Journal of Science and Technology
ISSN: 2456-5660 Volume 06,Special Issue 01, August 2021,

www.jst.org.in *DOI: https://doi.org/10.46243/jst.2021.v6.i04.pp558-570*

Experimental Analysis and FEA Validation of Woven Composite Pin Joints

Prof. P. D. Gharge[1], Prof. R. K. Nanwatkar[1],
Mr. Anand Omprakash Verma[2], Mr. Yogesh Devidas Lohot[2],
Mr.Rajesh Santosh Chavan[2], Aditya Dattatraya Gawande[2]
[1](Assistant Professor, Department of Mechanical engineering, NBNSSOE, SPPU Pune, India)
[2](UG Student, Department of Mechanical engineering, NBNSSOE, SPPU Pune, India)
Corresponding Author: prajakta.gharge@sinhgad.edu[1], ravikant.nanwatkar@sinhgad.edu,
Anandoverma.verma@gmail.com[2], ydlohot@gmail.com[2], rajeshchavan614@gmail.com[2],
aditya15feb1999@gmail.com[2]

To Cite this Article
Prof. P. D. Gharge1, Prof. R. K. Nanwatkar1,, Experimental Analysis and FEA Validation of Woven Composite Pin Joints, Vol. 06, Special Issue 01, August 2021, pp558-570: .

Article Info
Received: 15.07.2021 Revised: 24.07.2021 Accepted:10.08.2021 Published: 16.08.2021

Abstract: *The investigation is focus on developing a reliable computation procedure to analyses initial failure load for pin-loaded holes at layered composite structures. Finite element method (FEM) is used to determine deflection and stress distribution around the fastener hole. Hashing Failure Criterion is used to determine composite plate failure. Special attention in this work is paid to geometrical dimension variations and its effect on first failure loadof the composite plate. The main objective was to investigate the possibility of predicting the properties of the joint from the experimental tests, and validate the FEA model, the validated model further used for to study pin diameter variations properties of the joints. For material properties the standers test ware carried out on Universal Testing Machine to obtain its tensile yield load, and this obtained stress strain curve is utilized in FEA model, for material nonlinearity, remaining material properties are taken from the manufacturer of the plate. A refined finite element model was developed in which the nonlinearities due to contact between the pin and the hole were taken into account, and material nonlinearity also taken in to consideration for the analysis Particular attention was paid to account for the influence of the clearance between plate and pin ware investigated by numerically. In finite element pin/plate model is analyzed. The influence of coefficient of friction assembly containing pin-loaded hole is also investigated. The fixtures and the test specimens are prepared for the testing and its testing ware carried out on the Universal testing machine around 16 different geometrical variations. different geometrical variance samples are tested under the tensile test for prediction of the first failure load with [45]3S and [0] 3S two types stacking sequence, Specifically, the effect of orientation of the ply angel ware simulated in FEA, with validated FEA model and for first failure load verses angel of ply rotations effects ware studied, which has shown significant similarity to a basic load verses ply angel curve, In further simulations the effect of the increase in the diameter of the pin on failure load ware concluded. In conclusion, good agreement between experimental results and numerical predictions has been obtained from Finite Element Analysis, which is validated by the testing results the computation results are compared with obtained experimental results.*

***Key Word**: Composite, CFD, FEA, Tensile test, UTM*

I. Introduction

Mankind has been aware composite materials since several hundred years before Christ and applied innovation to improve the quality of life. Although it is not clear has to how Man understood the fact that mud bricks made sturdier houses if lined with straw, he used them to make buildings that lasted. Ancient Pharaohs made their slaves use bricks with to straw to enhance the structural integrity of their buildings, some of which testify to wisdom of the dead civilization even today. Contemporary composites results from research and innovation from past few decades have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range other applications. Ironically, despite the growing familiarity with composite materials and ever increasing range of applications, the term defines a clear definition. Loose terms like "materials composed of two or more distinctly identifiable constituents" are used to describe natural composites like timber, organic materials, like tissue surrounding the skeletal system, soil aggregates, minerals and rock. Composites that forms heterogeneous structures which meet the requirements of specific design and function, imbued with desired properties which limit the scope for classification. However, this lapse is made up for, by the fact new types of composites are being innovated all the time, each with their own specific purpose like the filled, flake, particulate and laminar composites. Fibers or particles embedded in matrix of another material would be the best example of modern-day composite materials, which are mostly structural. Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. Fabrics have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. Reinforcing materials generally withstand maximum load and serve the desirable properties. Further, though composite types are often distinguishable from one another, no clear determination can be really made. To facilitate definition, the accent is often shifted to the levels at which differentiation take place viz., microscopic or Macroscopic. In matrix-based structural composites, the matrix serves two paramount purposes viz., binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force. The demands on matrices are many. They may need to temperature variations, be conductors or resistors of electricity, have moisture sensitivity etc. This may offer weight advantages, ease of handling and other merits which may also become applicable depending on the purpose for which matrices are chosen. Solids that accommodate stress to incorporate other constituents provide strong bonds for the reinforcing phase are potential matrix materials. A few inorganic materials, polymers and metals have found applications as matrix materials in the designing of structural composites, with commendable success. These materials remain elastic till failure occurs and show decreased failure strain, when loaded in tension and compression. Composites cannot be made from constituents with divergent linear expansion characteristics. The interface is the area of contact between the reinforcement and the matrix materials. In some cases, the region is a distinct added phase. Whenever there is interphase, there has to be two interphases between each side of the interphase and its adjoin constituent. Some composites provide interphases when Surfaces dissimilar constituents interact with each other. Choice of fabrication method depends on matrix properties and the effect of matrix on properties of reinforcements. One of the prime considerations in the selection and fabrication of composites is that the constituents should be chemically inert non-reactive. Figure 1 helps to classify matrices.

