ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Failure Analysis of Single Pin Loaded E-Glass Epoxy Composite Plate

K. Ratnakara Rao
Department of Mechanical Engineering, SISTAM College, JNTUK, India.

J. Balabhaskara Rao
Department of Mechanical Engineering, SISTAM College, JNTUK, India.

ABSTRACT

The assessment and expectation of failure probability and safe levels of composite materials is of outrageous significance as far as manufacturing and structural design. The experimental examinations portrayed in the present paper were directed to concentrate the quality and disappointment conduct of composite plate under pointed load conditions. Pin bearing tests were done on E-glass/epoxy composite plate created by hand lay-up. The analyses examined the impact of vital parameters, including example geometry and stacking sequences, on the failure qualities. Tests were performed with two different stacking sequences: $[0/90/+30/-30]_s$ and $[0/90/+60/-60]_s$. Geometrical arrangements of examples, for example, proportion of edge distance to pin diameter (E/D) and proportion of example width to pin diameter across (W/D) were appropriately differed to watch all conceivable failure modes. A sum of 150 distinctive pin stacked composite plate examples, two laminate configurations, five edge: pin/diameter proportions, five width: pin/diameter proportions and three specimens for each condition were tried under static stacking conditions. The test estimations demonstrated that the load carrying capacity of a pin loaded hole could be changed by adjusting the example geometry and stacking sequences. In this way, the geometry of the pin connected joints was intended to attempt bearing failures as it were.

Keywords: ***Stacking sequence, Ultimate bearing strength, Pin loaded plates, Glass/epoxy, Ansys.***

1. INTRODUCTION

A composite material is a mixture of twoor more distinct constituents or phases. But this definition is not sufficient and three other criteria have to be satisfied before the material can be said to be a composite. First, both constituents have to be in reasonable proportions, say greater than 5%.

Secondly, it is only when the constituents phases having different properties, and hence the composite properties are noticeably different from the properties of the constituents. Thirdly, there are distinct, recognizable interfaces between the constituent phases.

Depending on the properties, relative amounts, degree of bonding &orientation of various constituents along with the size, shape & distribution of discontinuous constituents, composite materials possesses characteristics properties, such as stiffness strength, weight, high temperature performance, corrosion resistance, hardness, which are not possible with the individual constituents.

2. LITERATURE SURVEY

[1]Fu-Kuo Chang, Kuo-Yen Chang, “A Progressive Damage Model for Laminated Composite Containing Stress Concentrations”. [2]H. J. Lin & C. C. Tsai, “Failure Analysis Of Bolted Connections Of Composites With Drilled And Moulded-In Hole”. [3]Nahla K. Hassan, Mohamed A. Mohamdien and Sami H. Rizkalla, “Finite Element analysis of Bolted Connections for PFRP Composites”. [4]Y. Xiong and O.K. Bedair, “ Analytical and Finite Element Modeling of Riveted Lap Joints in Aircraft Structure. [5]P.P. Camanho and F.L. Matthews, “A Progressive Damage Model for Mechanically Fastened Joints in Composite Laminates”.[6]AlaattIcn Aktas,Ramazan Karakuzu, “Failure Analysis Of Two- Dimensional Carbon-Epoxy Composite Plate Pinned Joint ”.[7]Th. Kermanidis, G.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Lebeas, K.I.Tserpes and Sp. Pentelakis, "Finite Element Modeling Of Damage Accumulation In Bolted Composite Joints Under Incremental Tensile Loading".[8]Marie-Laure Dano, Guy Gendron and Andre Picard," Stress And Failure Analysis Of Mechanically Fastened Joints In Composite Laminates". [9]Q.M. Li, R.A.W. Mines, R.S. Birch, "Static and Dynamic Behavior of Composite Riveted Joints In Tension". [10]Okenwa I. Okoli and Ainullotfi Abdul-Latif, "Failure in Composite Laminates: Overview of an Attempt at prediction". [11]K.I. Tserpes, G. Labeas, P. Papanikos and Th. Kermanidis, "Strength Prediction Of Bolted Joints In Graphite/Epoxy Composite Laminates". [12]Bulent Murat Icten and Ramazan Karakuzu," Progressive Failure Analysis of Pin- Loaded Carbon–Epoxy Woven Composite Plates". [13]Buket Okutan and Ramazan Karakuzu, "The Strength Of Pinned Joints In Laminated Composites". [14]B. Yang , E. Pan , F.G. Yuan. "Three-Dimensional Stress Analyses In Composite Laminates With A Pinned Hole".[15]J. Wang,P.J. Callus, M.K. Bannister,"Experimental And Numerical Investigation Of The Tension And Compression Strength Of Un-Notched And Notched Quasi- Isotropic Laminates".

3. MATERIALS AND METHODS

3.1 Materials

This chapter describes the details of processing of the composites and the experimental procedures. The raw materials used in this work are

- E-glass Fiber mat
- Epoxy Resin CY225 and
- Hardener HY225

3.2 Definition of problem statement

In this study, a laminated composite plate with a single circular hole with a pin is used. It is desired to find the maximum failure load P_{max} that can be applied before the joint fails and the mode of failure for each geometry. Pin strength is very high compared with that of the composite plate. For this reason the failure of the pin has been neglected. The geometry of the composite specimens is shown in Fig 3.1, where L + E, W are the length and width of the specimen, respectively. D is the diameter of the holes. E is the distance from the free edge to the center of the hole. Pins are located at the centre of the holes. A uniform tensile load P is then applied to the plate and this load is resisted by a rigid pin. The load is parallel to the plate and is symmetric with respect to the center line. Thus, the load cannot create bending moments about x, y, z axes.

