Adhesive Bonding Analysis of Single Lap Joint Composite E-Glass Fiber WR 600

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Abstract: Composite is a material that is widely used in the manufacturing industry, especially in aircraft manufacturing. The use of composites generally lies in the airframe structure, which consists of joints. Composite joints are a method for combining structures and have become important research. The purpose of this study is to analyze the bonding strength and failure modes of single lap joint composite made of Epoxy resin and WR 600 Glass Fiber with different compositions for tensile testing. The standard for tensile testing is in accordance with ASTM D5868-01. The process started by making a specimen using the hand lay-up method with a vacuum bag. There were two types of specimens; A is a specimen with 74.82% resin and 25.18% fiber, while B is 66.42% resin and 33.57% fiber. Simply put, specimen B has less resin than specimen A. Tensile test results show that Specimen B had higher strength than specimen A. For bonding failure mode, specimen A was adhesive failure and for specimen B was cohesive failure. It was showed that the composition of the composite affects the shear lap strength.

1. Introduction
Composite is a material that is widely used in the manufacturing industry, especially in aircraft manufacturing. The use of composites generally lies in the airframe structure, which consists of joints. Mechanical joint (rivet or bolt) and adhesive joint are the common type or composite joint method. For some structure’s application, adhesive bonded joint was used to minimize weight other than rivet or bolt. Single lap joint is one the common type of adhesive joint types. Composite with types of Glass Fiber Reinforced Polymer (GFRP) is one of most applicable composites in joint structures.

The adhesive bonded joint shear strength is determined by bonded joint thickness and the interface bonding strength between matrix and reinforced. In composite, cohesive are determined for different layer thicknesses of an engineering adhesive [13]. The experiment shows that the thinner the adhesive bondline will makes the shear strength increase significantly [5]. But for some reason it is difficult to make bondline thinner as possible. Another researcher also state that the lap-shear strength will decreases as the adhesive layer gets thicker [7].

The adhesive single lap joint can be done according ASTM D5868-01. In there the specimen standard has already determined its dimensions, but there is possibility for arranging composition of Fiber and matrix in the composite specimen. By make two variation of composition, it will make different in volume fraction of fiber and matrix in specimen. So, there will be specimen with fewer matrixes than the other. By differentiating this matrix volume, will it affect the adhesive bonding
strength and failure mode of the specimen as its specimen thickness dimension and adhesive bonded thickness are fixed.

This research objective is to determine the relation between the composite fiber matrix composition arrangement with adhesive bonded joint shear strength and failure mode.

2. Method

2.1. Specimen Preparation

The specimen was made from E-Glass WR 600 (fiber) with Epoxy resin (matrix) into two variation. The A variation (specimen A) was made from 3-layer fiber and the B variation (specimen B) made from 4-layer fiber. The specimen dimension is according to ASTM D5868-01 as seen in figure 1.

![Figure 1. Specimen dimension](image)

The mold made from polymer was made to make the specimen (figure 2) with 310 mm × 185mm × 3mm. With this mold, it can be determined that the specimen A have 74.82% resin and 25.18% fiber, while specimen B has 66.42% resin and 33.57% fiber.

![Figure 2. Mold](image)  ![Figure 3. hand layup](image)
The next steps were cutting the fiber and weighing the resin according to the volume fraction, then make the composite using hand layup (figure 3). After all layers are complete and applied with resin, the composite need to be vacuum for 8 hours (figure 4). This process needs to absorb resin that not needed, so that the composite compact.

After 8 hours, the composite was taken out to be cut and prepare for single lap adhesive bonded joint. As the adhesive material is epoxy, the same material which used as matrix in composite (specimen) with the adhesive thickness is 0.4 mm. Figure 5 is the picture of the specimen that ready to be tested.

2.2. Lap Shear Test

There are three specimens A and two specimens B that ready to be tested. The specimen B only two specimens because one of the specimens was early fail when it was tested. The specimens were tested using Universal Testing Machine until fails. The output of the test is in Graph of load vs elongation as seen in figure 6.

3. Result and Discussion

Formula (1) was used in order to determine lap shear strength.

$$T_{\text{joint}} = \frac{F_{\text{max}}}{l_{0w}}$$  \hspace{1cm} (1)
Figure 7. Shear stress

Where, \( l_0 = \) length of joint, \( w = \) width of specimen, and \( F_{\text{max}} = \) Maximum Force. In this research, the dimensions of \( l_0 \) and \( w \) are the same which is 25.4 mm, so the shear lap strength of each specimen can be calculated (figure 7). In the table 1 (specimen A) and table 2 (specimen B) can be seen the result of the calculated shear lap strength.