Problem Statement:

A computation method in failure analysis of layered composites containing pin-loaded holes, the investigation is focused on developing a reliable computation procedure to analyze initial failure load for pin-loaded holes at layered composite structures. Finite element method (FEM) is used to determine deflection and stress distribution around the fastener hole. Hashin Failure Criterion is used to determine composite plate failure. Special attention in this work is paid to geometrical dimension variations and its effect on first failure load of the composite plate.

Objectives:

1. The main objective is to investigate the possibility of predicting the properties of the joint from the experimental tests, and validate the FEA model, the validated model further used for to study pin diameter variations properties of the joints.
2. For material properties the standers test will going to be carried out on Universal Testing Machine to obtain its tensile yield load, and this obtained stress strain curve will be utilized in FEA model, for material nonlinearity, remaining material properties will be taken from the manufacturer of the plate.
3. The fixtures and the test specimens is to be prepared for the testing and its testing will be carried out on the Universal testing machine with different geometrical variations.
4. The effect of orientation of the ply angel ware simulated in FEA, with validated FEA model and for first failure load verses angel of ply rotations effects will be studied.

Scope of Work:

1. Comparative study of different composite materials with its types joints in various industrial applications.
2. Finite element analysis of composite pin joints.
3. Various materials testing to verify the FEA and experimental results using universal testing machines.
4. Experimental and analytical validations of the results obtained.

Methodology:

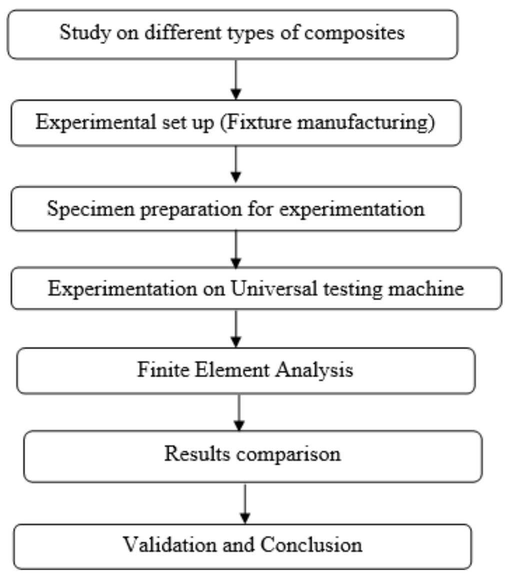

Figure 1: Methodology of the work

II. Literature Review

Fiber reinforced composite materials have been gaining wide application in joining composites either to composites or to metal. Most commonly, joints are formed using mechanical fasteners. Therefore, suitable methods must be found to determine the failure strength of mechanically fastened joints. Knowledge of the failure strength would help in selecting the appropriate joint size in a given application. Many investigators have studied the strength of mechanically fastened joints in composite structures. Chang et al. [1] have developed a computer code which can be used to calculate the maximum load, the mode of joints involving fiber reinforced laminates with different ply orientations, different material properties and different geometries. They have used Yamada failure criterion. Aktas and Karakuzu [2] have carried out a failure analysis of mechanically fastened carbon fiber reinforced epoxy composite plate of arbitrary orientation. In that work, failure load and failure mode have been analyzed experimentally and numerically using Tsai-Hill and fiber tensile-compressive failure criteria. Icten and Sayman [3] have investigated failure load and failure mode in an aluminum–glass–epoxy sandwich composite plate, with a circular hole, which is subjected to a traction force by a pin. To evaluate the effects of joint geometry and fiber orientation on the failure strength and failure mode, parametric studies were performed experimentally. Icten et al. [4] have investigated mechanical behavior and damage development of pin-loaded woven glass fiber–epoxy composites, numerically and experimentally. To verify the numerical predictions of mechanical behavior, a series of material configurations ([(0/90)3] S [(±45)3] S) and 20 different geometries. Icten and Karakuzu [5] have concerned with the prediction and examination of the behaviors of the pinned joint carbon–epoxy composite plates. The failure mode and bearing strength are investigated numerically and experimentally. Two-dimensional finite element method is used to determine the failure load and failure mode using Hoffman and Hashin criteria. Okutan et al. [6] have investigated the failure strength of pin-loaded woven fiber–glass reinforced epoxy. Laminates experimentally and have observed the effects of changing the geometric parameters were observed. Chang [7] has performed an analysis to evaluate the effect of the assumed pin load distribution. The calculations have utilized a finite element method of stress analysis combined with the Yamada-Sun failure criterion applied along the Chang- Scott Springer characteristic curve. Hung et al. [8] have investigated failure analysis of T800/3900-2 graphite– epoxy materials by using Hashin failure criteria. Pierron and Cerisier [9] have carried out a numerical and experimental study to determine the stiffness and the bearing strength of bolted woven composite joints. In addition, they have studied for the influence of the clearance. Kretsis and Matthews [10] showed that as the width of the specimen decreases, there is a point where the made of failure changes from one of bearing mode to one of tension mode, using E glass fiber-reinforced plastic and carbon fiber-reinforced plastic. A similar behavior between the end distance and the shear-out mode of failure was found. They concluded that lay-up had a great effect on both joint strength and failure mechanism. There is much literature on double lap pin joints with the composite plate for numerical analysis most of the papers are not used the frictional contact between the plate and the pin, which deviate our numerical model from its near prediction of the failure load This chapter summarizes various test and samples configurations used for reviewing the behavior of the pin joints.

