Jurnal Mekanikal
June 2012, No.34, 57-65

TENSILE BEHAVIOUR OF UNBALANCED WOVEN C-GLASS/EPOXY COMPOSITE LAMINATED PLATE WITH AND WITHOUT CIRCULAR CUTOUTS

Rizal Zahari, Sulaiman Kamarulazizi* and Dayang Laila Abang Abdul Majid

Department of Aerospace Engineering,
Faculty of Engineering,
University Putra Malaysia
43400 Serdang, Selangor, Malaysia

ABSTRACT

In present days experimental investigation for composites material has been a very important study to determine not only the materials properties but also the behaviour of the produced composite. For this study, an experimental investigation to determine the tensile behaviour and failure modes of unbalanced woven C-glass/epoxy composites laminated panels was performed. Series of coupon tests are carried out for the unbalanced C-glass/epoxy laminates according to ASTM 3039 to obtain their mechanical and strength properties which are then used to calculate the load-displacement curves, the ultimate load and the energy absorption capabilities for each coupon panel. Study conducted are by varying the cut-out sizes and varying the fibre angle orientations, it was discovered that cross ply laminates had the highest ultimate load and that increasing the cut-out size reduced the ultimate load of the panels. Visual inspections of the damage specimens using microscopic camera are also carried out for certain type of composite laminates to investigate the mode of failures. In general all of the samples exhibit almost similar types of failure modes such as fibre breakage, delamination, debonding and matrix cracking.

Keywords : *Composites, Energy, Glass, Circular Cutouts Tensile*

1.0 INTRODUCTION

Composite materials have been widely used in many industries, including aerospace, automobile, marine, civil, and commercial equipments, such as medical and sport. The increase use of composite materials is due to its advanced material properties. Numerous researches have been done to determine the property of a composite material; however, there are areas that have not been fully understood which involve the behaviour of the material. Cut-outs structures have also been used in the development of a product to reduce the weight of the material and also, in some cases, to increase the stability, manoeuvrability and accessibility for other systems. These structures will go through tensile loading and compressive loading during their use, and it is important for the engineer to determine the safe operating design and condition of the material. If there is a failure or a fracture in a composite material, it is also important to know the reason of the fracture. For most laminated composites, there are four important failure modes that will always occur, which will be the cause of the fracture. The failure modes are fibre breakage, debonding, matrix cracking and delamination. From the combination of these

*Corresponding author : man060985@yahoo.com

failure modes, a full crack will occur. One of the composite materials used in the industry is the textile glass fibre woven from continuous filaments. This material has been selected for its high damage tolerance and low fabrication cost. This material is woven from strands of filament glass to create a glass fabric, and from this glass fabric a fabrication process of laying-up the fabric is done to create a composite material.

