BUCKLING ANALYSIS OF DIFFERENT COMPOSITE LAMINATES WITH VARIOUS CUTOUTS

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Abstract

There are many applications of composite materials in fields like marine, mechanical, aerospace, and automotive industries in which they are used because, they are lighter and have high strength. Furthermore, cut-outs are provided in these laminated structures because of various reasons such as to serve as doors and windows, ports for mechanical and electrical systems, holes for damage inspection, etc. This project investigates the buckling analysis on various composite laminated plates with different cut-outs i.e., Elliptical-horizontal, Elliptical-vertical, Square, Rectangle, Circle, Diamond and Triangle using FE simulation. The effect of buckling load on symmetric cross-ply [$(0/90)_2$] is to be determined on these square composite laminates. Along with buckling analysis the total deformation of the body and equivalent stress and strain are also observed for the applied boundary conditions. The results of this analysis are compared between these composite laminates. These cut-outs are placed at the centre of the laminate. The cut-out shape and size are same for all materials is considered. The buckling analysis is performed using FE simulation software ANSYS, considering same area of composite plate for all cut-outs.

INTRODUCTION

Plates with circular holes and other openings are extensively used as structural members in aircraft design. These holes are referred to as cut-outs in the laminated plates. These holes can be access holes, holes for hardware to pass through, or in the case of fuselage, windows and doors. In some cases holes are used to reduce the weight of the structure. In aerospace and many other applications these structural components are also made up of composite material to further reduce the weight of the structure.

Cut-out are used for various reasons such as to serve as doors and windows, ports for mechanical and electrical systems, holes for damage inspection, etc. the cut-out shape can be circular, square, triangle, rectangle, diamond, elliptical (horizontal and vertical), etc as per our requirement.

LITERATURE REVIEW

Rekha Sakhya[1] in the paper "Effect of Various Cut-Out On Buckling Analysis Of Laminated Composite Plate Using FE Simulation" investigated about the buckling response of square composite laminated plate with various cut-out (i.e., Elliptical-horizontal, Elliptical-vertical, Square, Rectangle, Circle, Diamond, Triangle) made of woven-glass-polyester composite material using FE simulation and her investigation has shown that Buckling load increases as the circular cut-out moves from centre to edges, means laminate plate is weaker in centre of plate and as the circular cut-out moved away from centre it strength increases. Priya Dongare [2] in the paper "Effect of Fiber Angle Orientation on Stress, Deformation and Buckling Torque of the Composite Drive Shaft" analyzed about the composite drive shaft for power transmission applications.It was observed that by changing the fiber angle orientation in any one layer while keeping the others constant, the shear angle in that layer showed a sine nature of graph while in other layers it is in cosine nature. However the deflection in each layer is same for any angle of fiber orientation. 2nd, 3rd, 4th and 5th natural frequencies increases with angle of orientation and then remains constant. While 6th natural frequencies decreases with angle of orientation and then remains constant. From buckling analysis it has been concluded that the fiber orientation angle has effect on the buckling torque. Prabhakaran.V [3] in the paper "Finite Element Analysis of Composite Structures under Different Types of Loads" studied. It was noted that the buckling load/unit length decreases with increases of length to thickness ratio of plate and cylinder. And also that the buckling load/unit length gradually decreases with increases of diameter to width ratio of plate with hole. The results from this study indicate that numerical modeling can be used to evaluate the buckling strength accurately, provided the material properties and geometrical details properly modeled. Prabhuling Sarasambi [4] in the paper "Buckling Analysis of Composite Structures" an effort has been made to identify better configuration of given composite to achieve higher buckling strength for laminated composite structures subjected to uniaxial compressive loads. It has been concluded that simply supported, clamped and hinged, anti-symmetric and symmetric cross ply and angle ply of the critical buckling loads for laminate increases with increases in the number of lamina. Boundary conditions have significant effect on the different critical buckling loads of the composite structures.

In this study, a buckling analysis was carried out for square laminated composite plate with various cut-out (i.e., Elliptical-horizontal, Elliptical-vertical, Square, Rectangle, Circle, Diamond, Triangle) located at centre using FE simulation.

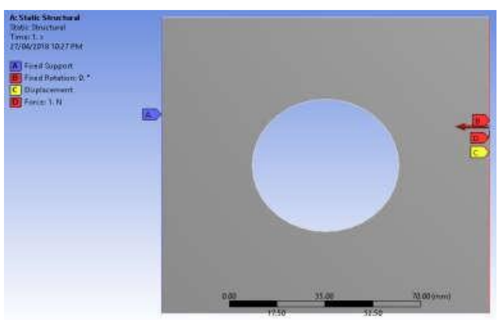
FE modeling :

In the present study, Ansys 17.0 which is known general purpose finite element software was preferred as numerical tool. In this triangular element were used. This triangular element is used for analyzing surface structures. It is also used for layered applications for modeling laminated composite shells or sandwich construction. It is well-suited for large rotation, linear, and/or large strain nonlinear applications. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z axes.