III. Experimental Set Up and Methodology

Experimental Analysis

The UTM machine were used for testing purpose the output such as force verses deflection, stress verses strain were obtain the testing were carried out in two phases. In first phase the material tensile material property for the test specimen ware obtained with the help of load verses deflection curve and stress verses strain curve. In second stage for different geometrical configuration a load verses deflection curve ware obtained.

1) Two sample's ware tested for obtaining the tensile material properties

2) Sixteen sample's ware tested for prediction of the failure load with different ply orientation and geometrical properties

A] ASTM D3039-01 standard test method ware utilized for obtaining the material properties, testing ware carried

Out on two test samples Form first test sample a maximum failure load ware obtained, and with some lower values of the failure load with attachment of the extensometer the testing ware carried out.

B] For prediction of the failure load with different fiber orientation and geometrical properties a Fixture is utilizes for configuration of the pin behavior, around 16 samples were tested, a gauge length for the all test samples 60 mm ware fixed To get a proper grip between the test samples and the clamping jaw, a serration clamping plates ware utilized for avoiding slippage between jaw and plate, in advance on test specimen the sand paper ware glued for getting the more grip between the plate and jaw Speed of the UTM machine ware kept 1 mm/ min during the testing of all samples.

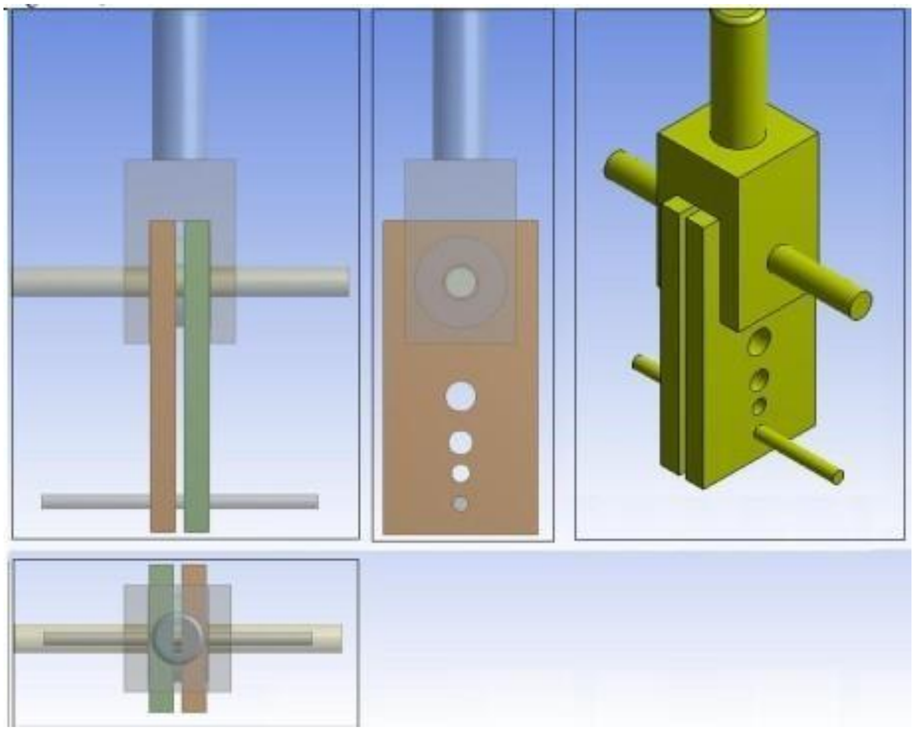

Figure 2: CAD Model of Fixture

Block with Top shaft:

For manufacturing of this block the slab of the 60 mm X 36 mm X 36 mm ware purchased, after that on milling machine the 20 mm wide and 40 mm deep groove ware made, on both side of the obtained object the 20 mm Drill ware made, after that on top surface of the slab the counter drill of 18 mm has been drilled for press fitting of the 18 mm bar having length of 50 mm, then the both component ware welded together with electrode welding process.

Washers:

The washers are purchased from the hardware shop.

Plate

For manufacturing of this plates the two slab of the 102 X50 X 8 mm 3 were purchased, after that, With the help of the height gauge the center locations of the holes were marked, to obtain a same hole location in both the plate the they are welded to each other to get a same hole location for each plates, with in welded position they are drilled according to dimension's mentioned. The assembly of the fixture ware containing the 8 components, which are made from the structural steel having material properties as E = 2 X 105 N/mm2 and Density = 7850 Kg/mm^3.

