy composite and basalt/epoxy composite with zero- degree orientation and the adhesive used was epoxy-based standard resin using ANSYS. The geometry of the lap joint dimensions were used for modeling (ASTM D 5868-01 and D 3528-96 standards). The width of all the members was 25 mm. The thickness of adherents was taken to be 3 mm, and the thickness of adhesive layer was 0.2 mm. An aluminum rivet was used for mechanical fastening. The glass fiber and basalt fiber materials used for the different lap joints and their properties are taken from supplier data manuals. The composite laminates of FEA model for bonded joints were developed by using Layered 46, a three dimensional (3D) brick element. The adhesive layer was modeled using SOLID-45, an 8-node brick element. The adherend and adhesive were glued together using Boolean operation. Finer mesh was used in the design. The rivet was designed using SOLID-45, 8-node brick element. The mesh was refined adjacent to the rivet hole and at the overlap ends. A neat fit was assumed between the rivet and laminates in all simulations. Contact was defined between the laminate and the rivet using TARGE 170 element for the target and a 3D non-linear contact element, CONTA 174 for the contact, with a friction coefficient of 0.2 for glass laminate and 0.37 for basalt laminate. Pretension section was defined at the middle portion of the rivet. The mesh structure of all the models were created using FEA software. Meshed model of bonded joint and hybrid joints are shown in Figure 1. The overlap bonded joints are the critical region of stress distribution where the bonding process is performed. The meshing of the lap joints is performed in a more sensitive manner by dividing it into very small elements. Different mesh sizes (2.5 mm and 5 mm) are used in adhesive- bonded joints. In the FEA study, the analysis of bonded and hybrid joints are examined, the element dimensions and mesh density does not affect the analysis results. Hence, the same element dimensions were used in all models as often as practicable [6].

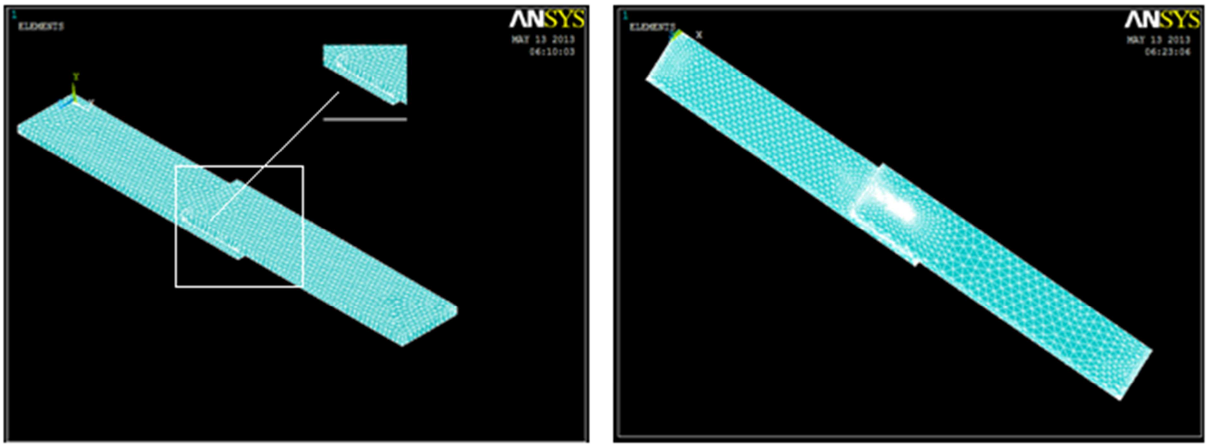

Figure 1. *Meshed models of bonded joint and hybrid joint.*

3. Boundary Conditions and Loads

The analysis for bonded joints was performed by applying a tensile load of 6000 N (from experimental work) at the end of the joint, which was free to move in the longitudinal direction only (UY = UZ = 0). The opposite end of the joint had fixed boundary condition (UX = UY = UZ = 0). The analysis for riveted and hybrid joints were performed in two steps. First, a clamping load of 6 kN was applied through the application of a pretension load at the middle portion of the rivet. Next, a tensile load of 10 kN was applied to the end of the joint, which was free to move in the longitudinal direction only (UY = UZ = 0). The opposite end of the joint had clamped boundary conditions (UX = UY = UZ = 0). The Von Mises criterion is a formula for calculating whether the stress combination at a given point will cause failure. Numerical simulation allows observing and analyzing of initial failure in the overlap region of single and double lap joints.