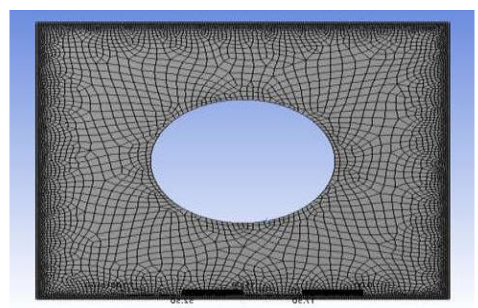
Geometry and Composite Materials:

Three different types of composite materials have been selected for this research basing on material properties, cost criteria, application. The materials we are using for this research are: Epoxy Carbon Woven (395GPa) Prepreg, Epoxy Carbon UD (395GPa) Prepreg, Epoxy S-Glass UD. The mechanical properties of the composite material are listed in Table below. In real composite applications, different plate and cutout form may be used owing to design necessities. Dimension of square composite plate considered is 120 mm x 120 mm. The thickness of square composite plate is 1.6 mm. The boundary condition apply to laminated plate is shown in Fig below

Cutout shapes	Cutout dimensions (in mm)
Elliptical horizontal	Major axis=0.012, Minor axis=0.06
Elliptical vertical	Major axis =0.06, Minor axis =0.012
Rectangular	length=0.06726, width=0.03363
Square	Each side=0.04756
Circular	Radius=0.0268
Diamond	Same as square just rotate 450
Triangular	base=0.07227, height=0.06259



Boundary conditions



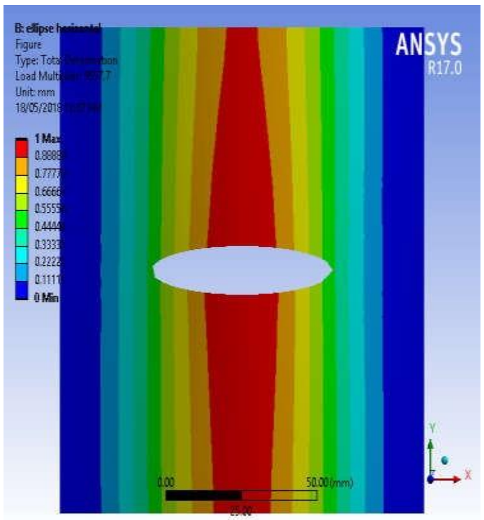
Completely meshed body

RESULTS AND DISCUSSIONS

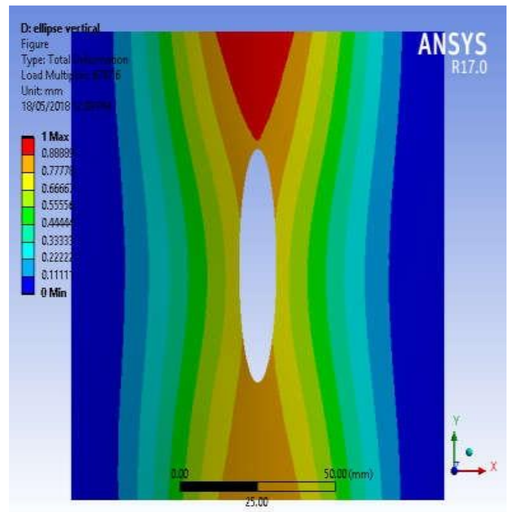
We have studied about the cutout shapes, materials, modeling and geometrical properties, meshing, loads and supports applied till now. Now we study about the buckling load multiplier, total deformation, Equivalent (Von-Mises) Stress and Strain obtained as a result of application of loads and supports. We discuss about all the above mentioned results individually for every material and each cutout.

Buckling load multiplier defines when the material will buckle. Multiply all of the applied loads on the model by the buckling load multiplier to obtain theoretical load that causes buckling. Total deformation is the deformation accounting to whole of the body that is the magnitude of individual directional deformations of X,Y,Z axes. Equivalent Stress is the stress at which the material starts to yield and equivalent strain is the measurement of permanent strain in a material.

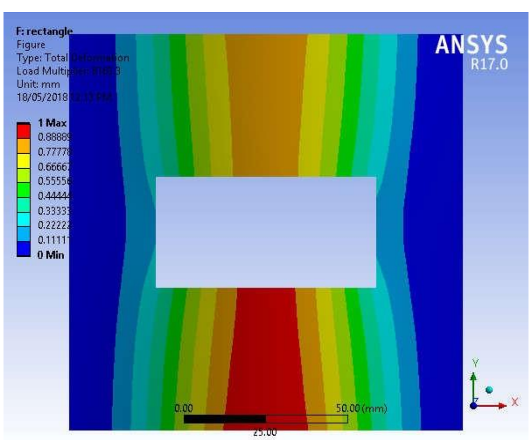
Buckling Load Multiplier:



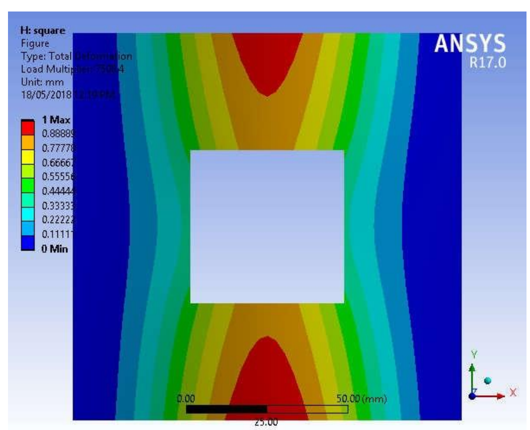
a) Ellipse Horizontal



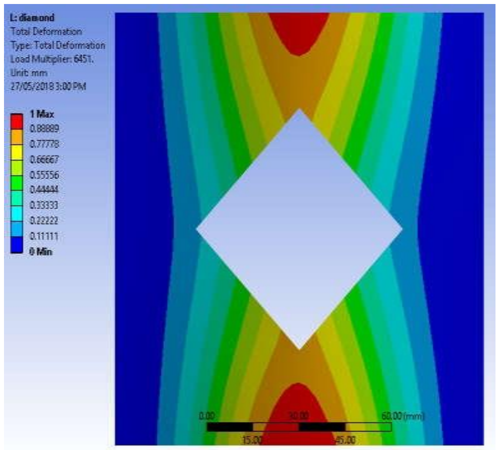
b) Ellipse Vertical



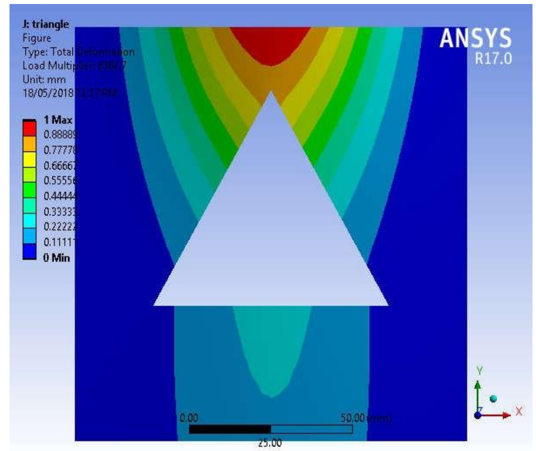
c) Rectangle



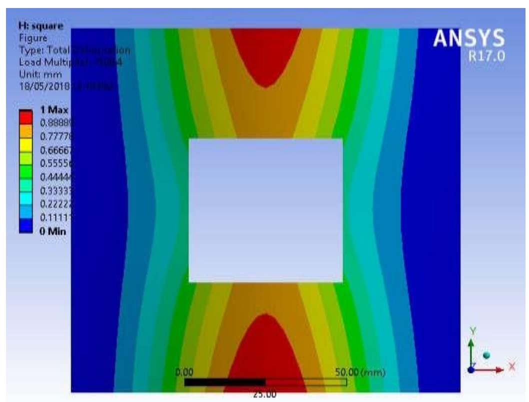
d) Square



e) Diamond



f) Triangle



g) Circle

Cutout	Epoxy Carbon Woven (395GPa) Prepreg	Epoxy Carbon UD (395 GPa) Prepreg	Epoxy S Glass UD
Ellipse Horizontal	9557.7	9741.8	2841.4
Ellipse Vertical	6747.6	6508	2034.8
Rectangle	8163.3	8263.9	2438
Square	7508.4	7667.3	2246.2
Diamond	6451	5909.7	1913.7
Triangle	6362.7	3947.6	1873.3
Circle	7318.6	7333.3	2172.2

Table 6.4: Comparison of Buckling Load Multiplier of all materials

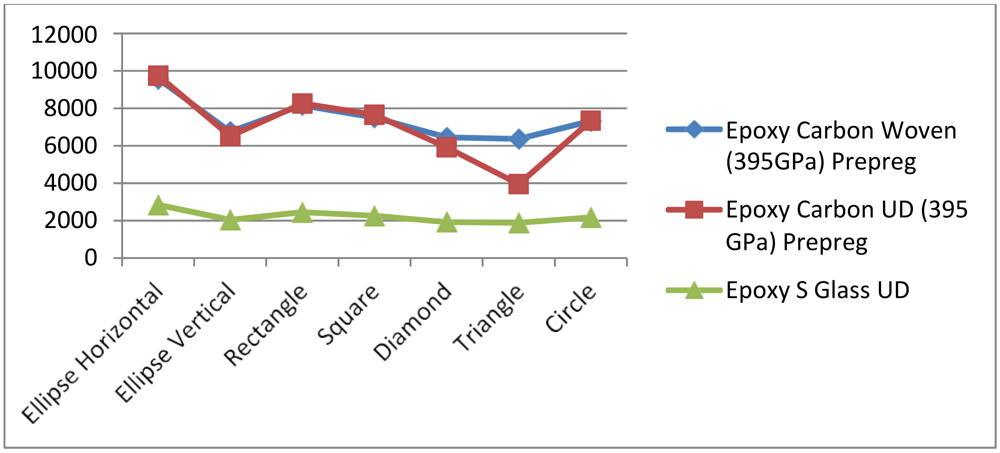


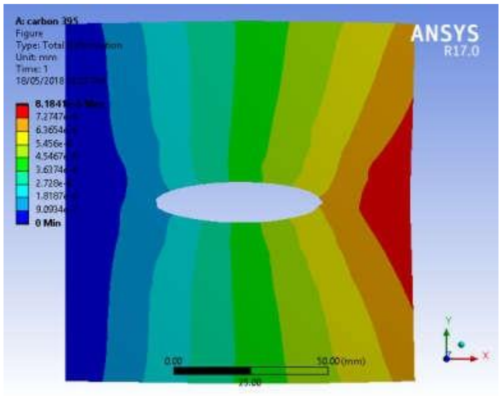
Fig 6.7: Comparison of graphs of Buckling Load Multiplier of all materials.