Ply orientation Overview

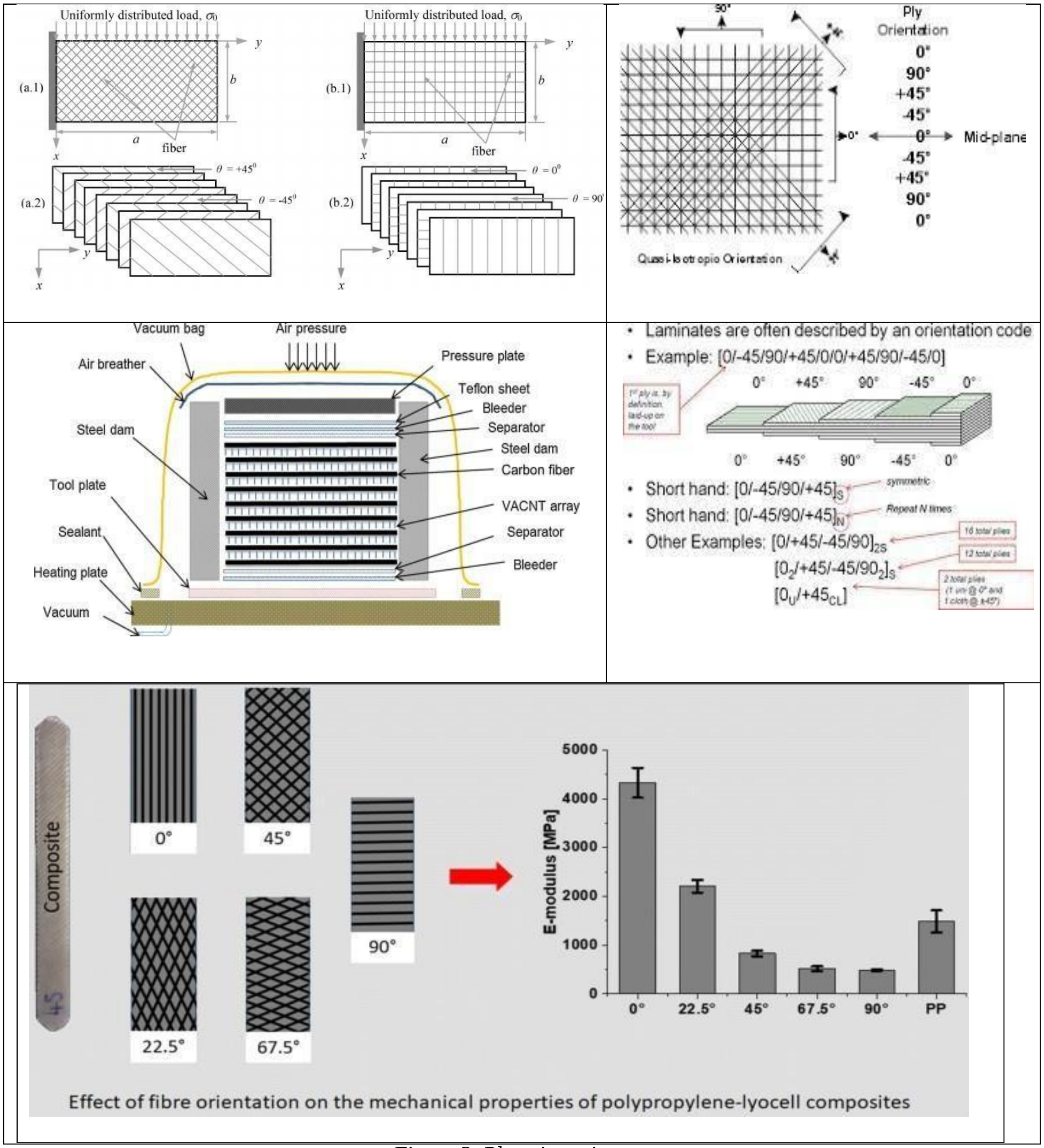

Figure 3: Ply orientation

Test Specimens

The test specimens ware created in two phases,

The two Test Specimen for obtaining the stress strain curve for material as per ASTM Standard D3039-01 the test specimen ware prepared. For tensile test the samples ware cute in 25 mm X 200 mm which is having the working length of 90 mm and width of 20 mm, the excess material ware removed on grinding wheel.

Figure 4: Isometric view of test Specimen

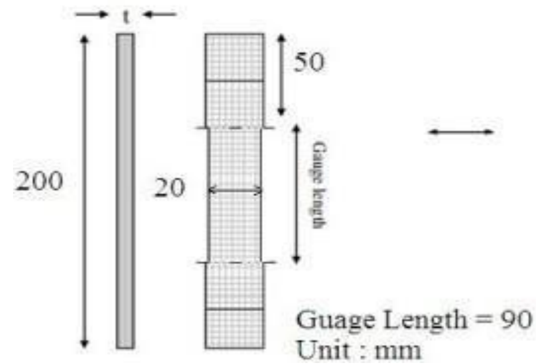

Figure 5: Dimensions of test Specimen

For geometrical variations total 16 specimens ware cute in according to W/D and E/Dratio as shown in Table Below, and samples were named according to below configurations, with total length of 110 mm, 60 mm is working length for the specimen.

Table 1: Sample's naming with Geometrical configurations

	W/D = 20	**W/D = 30**
E/D = 2	A20	A30
E/D = 3	B20	B30
E/D = 4	C20	C30
E/D = 5	D20	D30

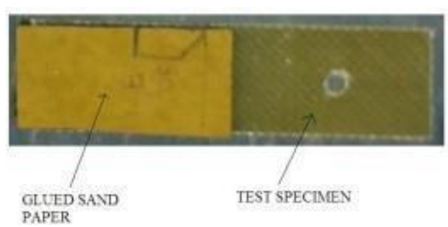

Figure 6: Photographic View of Samples

Above eight samples were made with ply orientations of [0] same configuration's ware repeated for ply orientations of [45] total 16 test samples were obtained. With variations of geometries and ply orientations, for ply orientation [45] The sample's naming ware provided with " ' " , example as A'20, B' 20 etc. For cutting the composite plate the diamond plated cutter ware used, a table feed cutting machine ware used for obtaining the desired shapes as mentioned. For drilling the hole in to a composite plate a High Speed Steel 5 mm drill bit were used, and on 16 specimens at respective E/D distance the holes are made. To get proper bonding between the test specimen and the jaw a sand paper ware glued on the test specimen for getting proper bonding between the plate and fixture, the gluing additive ware used for it.