The increasing use of composite laminates in the industry leads many researchers to investigate thoroughly the behaviour of this material. Kawata et al. [1] investigated on the characteristics of glass and carbon fibre reinforced composites to determine the dynamic tension at a high strain rate. From the experimental setup, a stress strain curve up to a breaking point has been developed. The research showed that the carbon fibre reinforced composites have a high strength and rigidity while glass fibre reinforced composites have high impact absorption. Huang [2] studied on fibre stacking orientation for the E-glass material, which was towed in both warp and weft directions. The study showed that stacking sequence affects greatly on the tensile and bending strength. Parallel lay-ups of the fabric would increase both the bending and tensile strength in a definite direction. Meanwhile, elongation at break in that direction was also greatly increased. The effect of stacking sequence for pinned-joint and mechanically fastened joint has been studied by Alaattin et al [3] and Heung [4]. The result of the work determined the most effective stacking sequence that is needed for pinned-joint and mechanically fastened joint. Stacking sequence effectiveness has also been studied for notched fabric woven composite laminates by Shembekar and Naik [5]. The study revealed the criteria for choosing the most optimum stacking sequence. Manufacturing of the composite material has also been done by researchers to determine the best possible process to achieve the needed properties with the lowest possible cost. One of the variables that can be changed is the curing pressure, which has been studied by Faizal [6].The result obtained from this study demonstrated the convergence of both elastic tensile stiffness and ductility with increasing curing pressure and that increasing the curing pressure will be detrimental to the tensile stiffness of the composite. Kazemahvazi et al [7] studied different failure modes observed from different hole densities created from an experimental tensile test. Three main failure modes could be observed from the test and was then used to create a foundation for a simple yet effective analytical model in order to predict the residual strength of damaged composite specimens. A finite element model was also created for drilled hole composite laminates by Rakesh et al [8], and the model created has a good agreement with the experimental work done. Lin and Lee [9] studied the strength difference between a drilled and moulded-in holes on a composite laminate. Four different hole sizes were created by drilling and moulding-in, and from this experiment, the result showed that moulded-in circular holes exhibited higher strength with strength enhancements of 28-77% compared to the drilled hole. Woven glass composite has also been studied for its variations in linear densities, which was varied from 200, 270, and 300 g/m^2 by Aso [10]. In his research, woven fibre glass epoxy resins were tested under tension loading and failure propagation, and the failure type was observed. The result shows that the increase in linear density will increase the bearing strength due to higher void contents and the crimp level of the composite. Woven fibre reinforced glass composite was also studied by Khashaba and Seif [11] for its different effect after different loading conditions. The test was done on a woven composite with a layup sequence of (0/±45/90)s. Hochard [12] studied the optimum design for a laminated composite structure and found out that the use of woven and unidirectional composite is the most optimum design for fabricating a composite laminates. Zheng et al [13] did a progressive damage analysis using the classical thin-laminate theory on eight different composite lay-ups. The model agreed well with the experimental set-up on the ultimate failure strength and the strength envelope. Hakim et al [14] studied the compressive behaviour of woven C-glass/epoxy panels, experimentally. The load-displacement curves and energy absorption capabilities of the C-glass composites were examined. From the literature, only a few studies have been reported in the past pertaining the tensile behaviour of unbalanced woven c-glass/epoxy.

The objective of this paper is to investigate the tensile behaviour of woven C-glass laminated composite plates (200g/m^2) with and without cut-outs. The ultimate load and energy absorption of each panel subjected to tensile force are studied. A parametric study by varying the cut-out sizes and the fibre orientation was also performed. After the tensile test, the sample underwent visual studies to examine the mode of failures.

2.0 SPECIFIC ENERGY ABSORPTION

The energy absorption value can be determined from the value of work done by the tensile force on the specimens during deformation. The value of work done can be determined from the area under the load-displacement curve, which can be represented by

$$Work\ Done, w = \int Pds \qquad (1)$$

Where P is the applied load and s is the displacement. From this equation, the specific energy absorption can be calculated as:

$$Specific\ Energy\ Absorption, SEA = \frac{w}{Mass} \qquad (2)$$

2.1 Sample Preparation

The laminated plates are made of eight layers of unbalanced fibre glass type C with 200g/m^2. Hand layup which is performed by cutting out desired fibre orientation and size, then stacking the fibre for eight layers. Between the layers is an epoxy and hardener mixture of 4:1 ratio. The laminated stacked plies have been allowed to cure between two pressured glass plates. The glass plates are used to squeeze out any entrapped air bubbles and any excessive epoxy hardener. The cured fibre glass laminated epoxy will then be cut into testing size and shape of 310 mm x 25 mm. Hole is then drilled into the centre of the test plates using drilled machine with four different size diameter of 3 mm, 6 mm, 7 mm and 10 mm, while the stacking sequences that have been studied are $[(0/90)_2]s$, $[(0/60)_2]s$, $[45]_8$, $[(45/135)_2]s$ and $[90]_8$. Safety precautions that were taken during the hand lay-up fabrication are 1) the mixture of epoxy-hardener must also be consistence and are mixed well to create the same thickness and to avoid any early delamination. 2) To ensure that the stacking sequence has been done correctly to maintain the mechanical properties of the composite in that sequence. 3) The mixture of epoxy-hardener has been distributed evenly to achieve equal thickness and to avoid excessive air bubble. Figure 1 shows the completed test samples with and without cut-outs whereas Figure 2 shows the schematic drawing and the dimensions of the test samples with length, l=250 mm, width, w=25 mm, thickness, t=2mm and a hole diameter D.