When we compare the buckling load multiplier for the materials ellipse horizontal cutout of Epoxy Carbon UD (395GPa) Prepreg is having the maximum value of 9741.8 and triangular cutout of Epoxy S-Glass UD is having the least value of 1873.3. Overall for all the materials ellipse horizontal is having maximum value and triangular cutout is having the least value.

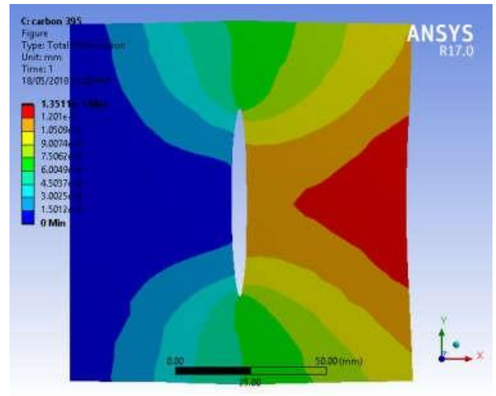
Total Deformation:

For the total deformation the minimum value is always zero because the initial deformation of the body is in static state i.e., rest hence zero and maximum value depends on the applied boundary conditions.

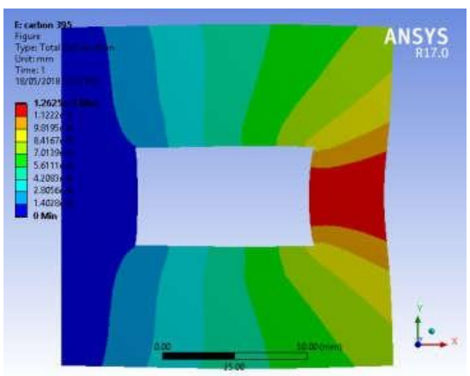
6.2.1. Epoxy Carbon Woven (395GPa) Prepreg