4. Finite Element Analysis Results

4.1. Bonded Joints

Numerical study is conducted on single and double lap bonded joints of glass-fiber reinforced plastic (GFRP) and basalt-fiber reinforced plastic (BFRP) laminates. Figures 2 and 3 show the distribution of various maximum stresses in the adhesive layer for bonded joints. From FEA results, it is observed that the maximum value of stresses occurred near both ends of the adhesive region. In adhesive joints, the applied loads on the adherents are transferred on to the adhesive layer mainly by stresses [5]. The corners of the surface where the load was applied had a stress distribution throughout the laminates. The displacement values are obtained through finite element approach as shown in Figure 2. It is observed from FEA results that the maximum displacement value of 1.46 mm is obtained for single lap bonded joints of GFRP laminates, and also the maximum displacement value of 1.55 mm is obtained for single lap bonded joints of BFRP laminates. In bonded joint specimens, peel or shear stresses occurred at each overlap region and the failure instantly took place without observing other failure. It is noted that these adhesive stresses are small compared to those found at the overlap area, if these stresses are too high, it may cause the delamination between the two adherents of the overlap region [8-12]. The use of bonded lap joints of basalt/epoxy specimens provide better results for Von Mises stress which are maximum than bonded lap joints of glass/epoxy specimens.

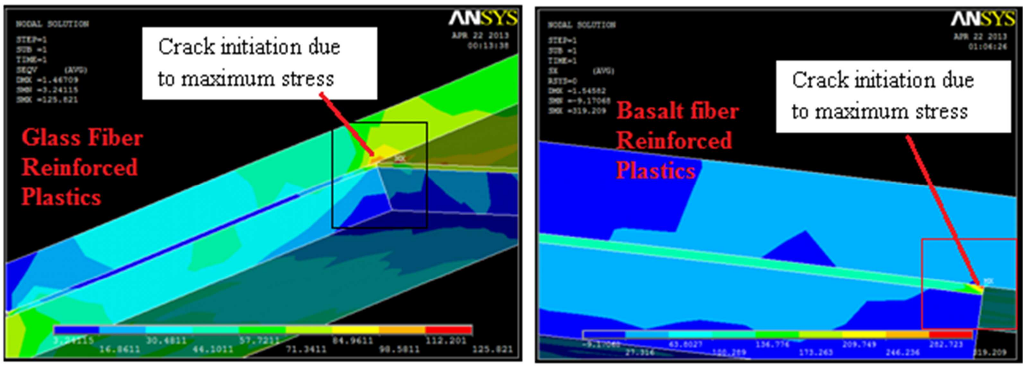

Figure 2. *Analysis result of single lap bonded joint.*

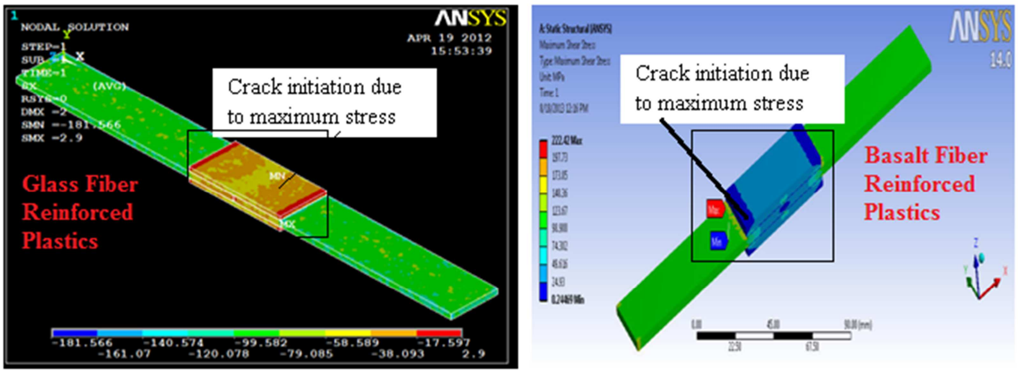

Figure 3. *Analysis result of double lap bonded joint.*

4.2. Hybrid Joints

From FEA results, it is observed that the maximum displacement value of 1.91 mm is obtained for single lap hybrid joints of GFRP laminates, and also the maximum displacement value of 2.08 mm is obtained for single lap hybrid joints of BFRP laminates. Figures 4 and 5 show the distribution of various maximum stresses in the adhesive layer for hybrid joints. The minimum value of stress was located on the laminates and the rivet head. The maximum value of stress was found to be in the adhesive layer near the laminate–shank interface. It was found that the adhesive layer took maximum stress, whereas the rivet shank took a varying stress distribution. Maximum shear stresses are visible at the two ends of each overlap of the specimen. Based on the stress distributions in the lap joints, FEA was used to predict the initial failure and crack initiate at the edge of the overlap region. Hence, the failure mode is likely to be the adhesive failure on the overlap region of lap hybrid joints [14]. In case of hybrid joint specimens, the Von Mises stresses are high in basalt laminate at the interface of two adherents as compared to glass laminate. The use of hybrid joint basalt/epoxy specimen provide better results for Von Mises stresses which are much higher than hybrid joint glass/epoxy specimens.