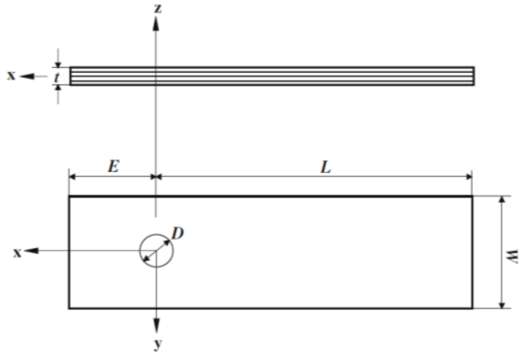


Fig. 3.1. The geometry of the specimen.

The ratios of E/D and W/D were changed in order to verify their influence on the load bearing performances and joint failure modes. In order to estimate the strength of single pin-loaded specimens, the static bearing strength is calculated as:

$$\sigma_b = \frac{P}{D.t}$$

Where σ_b, P, D and t represent bearing strength, maximum load, pin diameter and thickness of the specimen, respectively.

3.3 failure modes for pinned joints

The failure strength and failure mode of single-hole pin-loaded specimens depends upon three geometric variables: specimen width, edge distance and thickness. In general, there are three basic pinned joint failure modes related to composites: These are net tension, shear out, and bearing as shown in Fig 3.2. In practice, combinations of these failure modes are possible. Net-tension and shear out modes are catastrophic and result from excessive tensile and shear stresses. Bearing mode is local failure and progressive,and related to compressive failure. Net-tension and shear outmodes can be avoided by increasing the end distance (E) and width(W) of the structural part for a given thickness but

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

bearing failurecannot be avoided by any modification of the geometry. Designersare required toobtain the optimum E/D and W/D ratios to get thebearing mode, which shows the highest strength in pinned jointuses.

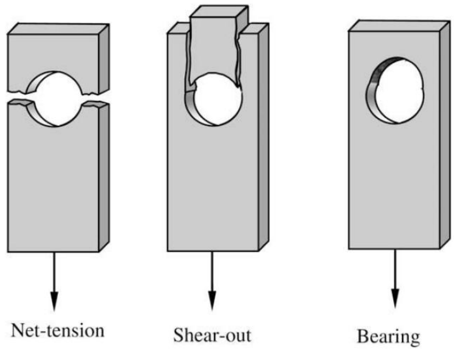


Fig. 3.2. Typical failure modes for pinned joints.

3.4 Production of Composite Plates

All laminates were made from E-glass fibre and epoxy resin using hand layup technique. Epoxy CY225 and hardener HY225 were mixed in the mass ratioof 100 : 80. The resin and hardener mix was applied to the fibres. Fibres were coated with this mix. Subsequent plies were placed one upon another toobtain required stacking sequences such as [0/90/+30/-30]s and [0/90/+60/-60]s.These stacking sequences were selected because a variety of failure modes and failure strengths can be observed with them. The composite material consists of eight layers of oriented unidirectional fibres. A hand roller was used to compact plies and remove entrapped air that could later lead to voids or layer separations. Then the laminates were cooled to room temperature. Afterwards laminates were trimmed to the size. The finished specimen had an average thickness of 2.8 mm and the overall length of 100 mm

In the present study, a total of 150 angle plied E-glass/ epoxy composite specimens with 5 mm diameter holes, different stacking sequences ([0/90/+30/-30]s and [0/90/ +60/-60]s) and geometrical configurations were fabricated. W wasvaried from 10 up to 30 mm and E from 5 up to 25 mm to ensure the variations of the two fundamental parameters E/D and W/D from 1 up to 5 and from 2 up to 6 respectively. The variations of these parameters had been made to find out the limit values for E/D and W/D to assure failure modes. Table 1.shows the list of dimensions of test specimens.

Table 1 Dimensions of test specimens

Ply stacking sequence	L mm	D mm	W mm	E mm	W/D ratio	E/D ratio
[0/90/+30/-30]s	90	5	10,15,20,25,30	5,10,15,20,25	2,3,4,5,6	1,2,3,4,5
[0/90/+60/-60]s	90	5	10,15,20,25,30	5,10,15,20,25	2,3,4,5,6	2,3,4,5,6

Table 2 Mechanical properties of unidirectional E-glass/ epoxy composite material

Properties	Magnitudes
Longitudinal modulus E1, MPa	37 200
Transverse modulus E2, MPa	16 400
Shear modulus G12, MPa	6400
Poisson's ratio v12	0.28
Longitudinal tensile strength Xt, MPa	950
Longitudinal compressive strength Xc, MPa	85
Transverse tensile strength Yt, MPa	945
Transverse compressive strength Yc, MPa	157
Shear strength S, MPa	87
Fibre volume fraction Vf, %	60

3.5 Experimental setup

A double-lap single-steel-pin joint was considered for experimental model. The end of specimen was placed in wedge grips. The steel pin was inserted into the hole of the specimen. The other end of the specimen passed through a specially manufactured fork fitting attached to the testing machine cross-head as shown in Figure 3.3. For single-hole joints, the strengths and failure modes have been obtained and the effects of variables such as ply orientation and geometric dimensions were discussed in the light of the tests. For each type of composite joint, three tests were conducted and the average bearing strength values were calculated.