Testing for Material Properties

The experimental method describes in details the materials and its fundamental constituents, the specimen preparation for the fabrication of composite plates, and the Experimental test methods and facilities according to standards. This test ware carried out in two steps.

1) To obtain the Failure Load of the sample prepared in this testing the sample ware fixed in to the jaws of the machine and gradual load ware applied till failure occurs from this test we have got failure load of the test specimen = 24304 N. To obtain the stress strain curve with help of extensometer. In this test the 98 % of failure load obtained from test 1 is applied to the test sample.
2) The stress calculation was defined based on the nominal cross-sectional of the test specimen, such that; Stress = Force / Area= Force / (width * Thickness)= 23520 / (20 * 3)= 392 MPa.

The Slop of stress strain curve provide us the modules of elasticity in x direction, E = 20769 MPa.

this is the composite orthotropic material we are using for testing which is contains the plane woven fabric, so the material properties obtained for the x direction will be the same for the y directions for maximum tensile stress and the modules of elasticity, these material properties further used for FEA analysis for defining the stress strain curve,

Table 2: All test specimens For Failure Load In and Deflection

Specimen Name	Failure Load In N	Deflection In mm	Type of Failure
A 20	3278	1.837	Shear
B 20	3370	1.753	Shear - Bearing
C 20	3698	1.912	Bearing
D 20	3778	2.102	Bearing
A’ 20	3632	1.563	Shear
B ‘20	3782	1.832	Shear - Bearing

Results for E/D ratio with [0]3s and [45]3s Configurations

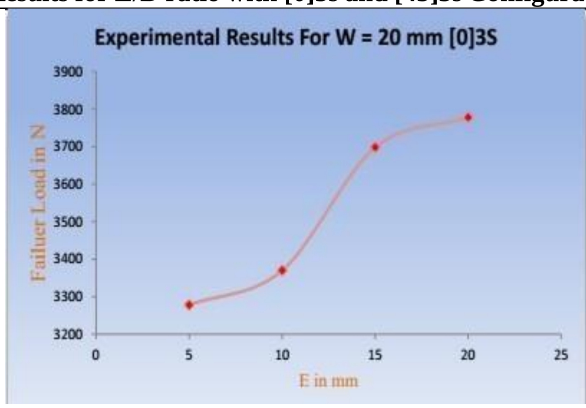

Figure 7: Graph of Failure Load V/S Depth of Pin for W= 20 mm and Ply orientation[0]3s

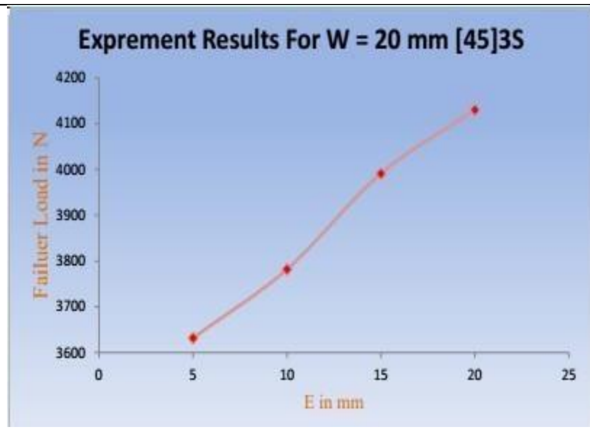

Figure 8: Graph of Failure Load V/S Depth of Pin For W= 20 mm and Ply orientation [45]3s.

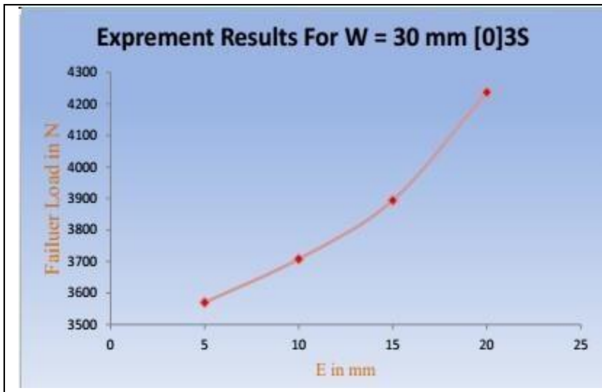

Figure 9: Graph of Failure Load V/S Depth of Pin for W= 20 mm and Ply orientation[0]3s

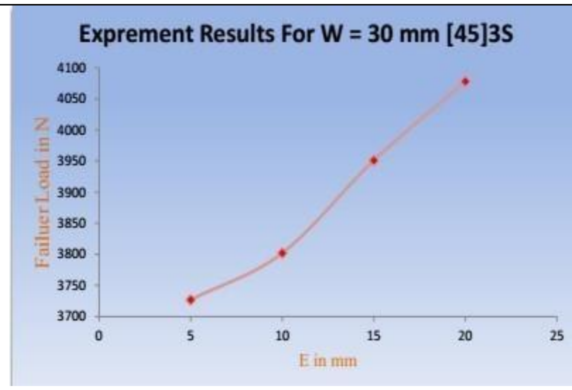

Figure 10: Graph of Failure Load V/S Depth of Pin for W= 30 mm and Ply orientation[45]3s

FEA Analysis

For simulation of the composite plate the shell 181 element is used for analysis. SHELL181 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. SHELL181 may be used for layered applications up to 250 layers for modeling laminated Composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first order shear deformation theory.