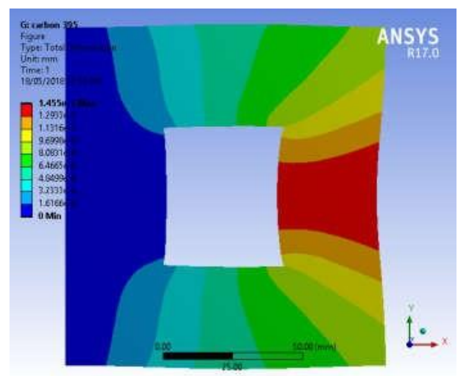
a) Ellipse Horizontal



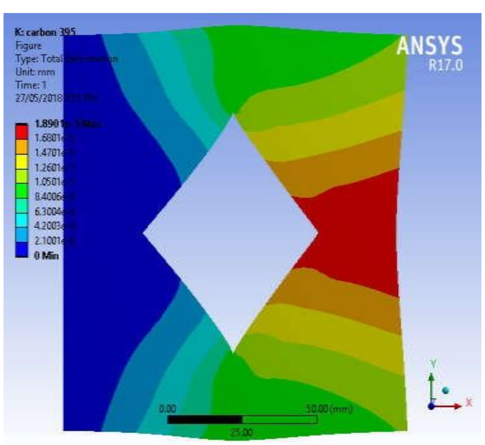
b) Ellipse Vertical



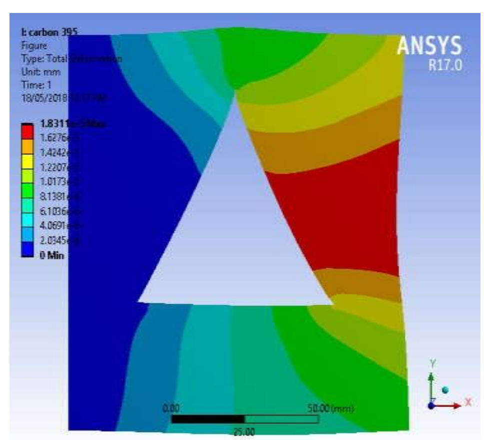
c) Rectangle



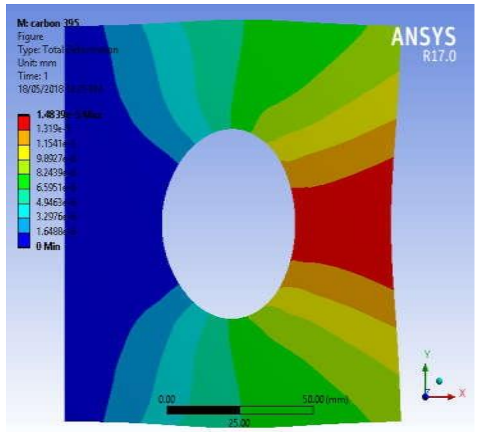
d) Square



e) Diamond



f) Triangle


M: carbon 395
Figure
Unit: mm
Time: 1
0 Min
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R17.0
0.00
50.00 (mm)
25.00
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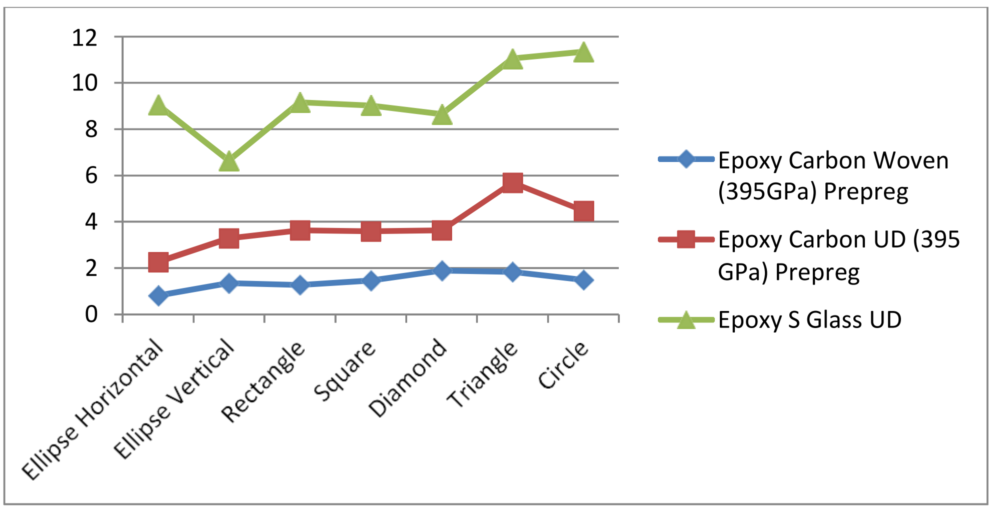
X

g) Circle

Cutout Shape	Total Deformation (e-005)		
	Epoxy Carbon Woven (395GPa) Prepreg	Epoxy Carbon UD (395 GPa) Prepreg	Epoxy S Glass UD
Ellipse Horizontal	0.81841	2.2617	9.048
Ellipse Vertical	1.3511	3.2806	6.6515
Rectangle	1.2625	3.6345	9.1627
Square	1.455	3.5844	9.0178
Diamond	1.8901	3.6339	8.6543
Triangle	1.8311	5.6877	11.049
Circle	1.4839	4.4819	11.353

Comparison of Total Deformation of all materials.

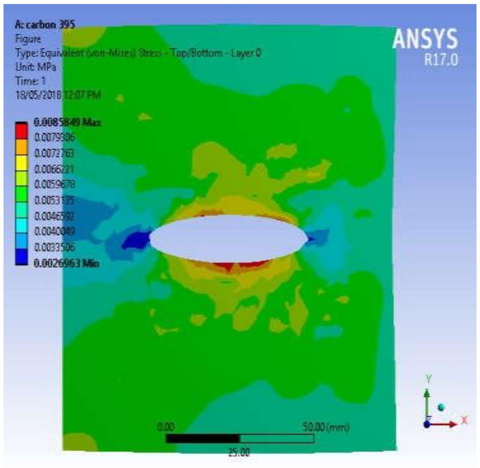


Graph of Comparison of Total Deformation of Epoxy S-Glass UD

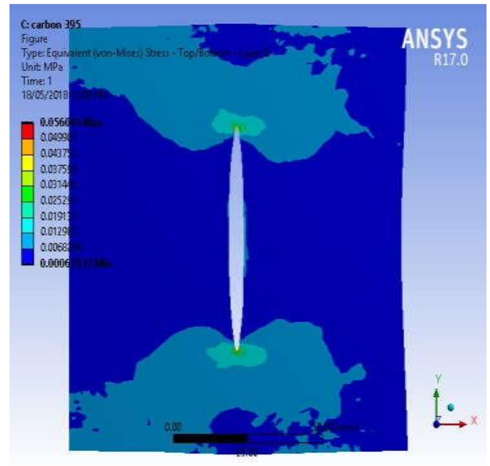
The overall total deformation is greater for the Epoxy S-Glass UD material and minimum for Epoxy Carbon Woven (395GPa) Prepreg material. The circular cutout of Epoxy S-Glass UD has the highest deformation and the horizontal elliptical cutout is having the least deformation for Epoxy Carbon Woven (395GPa) Prepreg material.