For bearing tests, each plate was cut and prepared with a circular hole, centrally placed with regard to the width and at the specified distance from the end. A series of experiments was carried out with two different stacking sequences [0/90/+30/-30]s and [0/90/+60/-60]s, in all over 150 specimens. Different edge distance/diameter ratios (1, 2, 3, 4, 5) and width distance/diameter ratios (2, 3, 4, 5, 6) were considered in the tensile test. Three specimens were used for each configuration. The failure load was taken as the mean value from three specimens.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

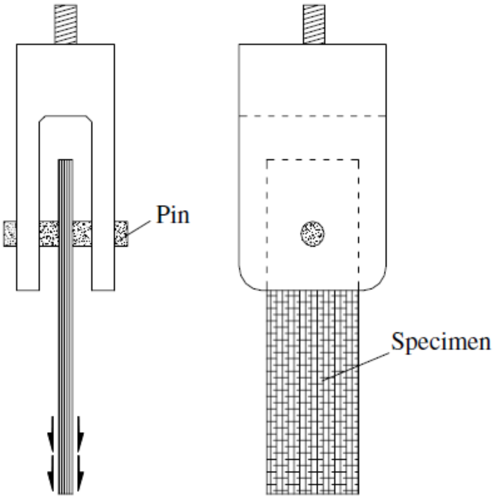


Figure 3.3. Experimental setup for pin-joint fixture.

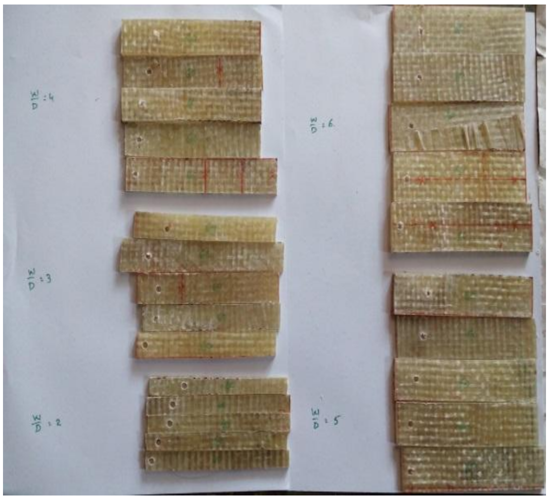
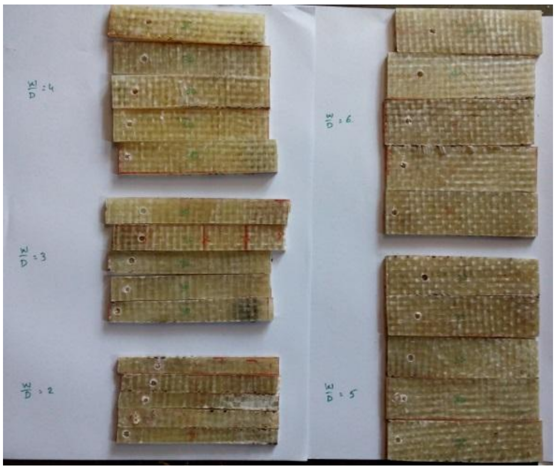


Fig 3.4 specimens of E/D, W/D ratios of stacking sequence of [0/90/+30/-30]s and [0/90/+60/-60]s

All specimens were mounted in the testing machine using a set of test fixture specially designed for this experiment and loaded at a constant crosshead rate of 0.5 mm min^{-1} to minimize any catastrophic failure. Applied load and pin displacement were continuously recorded from the chart recorder attached to the testing machine for each test. By using a load cell mounted on the testing machine, the magnitude of the applied load was measured. During the test, the displacement of bottom grip was also recorded. Specimens were tested to final failure. How failure is affected by geometry was observed.

Photographs of different types of failure modes for E/D and W/D series are shown in Figs 3.4. respectively.



4. VALIDATION OF ANSYS MODEL

The present work is to find the failure strengths and failure modes of pin loaded E Glass Epoxy composite plates with different geometric proportions. The variation in geometric proportions is done by varying E/D, W/D, keeping D and T constant. All the analyses are carried using a FEA package ANSYS16.1. For validating the model used in ANSYS, first the analyses are performed on pin loaded composite plates by varying E/D and W/D keeping D and T as constant and these results are compared with the experimental results. The work is then extended by varying D and T. In the present chapter validation of the ANSYS model is presented.

4.1 Geometry of the specimen

A composite rectangular plate of length L+E, width W and thickness T is considered. A hole of diameter D is made at a distance of E from one edge of the plate. A rigid pin is located at the centre of the hole. The load P is applied parallel to the plate along the longitudinal axis. The specimen has symmetry with respect to the longitudinal axis. Different specimens are obtained by varying the geometric proportions of the plate. This is done by changing E/D and W/D but keeping the parameters D and T as constant i.e. the distance of the hole from one edge of the plate and the width of the specimen only vary.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

The Ansys 16.1 work bench is taken as my path of work. The dimensions of the specimen as taking diameter 5 mm and thickness as 2.8 mm And overall length of the specimen as 100 mm and by changing the width and edge distance. With different ply angle orientations. And these can be done by Ansys ACP pre tool, Ansys ACP post and static structural

4.2step by step Procedure

Open Ansys ACP tool and set the engineering data for E-Glass Epoxy composite and open the model in the ACP tool.