Material Properties:

Material: woven composite as suggested in Project work
Young's modulus: 2.07×10^{10} Pa.
Poison's ratio = 0.3
Shear modulus: 4.13×10^{9} Pa
Tensile force = 3.95×10^{8} Pa
Compressive Force: -2.6×10^{8} Pa
Shear Force: 7.5×10^{8} Pa

FEA RESULTS

Results for E/D ratio with [0]3s and [45]3s Configurations

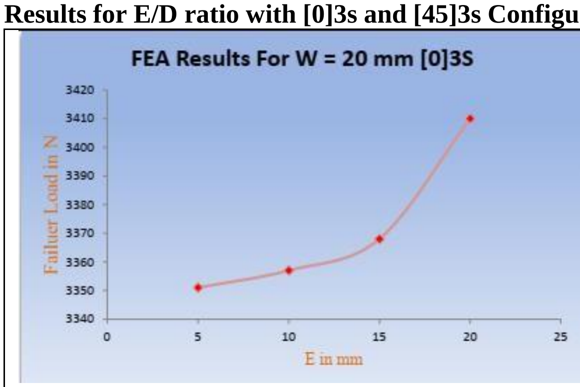

Figure 11: FEA Results For W = 30 mm [0]3S

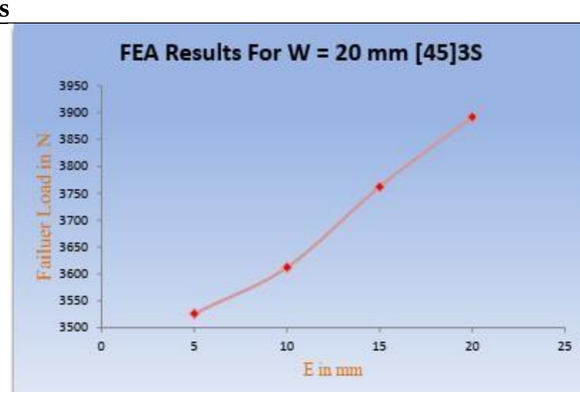

Figure 12: FEA Results For W = 20 mm [45]3S

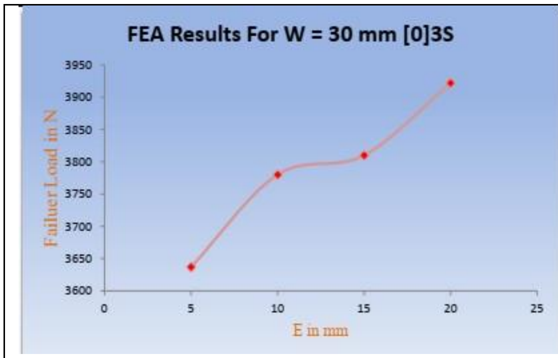

Figure 13: FEA Results For W = 30 mm [0]3S

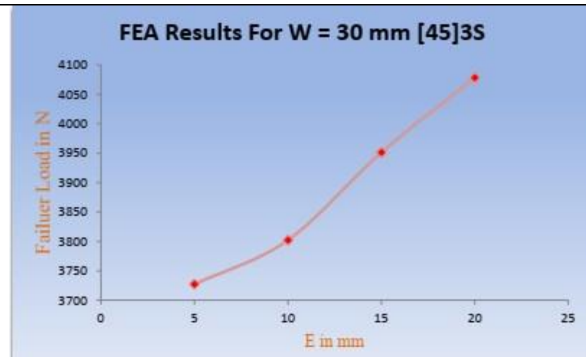

Figure 14: FEA Results For W = 30 mm [45]3S

Results for Failure Load for increase in Ply orientation's from [0]3s to [45]3s Configurations

From experimental and FEA results obtained for E/D ratio with [0]3s and [45]3s Configurations it has been seen that there is around 12% variation is available between the results, so this validated FEA model is utilized for the prediction of Failure Load for increase in Ply orientation's from [0]3s to [45]3s Configurations in five steps. A same parametric model ware utilized for this analysis with modification of the ply angel rotations for the layers. W = 20 mm E = 20.

Table 2: Results for the ply rotations form 0^0 to 45^0

Results for the ply rotations form 0^0 to 45^0 when width = 20 mm, and ply angel varied from 0^0 to 45^0in Five Steps					
Ply rotations in Degrees	0	15	22.5	30	45
Failure Load in Newton	3368	3446	3550	3653	3762

Results for Failure Load for increase in Diameter of Pin:

Results for the parametric analysis for the diameter varied from 5 mm to 9 mm, with increment of the 0.5 mm for every step, for w = 20 mm and E = 20 mm with ply orientation of [45] 3s We have chosen this configuration because the [45] 3s ply orientation configuration is having larger value of load carrying capacity than [0]3s ply orientation.

Table 3: Failure Load for increase in Diameter of Pin

Pin diameter	5	6	7	8	9	10
Failure load	3368N	3534 N	3432 N	2530 N	1820N	1530N

Results for Failure Load for increase in Clarence between Pin and Hole

For this Simulation the W = 30 mm and E/D = 5 with [45]3s ply orientation considered, for this Configuration of the object has highest loading capacity of 4078 N.