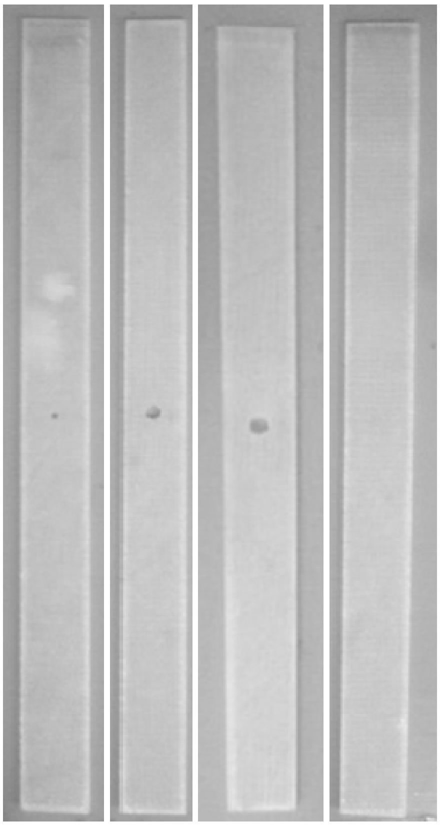

Figure 1: Test Specimen

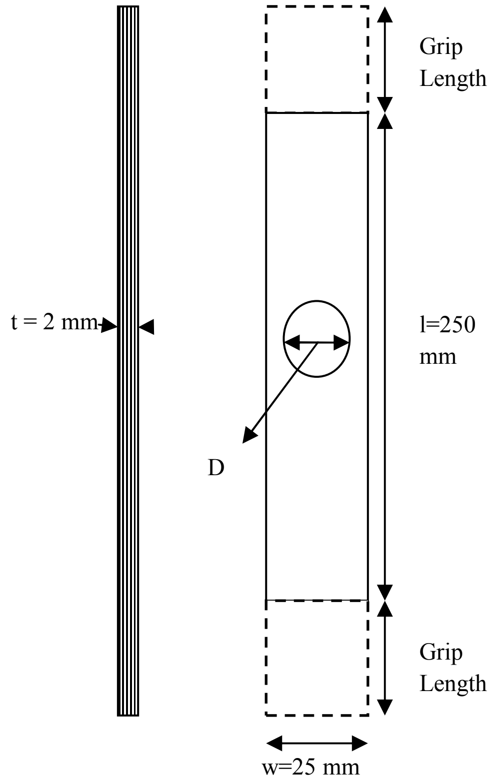

Figure 2 : Schematic drawing and dimensions of test sample

2.2 Experiment Setup

All tests have been conducted using the Universal Testing Machine, INSTRON. The test has been done by fully clamping one end of the test sample and displacing the other end with a constant speed. The grip length as shown in Figure 2 is 30 mm for both ends of the test sample. Sufficient pressure grip was applied in order to prevent slippage and premature failure at the gripper sections during the test. Test results such as load and displacement were automatically logged into a raw data file via a data acquisition system. The data collection will be stopped when total failure occurs. From this data, young modulus value has been calculated and load-displacement curves were produced.

3.0 RESULTS AND DISCUSSION

Tensile test has been performed on all test samples until final fracture. Figure 4 shows one of the specimens used in the tensile test using the universal testing machine while Figure 5 and 6 show the load versus displacement curves for the test samples. The comparison of different fibre orientations can be seen in Figure 5 while comparison for the different in hole sizes is shown in Figure 6.

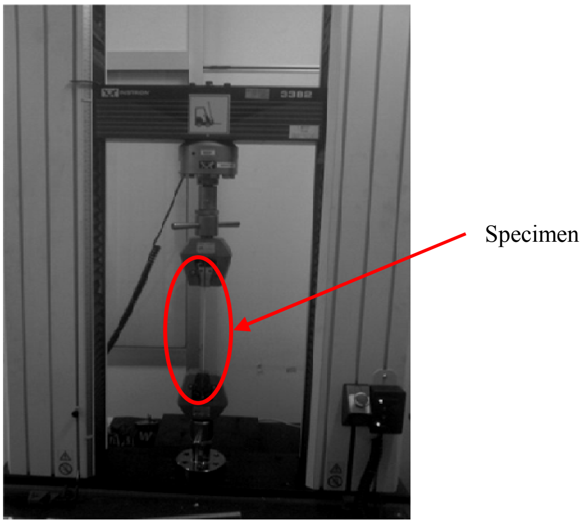

Figure 4 : Tensile tests using INSTRON Universal Testing Machine.