Draw the sketch with required dimensions

Apply the surface to that sketch.

Open the slice tool and make the surface in to 4 slices by using along the axis button i.e. ZX plane and YZ plane.

Open the object in the model and apply mesh

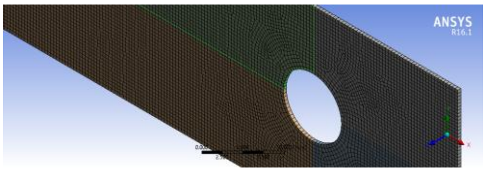


Fig 4.1 Generated mesh on the object

Open the setup in Ansys work bench and apply the material properties and the element thickness.

Create a fabric in the tool by applying material as E-Glass Epoxy and the element thickness.

After applying the fabric open the rosette, create the rosette and set the origin other than the origin point and click on the screen and ok.

Open the oriented selections set and create orientation point as other than origin and select the point on the screen. On the selection methods set the minimum angle and select the rosettes as rosette 1 click on ok.

Open the modeling group and create the new model, Create the ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as 0^0, Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as 90^0. Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as $+30^0$.

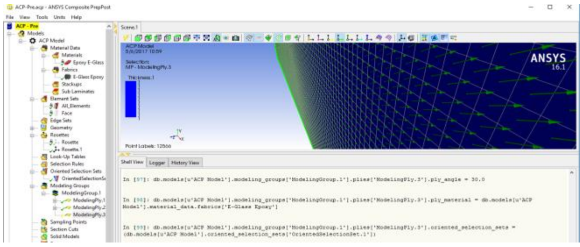


Fig 4.2 Orientation of fiber at $+30^0$ ply

Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as -30^0. Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as -30^0. Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as $+30^0$. Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as 90^0. Create another ply and on oriented selection set select oriented selection set 1, ply material as E-Glass Epoxy, ply angle as 0^0. Follow the same procedure for the stacking sequence of [0/90/+60/-60]s path.

Create the section cut on the section cut tab and deselect the interactive plane and on normal tab set the points as 0, 1, 0. And click on ok. The section cut as shown in the figure.

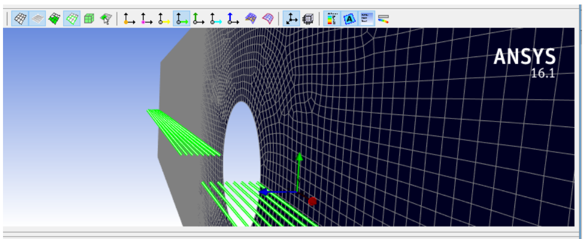


Fig 4.3 Sectional view of the plate

The fully generated work piece as show in the figure with generated mesh.

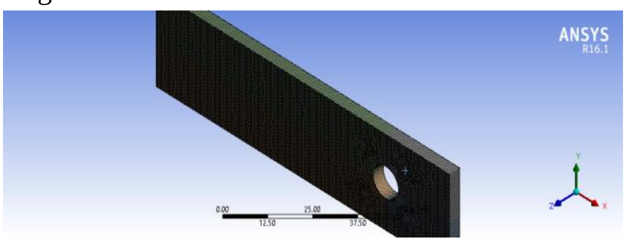


Fig 4.4Fully generated work piece

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

On the work bench open the static structural section apply all paths on it. Apply the boundary sections on the work piece like fixed support and displacement section. Those all are shown in the figure.
Applying boundary conditions fixed support
Applying boundary conditions displacement
Applying boundary conditions displacement Z=0

4.3 Solution

On the solution apply the maximum failure criterion, von-misses stress and total deformation are shown in the figure.

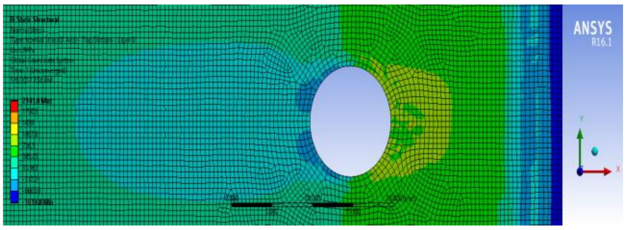


Fig 4.5 The normal stress developed in the plate

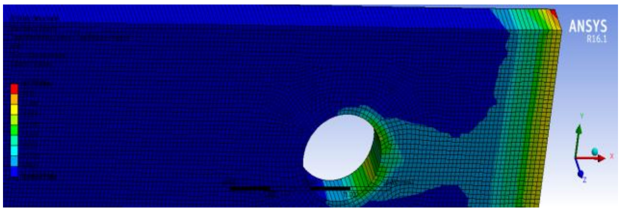


Fig 4.6 The maximum failure criteria in the plate.

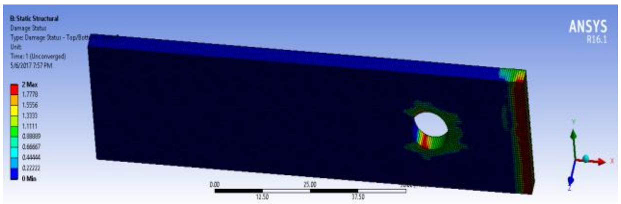


Fig 4.7 The damage status of the plate.