Equivalent Stress

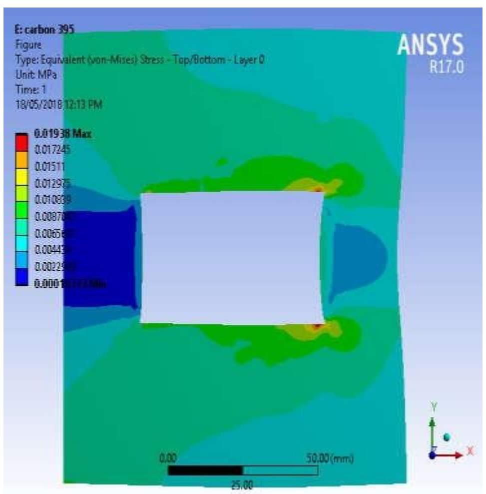
Epoxy Carbon Woven (395 GPa) Prepreg



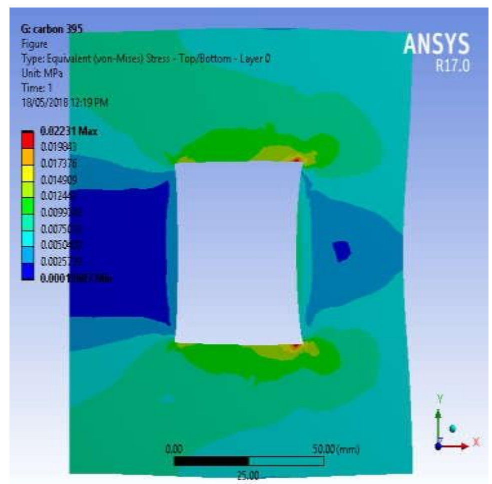
a) Ellipse Horizontal



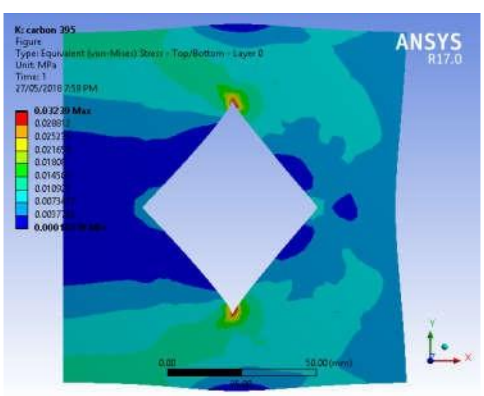
b) Ellipse Vertical



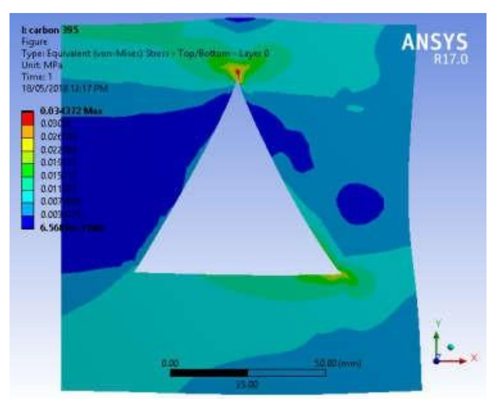
c) Rectangle



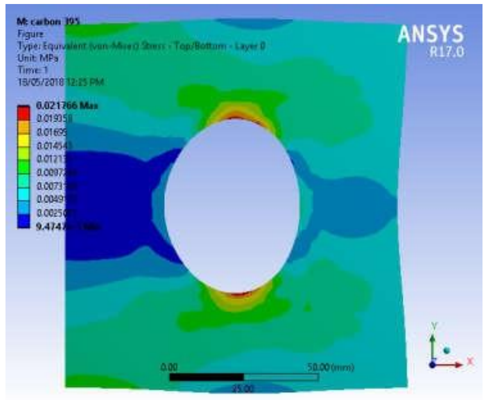
d) Square



e) Diamond



f) Triangle

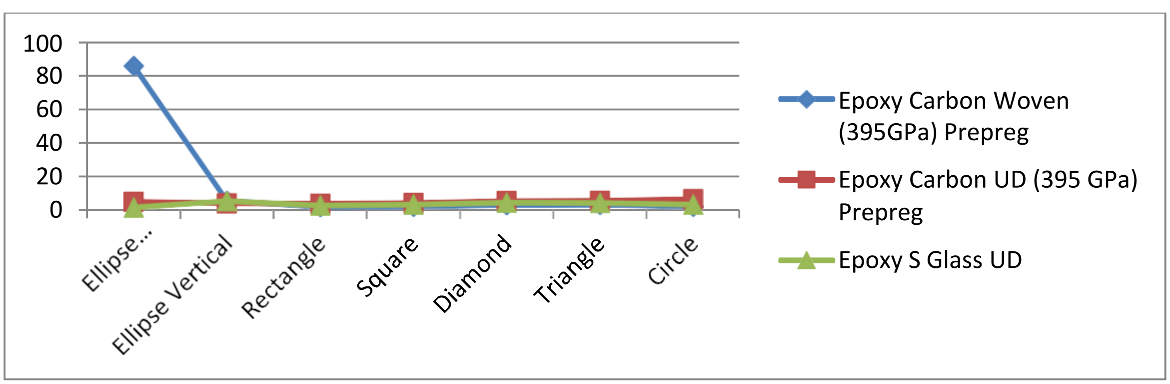


g) Circle

Equivalent Stress of Epoxy Carbon Woven (395 GPa) Prepreg

Cutout Shape	Equivalent Stress Maximum (e-002)		
	Epoxy Carbon Woven (395GPa) Prepreg	Epoxy Carbon UD (395 GPa) Prepreg	Epoxy S Glass UD
Ellipse Horizontal	85.849	5.0543	1.5637
Ellipse Vertical	5.6061	4.1582	5.5397
Rectangle	1.938	3.9262	2.8542
Square	2.231	4.3065	3.2669
Diamond	3.239	5.4573	4.5932
Triangle	3.4372	5.586	4.3452
Circle	2.1766	6.6703	3.3944