3.1 Effect of Stacking Sequence

Figure 5 shows the effect of varying the stacking sequence on the tensile behaviour of the test samples. Three type of test samples $[(0/90)_2]s$, $[(0/60)_2]s$, and $[90]_8$ shows behaviour of a very brittle material while $[45]_8$ and $[(45/135)_2]s$ laminates shows a much ductile behaviour. This can be seen as the result of increasing the angle ply which will in turn reduce the Young's modulus of the specimen. The orientation of $[(0/90)_2]s$ has the highest strength with a maximum load value of 8.766 kN. The laminate with the orientation of $[(45/135)_2]s$ exhibit the highest work done of 187.43 J/kg which shows that it can absorb the highest amount of energy before rupture. The inclusion of an angled fibre orientation will reduce the ultimate strength of the composite as demonstrated by the behaviour of the $[(0/60)_2]s$ laminate in Figure 5.

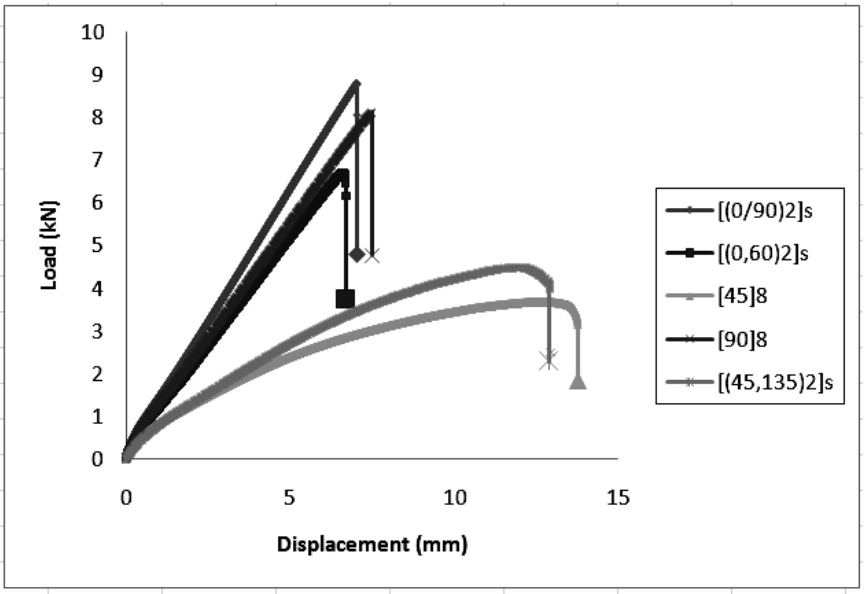

Figure 5 : Load Displacement graph for different stacking orientation

Table 1 compares the value of maximum load, maximum displacements and the energy absorption capability for each test samples with varying fibre orientations. It can be seen that $[(0/90)_2]_s$ has the highest maximum load with the highest modulus young while $[45]_8$ has the lowest value of maximum load. In general, the results obtained show similar behaviour with the results obtained by Faizal et al [6] on E-glass composite laminate under tensile load.

Table 1: Properties of test sample according to fibre orientation

Specimen	P_{max} max (kN)	s_{max} (mm)	w (J)	SEA (J/kg)
$[(0/90)_2]$s	8.766	7.034	30832.46	150.40
$[90]_8$	8.110	7.503	30427.44	148.24
$[(0/60)_2]$s	6.152	6.726	20689.74	100.92
$[(45/135)_2]$s	4.462	12.927	38424.16	187.43
$[45]_8$	3.680	13.765	35723.41	174.26

3.2 Effect of Different Hole Size

As predicted test samples without hole has the highest maximum load and displacement making it the most capable in absorbing energy without fracture. The increase in cut-out size will also decrease the maximum load and displacement which in turn will decrease the energy absorption capability.