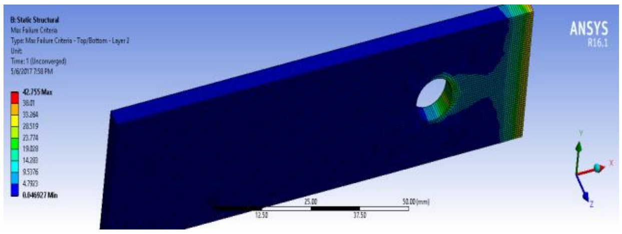


Fig 4.8 The maximum failure criteria of the plate

After the solution is done open the Acp post in the Ansys work bench and on the solution, Create the solution we can see the damage level on each layer of different ply angles as shown in the figure.

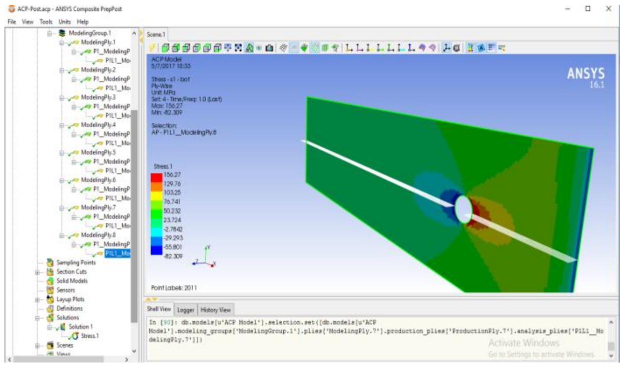


Fig 4.9 The stress failure in the modeling ply no.8

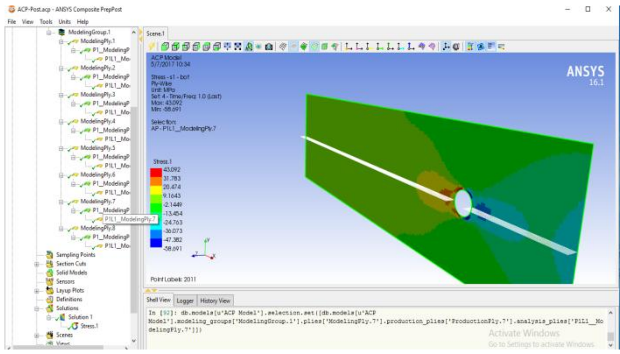


Fig 4.10 The stress failure in the modeling ply no.7

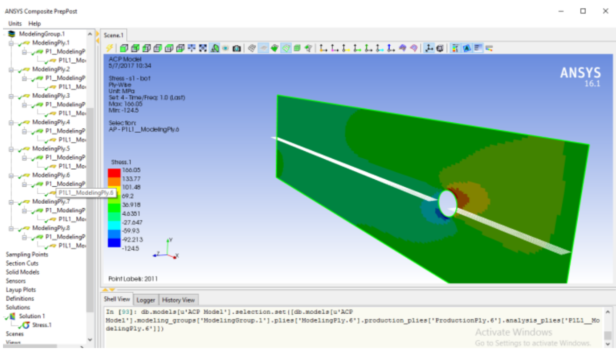


Fig 4.11 The stress failure in the modeling ply no.6

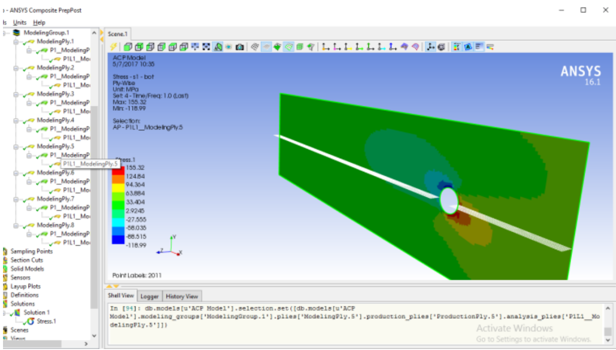


Fig 4.12 The stress failure in the modeling ply no.5

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

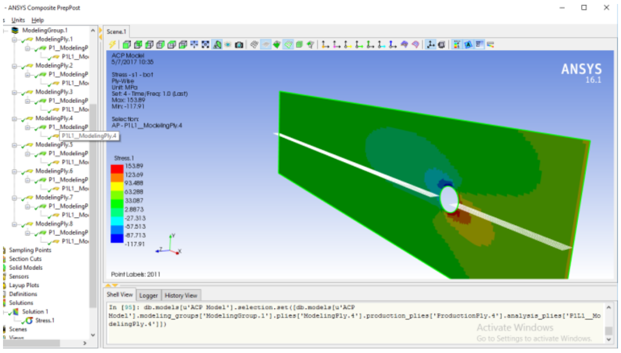


Fig 4.13 The stress failure in the modeling ply no.4

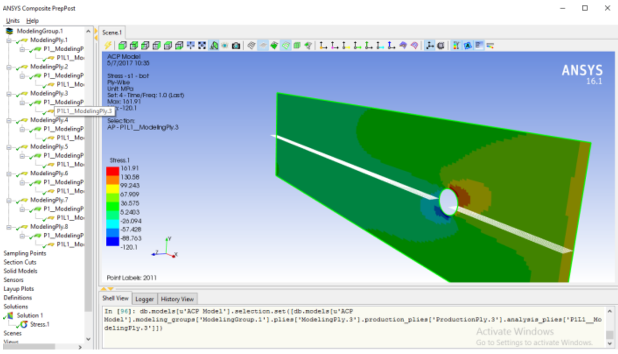


Fig 4.14 The stress failure in the modeling ply no.3

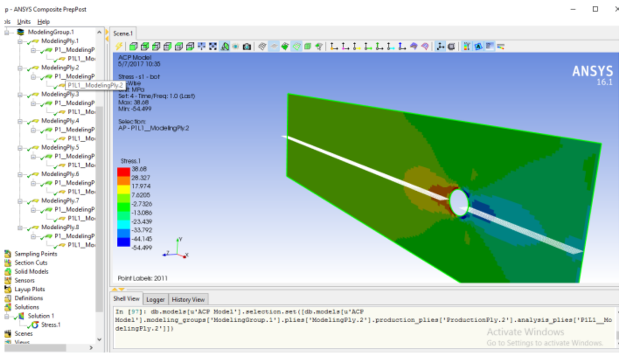


Fig 4.15 The stress failure in the modeling ply no.2

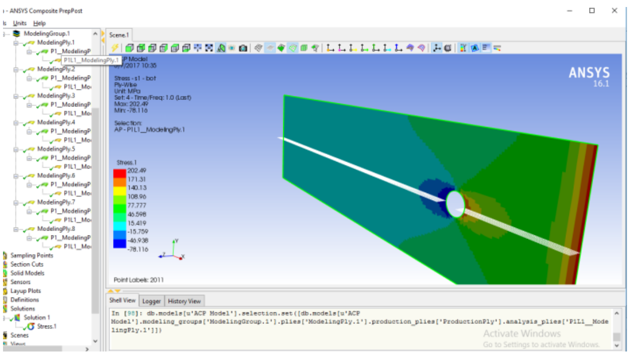


Fig 4.16 The stress failure in the modeling ply no.1

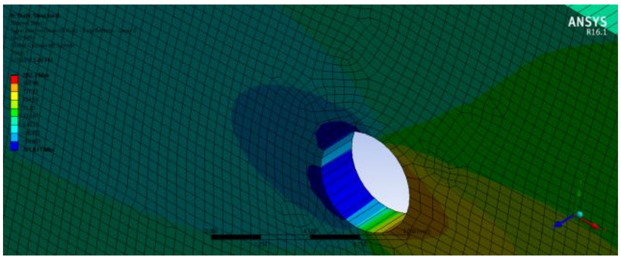


Fig 4.17 Full sectional view of normal stress on the plate

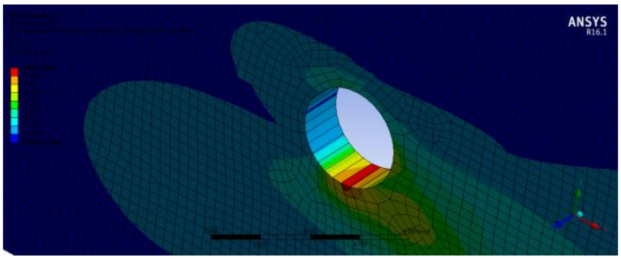


Fig 4.18 Maximum failure criteria on the modeling ply 3.

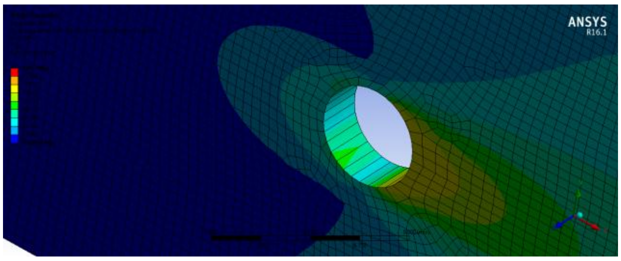


Fig 4.19 Von misses stress on the plate