Table 4: Failure Load for increase in Clarence between Pin and Hole

Clearance (mm)	0.1	0.5	1	1.5	2
Failure load (N)	3850	2852	2392	2162	2070
Deflection (mm)	1.723	1.375	0.829	0.693	0.667

The above results can be tabulated as below,

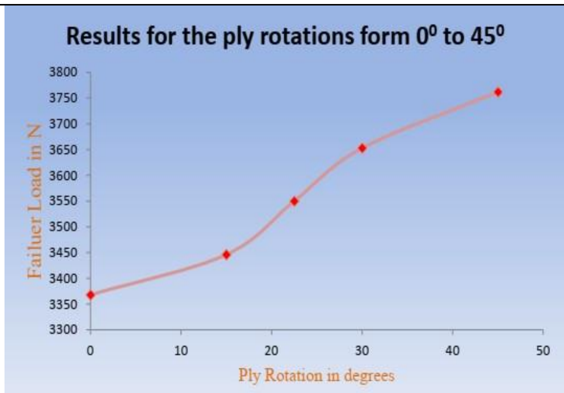

Figure 15: Results for the ply rotations form 0^0 to 45^0

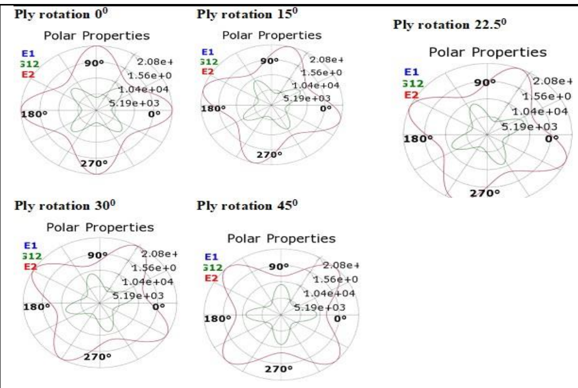

Figure 16: ply rotations form 0^0 to 45^0

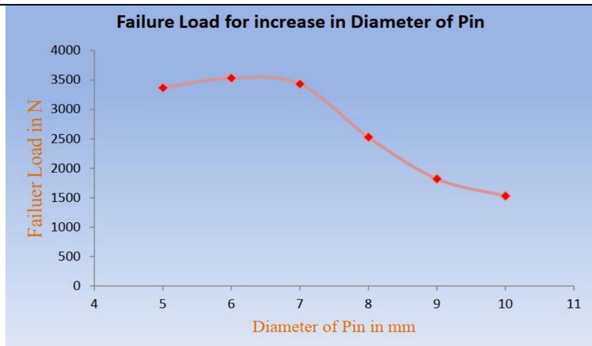

Figure 17: Failure Load for increase in Diameter of Pin

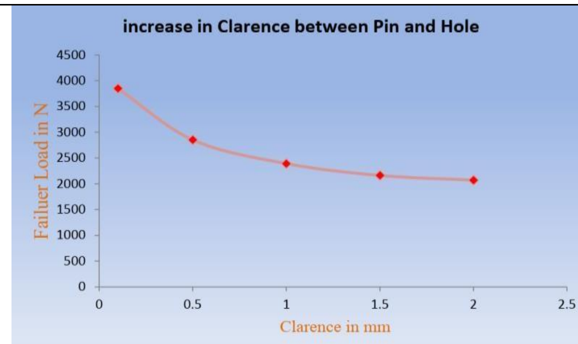

Figure 18: Failure Load for increase in Clarence between Pin and Hole

Results Comparison:

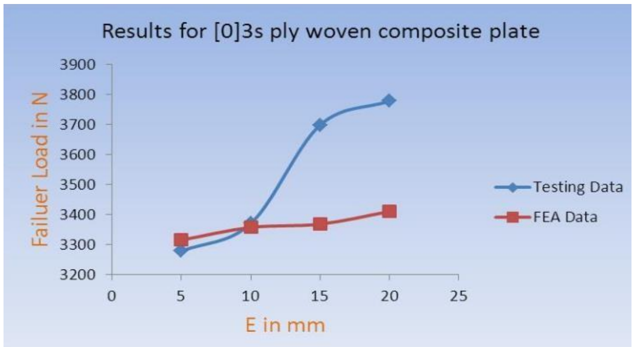

Figure 19: Width = 20 mm, and depth ware vary from 5 to 20 with increment of 5 mm

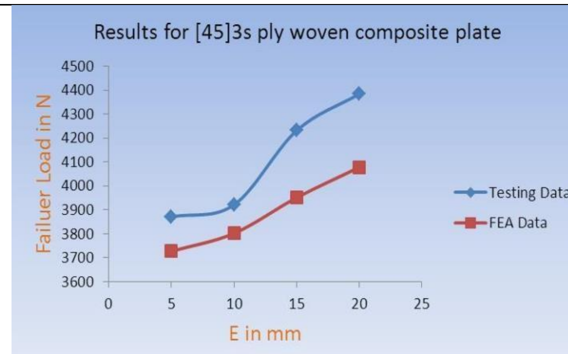

Figure 20: width = 20 mm, and depth ware vary from 5 to 20 with increment of 5 mm

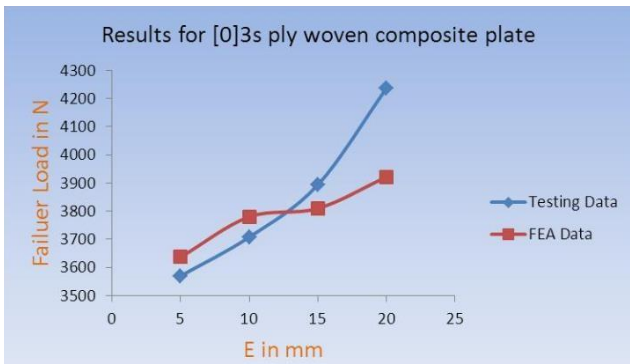

Figure 21: width = 20 mm, and depth ware vary from 5 to 20 with increment of 5 mm