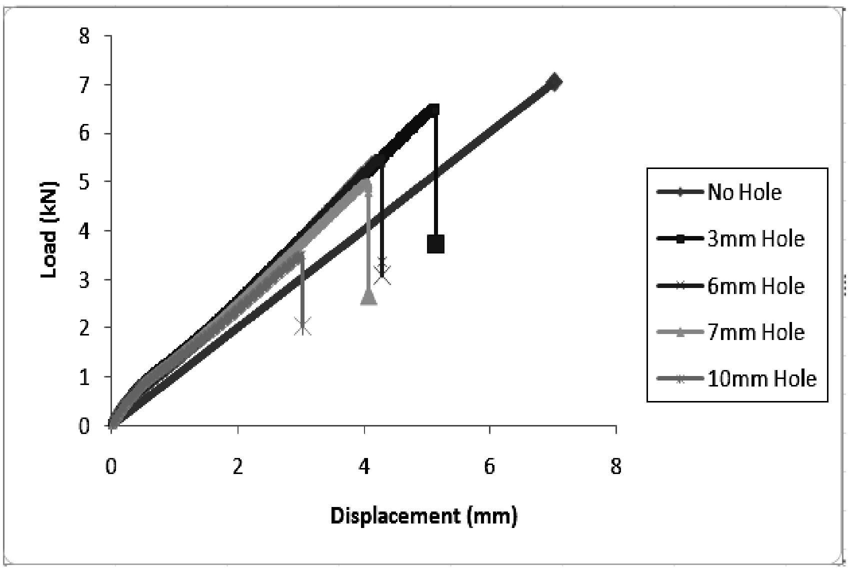

Figure 6: Load Displacement graph $[(0/90)_2]$s orientation for various hole size

From Table 2, it can be seen that no noticeable variation of maximum load and the maximum displacement.

Table 2 : Properties of test sample according hole size for orientation (0,90,0,90)s.

Specimen	P_{max} (kN)	s_{max} (mm)
No Hole	8.766	7.034
3mm Hole	6.514	5.140
6mm Hole	5.482	4.295
7mm Hole	4.971	4.073
10mm Hole	3.483	3.037

3.3 Failure Mode

Visual inspection was performed on the damaged specimen to see the failure mode of each layup using microscopic camera LEICA MS5. Figure 7 to Figure 10 shows the damaged specimen picture taken from the microscopic camera. It can be observed that most composite laminates underwent four typical failure modes fibre breakage, delamination ,matrix cracking and debonding. In general, if the fibre in the composite laminate carries a higher load then its strength then a fibre breakage will occur first and if the higher load is distributed more on the matrix which will exceed the ultimate load of the matrix then matrix cracking will first occur. Delamination and debonding will usually happen when the glass fibre/epoxy has not been distributed evenly throughout the composite material and notch will happen when there is imperfection on the composite laminate. The most common failure modes for cross ply composite laminates with orientations of $[(0,90)_2]$s and $[90]_8$ is fibre breakage, while most common failure modes for angled ply orientations are delamination and matrix cracking.This is due to the fact that the fibres with cross ply orientations carry most of the tensile loads whereas, for angled ply orientation $[45]_8$ and $[(0,60)_2]$s the matrix carries the highest tensile load. The mode of failures observed from the visual inspection are almost similar to the mode of failures for compressive tests conducted by Hakim et al [14] except that delamination is more prominent in his work as compared to current work.