5.Results and Discussions

The bearing strength and maximum failure load are investigated experimentally and numerically. The specimens for each E/D and W/D ratio are tested for experimental study. Bearing strength values, failure loads are investigated for two variables, E/D ratio (1,2,3,4,5) and W/D ratio (2,3,4,5), orientation angle of fiber for two stacking's [0/90/+30/-30]s , [0/90/+60/-60]s, is used in this study.

In the experimental study, we will see, graphs for failure load and E/D, W/D ratios for two stacking's [0/90/+30/-30]s , [0/90/+60/-60]s and compared with the Ansys results.

In addition, when edge distance to diameter ratio (E/D) and width to diameter ratio (W/D) are increased, the failure load reaches higher values.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Table 5.1Comparison of experimental and Ansys failure loads at W/D=2,3,4,5,6 for orientation [0/90/+30-30]s

UNITS	E/D=1		E/D=2		E/D=3		E/D=4		E/D=5	
Mpa	EXP	ANSYS	EXP	ANSYS	EXP	ANSYS	EXP	ANSYS	EXP	ANSYS
W/D=2	127.19	134.82	128.98	136.72	145.73	153.02	146.12	153.23	152.93	162.10
W/D=3	133.28	139.94	149.86	158.85	150.98	160.04	153.88	163.11	161.61	171.31
W/D=4	134.96	143.06	161.00	169.05	168.09	178.17	174.56	185.04	185.04	189.69
W/D=5	140.87	149.32	167.71	177.77	174.65	185.13	185.38	196.51	191.68	203.18
W/D=6	141.37	149.86	172.86	183.23	178.29	188.99	187.25	198.49	192.44	203.98