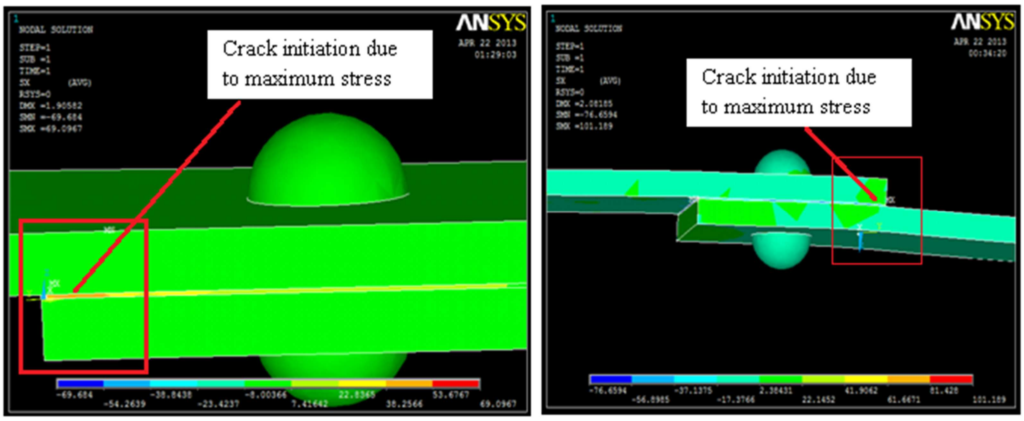

Figure 4. *Analysis result of single lap hybrid joint.*

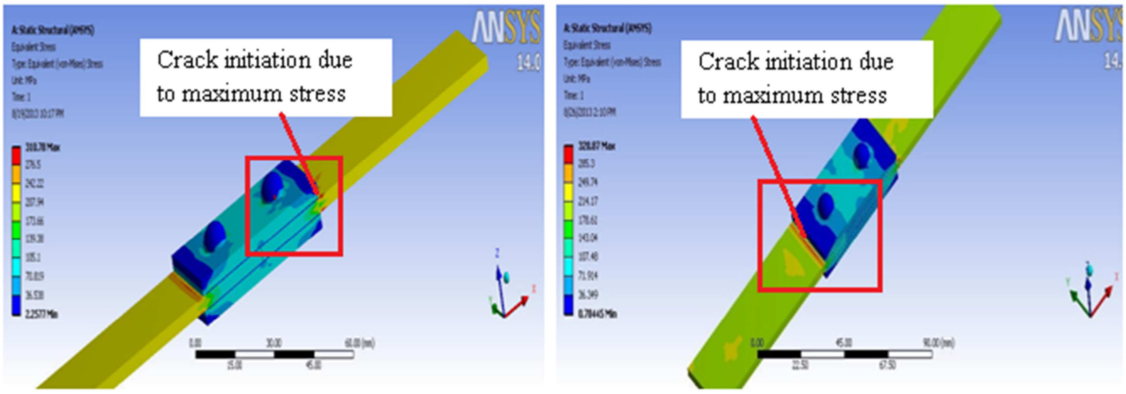

Figure 5. *Analysis result of double lap hybrid joint.*

5. Conclusion

The main objective of this study is to investigate the joint strength and stress distribution for single and double lap joints of glass-fiber reinforced plastic (GFRP) and basalt-fiber reinforced plastic (BFRP) laminates using FEA ANSYS.

(1) Based on the FEA results, the bonded joint and hybrid joint of basalt/epoxy specimens have higher von Mises stresses values than bonded joint and hybrid joint of glass/epoxy specimens.

(2) It is observed that the initial failure occurred at the overlap edge of lap joints when the equivalent stress reached the ultimate stress of the adhesive.

(3) FEA software used to predict the initial failure and crack initiate at the edge of the overlap region based on the Von Mises stress distributions.

(4) Hybrid joints may be used in repair situations of composite structures instead of bonded joints.

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