Comparison of equivalent stress for all materials

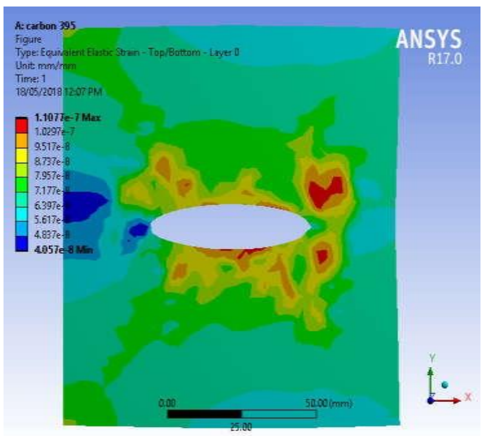


Graph of Comparison of equivalent stress for all materials

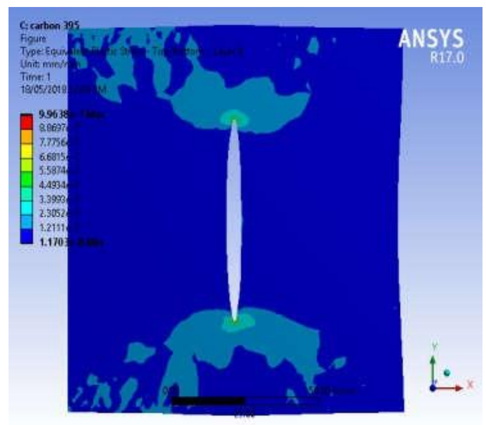
The horizontal elliptical cutout of Epoxy S-Glass UD has the least maximum equivalent stress and the horizontal elliptical cutout is having the highest maximum equivalent stress for Epoxy Carbon Woven (395GPa) Prepreg material.