Figure 7: Damaged $[(0,90)_2]$s Test Specimen

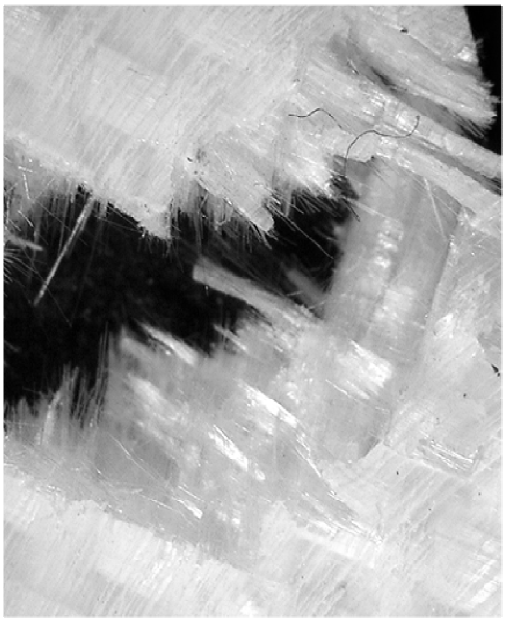

Figure 8: Damaged $[45]_8$ Test Specimen

Figure 9 : Damaged $[(0,60)_2]$s Test Specimen

Figure 10 : Damaged $[(0,90)_2]$s Test Specimen with 10 mm diameter hole

4.0 CONCLUSION

From this study, it can be seen that unbalanced woven C-glass laminated composite plates has the behaviour of a brittle material but by adding angle ply layup the composite become more ductile. The parametric study shows that composite with the orientation of $[(0/90)_2]$s has the highest ultimate load and that increasing the cut-out size will reduce the ultimate load of the panels. From the visual study most of the panels exhibit delamination, debonding, matrix cracking and fibre breakage.

ACKNOWLEDGEMENTS

The authors would like to thank the University Putra Malaysia for providing the research grant and University Science Malaysia for the financial support for this research program.

REFERENCE

1. Kawata K, Hondo A, Hashimoto S, Takeda N, and Chung H.L (1981), “Dynamic Behaviour of Composite Materials”, Composite Materials, Vol3, Issue3,pp2-11.
2. Huang G (2006),”Tensile and Bending Behaviour of Laminates with Various Fabrc Orientation”, Material & Design, Vol27 Issue10, pp1086-1089.
3. Alaattin A and Husnu M.D (2003), “The Effect of Stacking Sequence of Carbon Epoxy Composite Laminates on Pinned-Joint Strength”, Composite Structures, Vol62 issue1, pp107-111.
4. Heung J P (2001), “Effects of Stacking Sequence and Clamping Force on The Bearing Strengths of Mechanically Fastened Joints in Composite Laminate”, Composite Structures, Vol53 Issue2, pp213-221.
5. Shembekar P.S. and Naik N.K (1992), “Notched Strength of Fabric Laminates ii: Effect of Stacking Sequence”, Composites Science and Technology, Vol44 issue1, pp13-20.

6. Faizal M.A, Yeo K. B and Dalimin M.N (2006), "Tensile Property of Han Lay-Up Plain Weave Woven E-Glass/Polyester Composite: Curing Pressure and Ply Arrangement Effect", Borneo Science vol19, pp27-34.
7. Kazemahvazi S, Kiele J and Zenkert D (2010), "Tensile Strength of UD-Composite Laminates with Multiple Holes", Composites Science and TechnologyVol70 issue 8, pp1280-1287.
8. Rakesh P.K, Singh I. and Kumar D (2010), "Failure Prediction in Glass Fibre Reinforced Plastics Laminates with Drilled Hole under uni-axial Loading", Material & Design, Vol31 isue6, pp3002-3007.
9. Lin H.J and Lee Y.J (1992), "Strength of Composite Laminates with Continuous Fibre Around a Circular Hole", Composite Structures, Vol21 issue3, pp155-162.
10. Aso O (2009), "Effect of Different Woven Linear Densities on the Bearing Strength Behaviour of Glass Fibre Reinforced Epoxy Composites Pinned Joints", Composites Structure, vol90 issue 1, pp43-52.
11. Khashaba U.A, Seif M.A (2005), "Effect of Different Loading Conditions on the Mechanical Behavior Composites", Composites Structure, Vol74 Issue 4, pp440-448.
12. Hochard C (2004), "Optimum Design of Laminated Composite Structure", Composites Structures, vol 63 Issue 2, pp159-165.
13. Zheng M.H, Yan Z.Z and Ramakirshna S (2001), "Modeling of the Progressive Failure Behaviour of Multilayer Knitted Fabric-Reinforced Composite Laminates", Composites Science and Technology, Vol61 Issue14, pp2033-2046.
14. Hakim S, Chong W.P, Mahlia T.M.I,Chong W.T, Prasetyo E, Haidar A, Irfan A, Zahari R (2010), "Load-Displacement Behaviour of Glass Fibre/Epoxy Composite Plates with Circular Cut-Outs Subjected to Compressive Load", Material and Design,Vol31 ,pp466-474.