Table 5.2Comparison of experimental and Ansys failure loads at W/D=2,3,4,5,6 for orientation [0/90/+60-60]s

UNITS	E/D=1		E/D=2		E/D=3		E/D=4		E/D=5	
Mpa	EXP	ANSYS	EXP	ANSYS	EXP	ANSYS	EXP	ANSYS	EXP	ANSYS
W/D=2	101.56	107.65	112.97	119.74	118.01	125.09	124.02	131.47	134.93	143.03
W/D=3	111.71	117.30	118.84	125.97	122.04	129.36	133.87	141.91	141.35	149.83
W/D=4	116.43	123.42	120.26	127.48	128.16	135.85	137.28	145.52	137.99	146.27
W/D=5	120.97	128.23	140.77	128.23	142.61	151.17	142.75	151.31	142.80	151.36
W/D=6	121.10	128.37	142.21	150.74	142.85	151.42	146.94	155.76	147.54	156.39

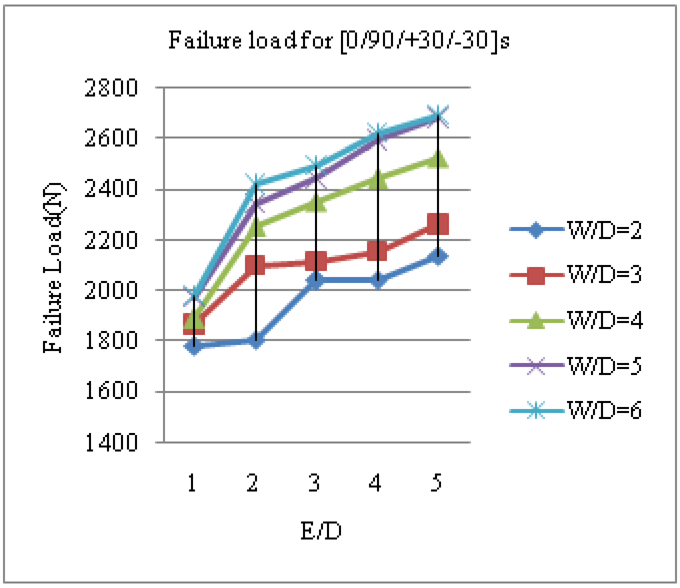


Fig 5.1 Effect of E/D and W/D ratios on Failure load for [0/90/+30/-30]s

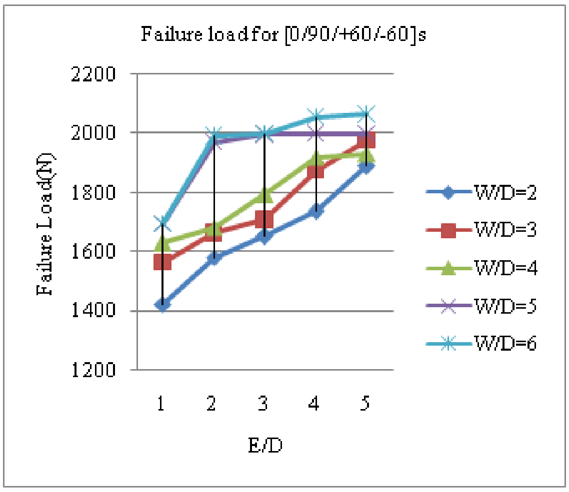


Fig 5.2 Effect of E/D and W/D ratios on Failure load for [0/90/+60/-60]s

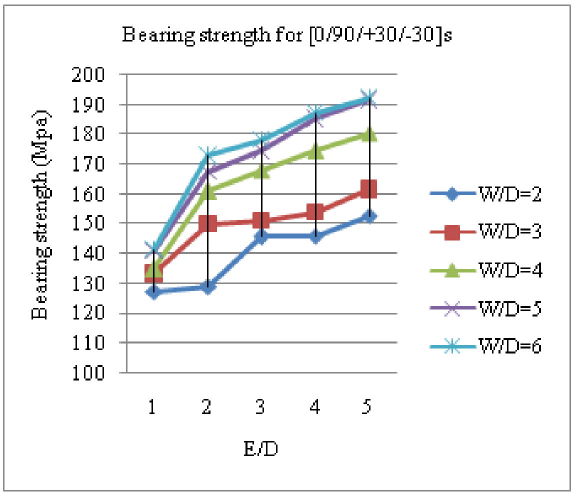


Fig 5.3 Effect of E/D and W/D ratios on Bearing strength for [0/90/+30/-30]s

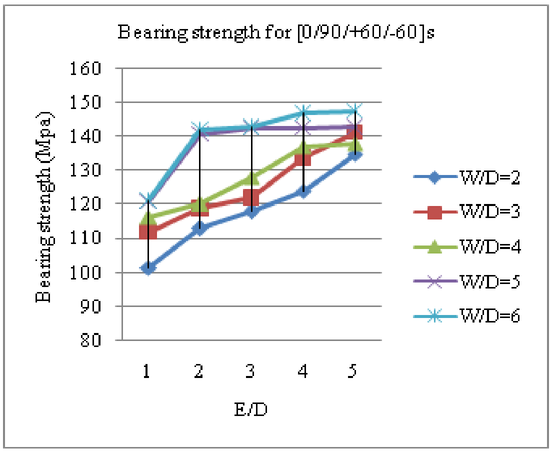


Fig 5.3 Effect of E/D and W/D ratios on Bearing strength for [0/90/+60/-60]s

6. Conclusion

When W/D=2 (the smallest value of this ratio tested), the most dangerous mode developed. The load capacity of the joint increased as the W/D ratio increased. When W/D=4, full bearing failure mode was observed. Low E/D values gave rise to shear out failure or net tension modes. Shear out or net tension failure mode was observed when the E/D ratio was 1. When E/D=1, the plate was the weakest because the hole was too close.