Equivalent Strain

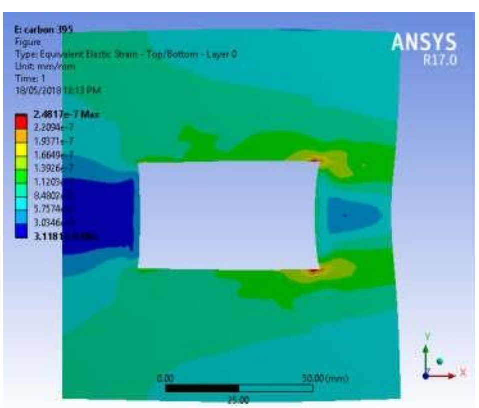
Epoxy Carbon Woven (395 GPa) Prepreg



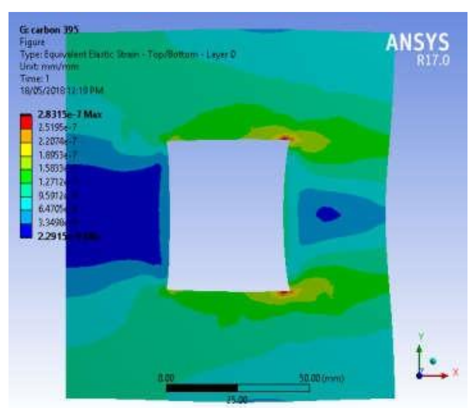
a) Ellipse Horizontal



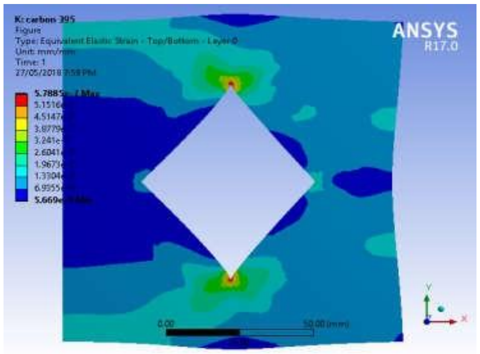
b) Ellipse Vertical



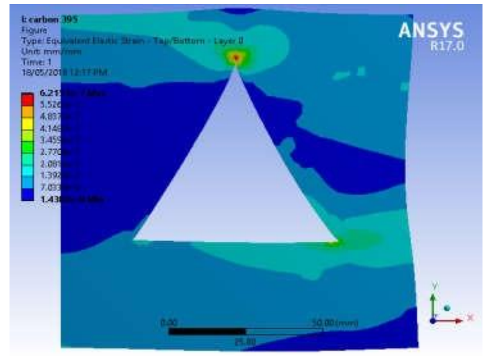
c) Rectangle



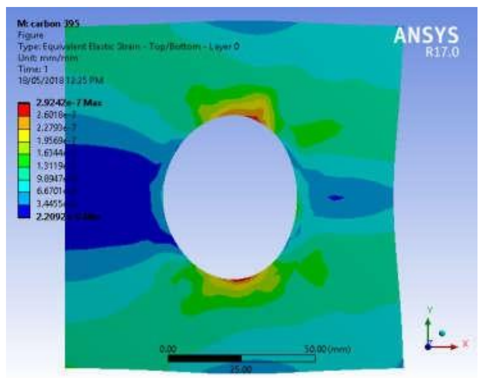
d) Square



e) Diamond



f) Triangle

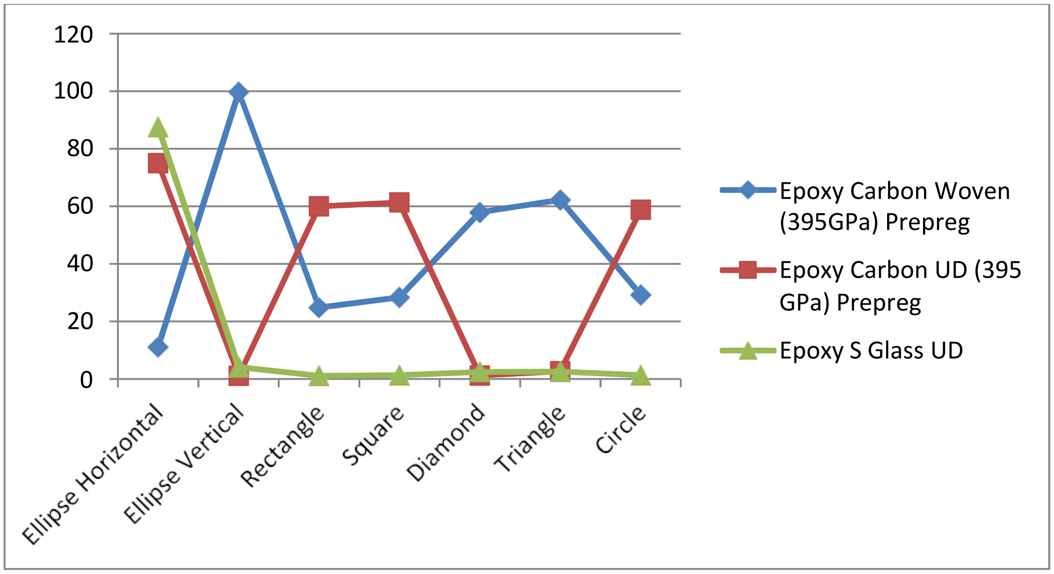


g) Circle

Equivalent Strain of Epoxy Carbon Woven (395 GPa) Prepreg.

Cutout Shape	Equivalent Strain Maximum (e-006)		
	Epoxy Carbon Woven (395GPa) Prepreg	Epoxy Carbon UD (395 GPa) Prepreg	Epoxy S Glass UD
Ellipse Horizontal	11.077	74.915	87.503
Ellipse Vertical	99.638	1.1295	4.1495
Rectangle	24.817	59.991	1.0911
Square	28.315	61.297	1.3355
Diamond	57.885	1.2038	2.5009
Triangle	62.153	2.7218	2.5161
Circle	29.242	58.802	1.2941

Comparison of Equivalent Strain of all materials



Graph of comparison of Equivalent Strain of all materials

The maximum Equivalent Elastic Strain is least for the rectangular cutout of Epoxy S-Glass UD material and highest for the elliptical horizontal cutout of Epoxy Carbon Woven (395GPa) Prepreg material.

CONCLUSION

In this paper we have studied about the buckling load multiplier, total deformation, equivalent stress and equivalent elastic strain for the applied boundary conditions and loads using the materials epoxy carbon woven 395 GPa Prepreg, epoxy carbon UD 395 GPa Prepreg, epoxy S-Glass UD and the following results have been observed:

- Ellipse horizontal cutout of Epoxy Carbon UD (395GPa) Prepreg is having the maximum value of 9741.8 and triangular cutout of Epoxy S-Glass UD is having the least value of 1873.3. Overall for all the materials elliptical horizontal cutout is having maximum value and triangular cutout is having the least value.
- The overall total deformation is greater for the Epoxy S-Glass UD material and minimum for Epoxy Carbon Woven (395GPa) Prepreg material. The circular cutout of Epoxy S-Glass UD has the highest deformation and the horizontal elliptical cutout is having the least deformation for Epoxy Carbon

Woven (395GPa) Prepreg material.

- The horizontal elliptical cutout of Epoxy S-Glass UD has the least maximum equivalent stress and the horizontal elliptical cutout is having the highest maximum equivalent stress for Epoxy Carbon Woven (395GPa) Prepreg material.
- The maximum Equivalent Elastic Strain is least for the rectangular cutout of Epoxy S-Glass UD material and highest for the elliptical horizontal cutout of Epoxy Carbon Woven (395GPa) Prepreg material.
- If we compare the results Epoxy Carbon Woven (395GPa) Prepreg material is having the best material and results but also have a high cost. Epoxy S-Glass UD material is having the low cost among the three materials but the properties are also less when compared to others.

So we can choose any of the materials depending on our application and cost basis.

FUTURE SCOPE

The research can be taken further by changing the materials used, changing the material properties in the engineering data in ANSYS Workbench as required, changing the applied boundary conditions and loads, changing the composite laminate design, cutout design, laminate orientation, as per the purpose etc.

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[2] Miss. Priya Dongare & Dr. Suhas Deshmukh in the paper "Effect of Fiber Angle Orientation on Stress, Deformation and Buckling Torque of the Composite Drive Shaft"-Global Journal of Researches in Engineering Mechanical and Mechanics Engineering Volume 13 Issue 6 Version 1.0 Year 2013.

[3] Prabhakaran.V, Arul Marcel Moshi.A, Selwin Rajadurai J in the paper "Finite Element Analysis of Composite Structures under Different Types of Loads" International Journal of Engineering Science and Computing, August 2016.

[4] Prabhuling Sarasambi, Sangameshwar Patil, Shravankumar B. Kerur in the paper "Buckling Analysis of Composite Structures" Proceedings of 12th IRF International Conference, 29th June-2014, Pune, India, ISBN: 978-93-84209-31-5