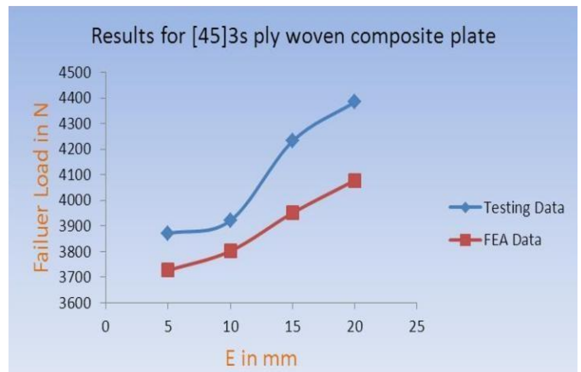

Figure 22: width = 20 mm, and depth ware vary from 5 to 20 with increment of 5 mm

Table 5: comparison of Experimental and FEA results

Specimen Name	**Failure Load In N (Experiment)**	**Failure Load In N For (FEA)**	**% Error**	**Specimen Name**	**Failure Load In N (Experiment)**	**Failure Load In N (FEA)**	**% Error**
A 20	3278	3315	-1.128	A 30	3570	3637	-1.876
B 20	3370	3357	0.385	B 30	3708	3780	-1.941
C 20	3698	3368	8.923	C 30	3894	3810	2.157
D 20	3778	3410	9.740	D 30	4237	3922	7.434
A’ 20	3632	3526	2.918	A’ 30	3871	3727	3.719
B ‘20	3782	3612	4.494	B ‘30	3921	3802	3.0349
C ‘20	3991	3762	5.737	C ‘30	4231	3951	6.617
D ‘20	4130	3892	5.762	D ‘30	4384	4078	6.979

IV. Conclusion and Future Scope

Conclusion

1) At low values of E/D, the failure types are net-tension or shear-out which is a weak type of failure.
2) The load carrying capacity in the cross [45]3S play composite plate ware more than the 3S oriented ply.
3) As the angel of the ply rotation ware increases from 00 to 450 the load carrying capacity of the joint significantly increases from low value to its maximum value.
4) The gradual increase in the diameter of the pin has shown the Different types of the failures starting from the bearing failure to shear out then after shear out to net tension. For small diameter values the net shear out failure has been seen further increase in diameter shown the considerable increase in the failure load with baring failure but further increase in the diameter shown the net tension failure pattern with the decrease in the failure load.
5) The optimum Diameter value for w = 20 mm and E = 20 mm with ply orientation of [45] 3s Configuration is 6 mm.
6) As Clearance between the pin and hole increases the load carrying capacity of the pin-plate assembly decreases.

Future Scope:

1) A mathematical model for Composite plate pin joints can be developed with different types, pin shapes such as rectangular, triangular etc., cross-sections for better understanding of pin joints.
2) Simulation can be done for pin loads, with different techniques can be used such as cosine load distribution, radial boundary condition and are full contact, a comparative study of this kind of simulation with effect of ply rotation.
3) A study of the composite pin joints with different types of stacking sequence for pin joints to obtain its load carrying capacity can be performed for studying its behavior on pin joints for future developments.

References:

[1] Chang FK, Scott RA, Springer GS. Strength of mechanically fastened composite joints. J Compos Mater 1982; 16:470–94.
[2] Aktas A, Karakuzu R. Failure analysis of two-dimensional carbon–epoxy composite plate pinned joint. Mech Compos Mater Struct 1999; 6:347–61.
[3] Icten BM, Sayman O. Failure analysis of pin-loaded aluminum–glass–epoxy sandwich composite plates. Compos Sci Technol 2003; 63:727–37.
[4] Icten BM, Okutan B, Karakuzu R. Failure strength of woven glass fiber–epoxy composites pinned joints. J Compos Mater 2003; 37:1337–51.
[5] Icten BM, Karakuzu R. Progressive failure analysis of pin loaded carbon–epoxy woven composite plates. Compos Sci Technol 2002; 62:1259–71.
[6] Okutan B, Aslan Z, Karakuzu R. A study of the effects of various geometric parameters on the failure strength of pin-loaded woven–glass–fiber reinforced epoxy laminate. Compos Sci Technol 2001; 61:1491–7.
[7] Chang FK. The effect of pin load distribution on the strength of pin loaded holes in laminated composites. J Compos Mater 1986; 20:401–8.
[8] Hung CL, Chang FK. Bearing failure of bolted composite joints. Part II: Model and verification. J Compos Mater 1996; 30: 1359–400.
[9] Pierron F, Cerisier F. A numerical and experimental study of woven composite pin- joints. J Compos Mater 2000; 34:1028–54.
[10] Kretsis G, Matthews FL. The strength of bolted joints in glass fibre/epoxy laminates. J Compos Mater 1985; 16:92–102.
[11] ASTM Standard D3039-01, Standard Test Method for Tensile properties of polymer matrix composite materials. American Society for Testing Materials, West Conshohocken, PA, 2001.
[12] BS EN ISO 527-4/BS 2782-3 Method 362F. Plastics-Determination of tensile properties-Part 4: Test conditions for isotropic and orthotropic fiber-reinforced plastic composites. United Kingdom: British Standard, 1997.
[13] Hashin Z. Failure criteria for unidirectional fibre composites, ASME Journal of Applied Mechanics, Vol. 47 (2), 1980, pp 329-334.
[14] ANSYS 14.5 User Manual.
[15] “Finite Element Analysis of Composite material” by Ever J. Barbero
[16] www.nptl.iitm.ac.in