When E/D ratio was < 2, the shear out failure mode occurred. If E/D>2, net tension failure mode with crack initiation at the horizontal edges of the hole developed. In this failure mode, hole cross-section area was minimum. If E/D ratio had low values, the net tension or shear our failure modes developed. Increasing E/D, the failure mode changed from shear out to bearing and the failure load increased. While E/D was constant, maximum failure loads increased when W/D ratio increased. The minimum failure load was observed when W/D=2 and E/D=1 for every stacking sequence. On the other hand, the maximum failure load was observed when W/D=6 and E/D=5 for every stacking sequence.

When W/D=2, the plate was the weakest. If W/D ratio increased, the failure mode changed from net tension to shear out while E/D=1. As the width of the specimen increased, the failure mode also altered to bearing mode. Therefore, the use of composite joints with small W/D ratio was not advised.

When W/D ratio was ≥4, bearing failure mode was seen for [0/90/+30/-30]s and [0/90/+60/-60]s stacking sequences. Among these the preferable failure mode was the bearing one because soon after the achievement of maximum load, it allows the specimen to further endure a certain load.

The bearing failure resulted in a safe behaviour with the joint being able to support further load. Bearing failure mode was considered to be the desirable mode since it generally gave a higher strength and the failure was less brittle. Bearing failure mode was local failure and progressive.

7. REFERENCE

1. Fu-Kuo Chang, Kuo-Yen Chang, "A Progressive Damage Model for Laminated Composite Containing Stress Concentrations". Journal Of Composite Materials, 21(1987) 834-855.
2. H. J. Lin & C. C. Tsai, "Failure Analysis Of Bolted Connections Of Composites With Drilled And Moulded-In Hole", Composite Structures, 30 (1995) 159-168.
3. Nahla K. Hassan, Mohamed A. Mohamdien and Sami H. Rizkalla, "Finite Element analysis of Bolted Connections for PFRP Composites", Composite part B, 27B (1996) 339-349.
4. Y. Xiong and O.K. Bedair, " Analytical and Finite Element Modeling of Riveted Lap Joints in Aircraft Structure", 39 th AIAA/ ASME/ ASCE/ AHS/ ASC Structures, Structural Dynamics And Material Conference, April 1998/ Long Beach, CA
5. P.P. Camanho and F.L. Matthews, "A Progressive Damage Model for Mechanically Fastened Joints in Composite Laminates", Journal Of Composite Materials, 33(24) (1999) 2248-2279.
6. AlaattIcn Aktas,Ramazan Karakuzu, "Failure Analysis Of Two- Dimensional Carbon-Epoxy Composite Plate Pinned Joint ",Mechanics Of Composite Materials And Structures, 6 (1999)
7. Th. Kermanidis, G. Lebeas, K.I.Tserpes and Sp. Pentelakis, "Finite Element Modeling Of Damage Accumulation In Bolted Composite Joints Under Incremental Tensile Loading", ECCOMAS 2000 Barcelona, September, (2000) ,1-14.
8. Marie-Laure Dano, Guy Gendron and Andre Picard," Stress And Failure Analysis Of Mechanically Fastened Joints In Composite Laminates", Composite Structures, 50 (2000)
9. Q.M. Li, R.A.W. Mines, R.S. Birch, "Static and Dynamic Behavior of Composite Riveted Joints In Tension", International Journal Of Mechanical Sciences, 43 (2001) 1591-1610.

10. Okenwa I. Okoli and Ainullotfi Abdul-Latif, "Failure in Composite Laminates: Overview of an Attempt at prediction",ELSEVIER, Composites: Part-A: Applied Sciences and Manufacturing , 33 (2002) 315-321.
11. K.I. Tserpes, G. Labeas, P. Papanikos and Th. Kermanidis, "Strength Prediction Of Bolted Joints In Graphite/Epoxy Composite Laminates", Composites: Part B, 33 (2002) 521–529.
12. Bulent Murat Icten and Ramazan Karakuzu," Progressive Failure Analysis of Pin- Loaded Carbon–Epoxy Woven Composite Plates", Composites Science and Technology, 62 (2002) 1259–1271.
13. Buket Okutan and Ramazan Karakuzu, "The Strength Of Pinned Joints In Laminated Composites", Composites Science and Technology, 63 (2003) 893–905.
14. B. Yang , E. Pan , F.G. Yuan. "Three-Dimensional Stress Analyses In Composite Laminates With A Pinned Hole", International Journal Of Solids And Structures, 40 (2003) 2017–2035.
15. J. Wang,P.J. Callus, M.K. Bannister," Experimental And Numerical Investigation Of The Tension And Compression Strength Of Un-Notched And Notched Quasi- Isotropic Laminates", Composite Structures, 64 (2004) 297–306.