Specimen A2 have the highest max forces value with 1,074,327 N. The average max forces value for specimens A is 907,909 N. As for the shear stress average value is 1,407 N/mm\(^2\). Specimens B have average stress higher than specimen A. The average shear stress on specimen B is 5,536 N/mm\(^2\). The difference between the average stress of specimen A and specimen B is 293.36 %.

Table 1. Specimen A bonding shear stress results

| No | Specimen | \( F_{\text{max}} \) (N) | \( \tau \) (N/mm\(^2\)) |
|----|----------|----------------|------------------|
| 1  | A1       | 792,994        | 1,229            |
| 2  | A2       | 1,074,327      | 1,665            |
| 3  | A3       | 856,406        | 1,327            |
|    | average  | 907,909        | 1,407            |

Table 2. Specimen B bonding shear stress results

| No | Specimen | Max Force (N) | Shear stress N/mm\(^2\) |
|----|----------|---------------|-------------------------|
| 1  | B1       | 3,492,498     | 5,413                   |
| 2  | B2       | 3,650,205     | 5,658                   |
|    | average  | 3,571,351     | 5,536                   |

Figure 8. Diagrams of bonding shear stress
The specimens A have adhesive failure type in bondline. As seen in figure 9, the adhesive failure is interfacial bond failure between the adhesive and the adherend. Adhesive failure at bondline caused by matrix interfacial bonding to the fiber (adherend) was stronger than the adhesive bonding.

For the B specimen have cohesive type failure (figure 10). This type of failure was better than the adhesive failure. It was because with this type of failure, the maximum strength of the materials in the joint has been reached. The adhesive bonding was stronger than the matrix interfacial bonding to the fiber that cause matrix deboning on specimen.

4. Conclusion
This preliminary results in this research assumed that the thicker matrix interfacial bonding to the fiber have the ability to resist deformation (failure), but less strength in adhesive bonding. As for thinner matrix interfacial bonding was weak, but better strength in adhesive bonding. For better result, it needs further study to investigate this condition with different variation.

References
[1] Boeing M 2008 Boeing Aero Magazine QTR.4.06
[2] Mohamed Bak K, Venkatesen KP and Chelvan KK 2012 Parametric Study of Bonded, Riveted, and Hybrid Composite Joints Using FEA Journal of Applied Science 12 1058-1062
[3] Pocjus AV 1986 Fundamentals of Structural Adhesive Bonding In: Hartshorn S.R. (eds) Structural Adhesives Topics in Applied Chemistry (Boston: Springer)
[4] Hoke MJ 2010 Abaris Training Inc: Adhesive Bonding of Composites Abaris Inc
[5] da Silva LFM, Rodrigues TNSS, Figueiredo MAV, de Moura MFSF and Chousal JAG 2006 Effect of Adhesive Type and Thickness on the Lap Shear Strength The Journal of Adhesion 82 1091-1115
[6] Mercy L 2015 Joint Strengh Analysis of Single Lap Joint in Glass Fiber Composite Material Sathyabama University
[7] Banea MD, da Silva LFM and Campilho RDSG 2015 The Effect of Adhesive Thickness on the Mechanical Behavior of a Structural Polyurethane Adhesive The Journal of Adhesion 91 331-346
[8] Ebnesajjad S and Landrock AH 2015 Adhesives Technology Handbook (Third Edition) Elsevier
[9] Ebnesajjad S 2014 *Surface Treatment of Materials for Adhesive Bonding (Second Edition)* Elsevier
[10] Solmaz MY, Kocabas I, Gur M 2017 Effect of Riveting On The Joint Strenght of Adhesively Bonded Double Lap Joints *J. of Sci. and Technology A – Appl. Sci. and Eng.* 19
[11] Sugiyanto 2012 *Optimasi Sambungan Kekuatan Serat Gelas* (Solo: Universitas Sebelas Maret)
[12] Dimas SA 2018 *Pengaruh Diameter Hole Terhadap Kekuatan Single Lap Joint Pada Material Alumunium 2014-T3*
[13] Carlberger T and Stigh U 2010 Influence of Layer Thickness on Cohesive Properties of an Epoxy-Based Adhesive-An Experimental Study *The Journal of Adhesion* 86 816-835