Comparative Study of Steel, Aluminum and FRP plates on Ansys work bench

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ABSTRACT

Automobile components manufacturing industries vastly use steel and aluminum material to produce most of the components, the challenges they face is the optimization of weight with respect to the static loading. So there is need to identify optional material. Objective of this paper is the comparative study of steel, aluminum; graphite-Epoxy and glass-Epoxy plates under static loading, also the effect of fiber orientation of laminates under static loading have been investigated for glass-epoxy & graphite epoxy plates. The composite plate 3D model of three layers is studied for double holes under static loading. For modeling the CREO 4.0 workbench has been used and analysis carried out on the ANSYS workbench.

Keywords : *Static loading, strength, Steel, aluminum, graphite-epoxy (GR/E), glass-epoxy (GL/E)*

1. Introduction

FRP composites are gaining wide acceptance as structural material because of their intrinsic advantages over conventional materials. However the main drawback of such material is that, they are susceptible to delamination damage, which may significantly reduce the stiffness and strength of material, depending upon the size and location of delamination.

The delamination may occur due to low velocity impact, generally some weak fibers break and create an internal flaw and may grow under static cyclic loads and thus further weakening the material. Delamination may start from the location of such flaws as they are the weakest points in the laminate and high stress concentration occurs near vicinity of such flaws. The aim of present work is to calculate stress and strain of a FRP composite laminates having embedded holes, which replicate the delamination at the interface under static load by using Ansys software.

A 3D FE analysis has been performed on plate model with two holes to compare the values such as deflection, maximum stress, minimum stress, strain and stress at holes for glass-epoxy and graphite-epoxy and compare the results with steel and aluminum.

2. Finite Element Analysis of FRP Composite (Gl/E & Gr/E)

Finite Element Method has been used for the analysis. 3D FE analysis has been done using general purpose FE software *ANSYS*. For modeling the specimen, eight nodded layered element of *ANSYS* solid 46 is used. Orthotropic material properties have been input for bottom and top sub laminate and isotropic properties are assigned for the thin resin rich layer. In the present analysis, glass-epoxy laminate specimen has been considered. The glass fiber used is E-glass type and the required properties are shown the Table 1

A composite laminate specimen having two embedded delamination is generated using three layers of solid191 elements. Each sub laminate contains a number of plies and its orientation can be altered.

Table 1. Composite material properties [1]

Material properties	Graphite-Epoxy (GL/E)	Glass Epoxy (GR/E)	Resin
E_x (GPa) E_y (GPa) E_z (GPa)	181 10.30 10.30	38.6 8.27 8.27	$E_r = 3.89$ GPa
V_{xy} V_{yz} V_{xz}	0.30 0.28 0.28	0.25 0.25 0.27	$V_r = 0.37$
G_x (GPa) G_y (GPa) G_z (GPa)	7.17 4 7.17	4.14 4 4.14	$G_r = 1.42$ GPa

The specimen is subjected to axial loading in static condition. Proposed plate having stacking sequence [$\ddot{Y}_{1m}$ / $\ddot{Y}_{2n}$] as shown in Fig 1 has been considered, the plate is having two holes at the centre of the laminate $\ddot{Y}_{1m}$ and $\ddot{Y}_{2n}$ layers. The bottom sub laminate contains m number of plies where as the top sub laminate contains n number of plies. The plate dimensions (Table 2) to be modeled in *CREO 4.0* for the analysis are as shown in Fig.1.

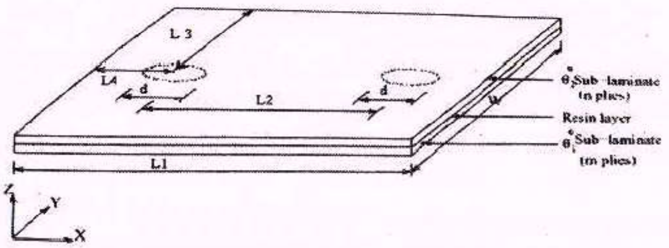


Fig.1. Laminate specimen with two holes

2.1 FE Model & Analysis

Fig. 2 shows the 3D full finite element model of the composite laminate having two embedded holes. Eight nodded layered solid element Solid 191 of *ANSYS* have been used to model the top and the bottom laminate and the resin is modeled by Solid 95 (Fig. 3).

2.2 Axial Loading for Glass-Epoxy (GL/E) Plate

The uniaxial tensile loading of 2000N is applied and the plate is fixed at one end and other end is subjected to uniform displacement. The obtained results have been discussed in the following sections. In all cases of plies in each sub laminate is taken as m=n=10.

Table 2. Proposed plate dimension

L_1= Length of the laminate	500 mm
L_2= Centre distance of two holes	300 mm
L_3= Distance of hole centre along width	100 mm
W= Width of the laminate	200 mm
d= Diameter of the hole	20 mm
Thickness of the plate	5 mm
Sub laminate thickness, times ply thickness	0.254
Resin layer thickness ,times the ply thickness	0.0254
Number of plies (m=n)	10

2.3 Axial Loading for Graphite-Epoxy plate

From the Table 3, it is clear that the glass-epoxy has less stresses compared to graphite-epoxy, but the value of mass is near about same for both the composites

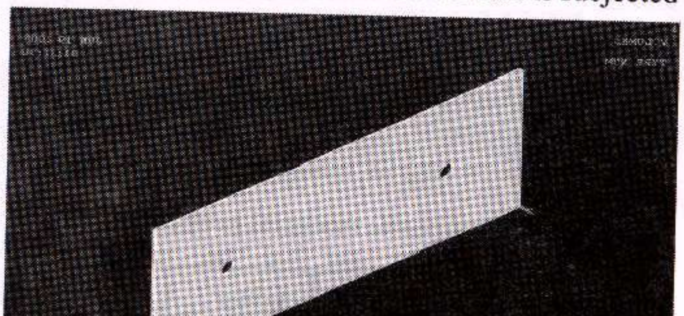


Fig. 2. Element model for GL/E plate

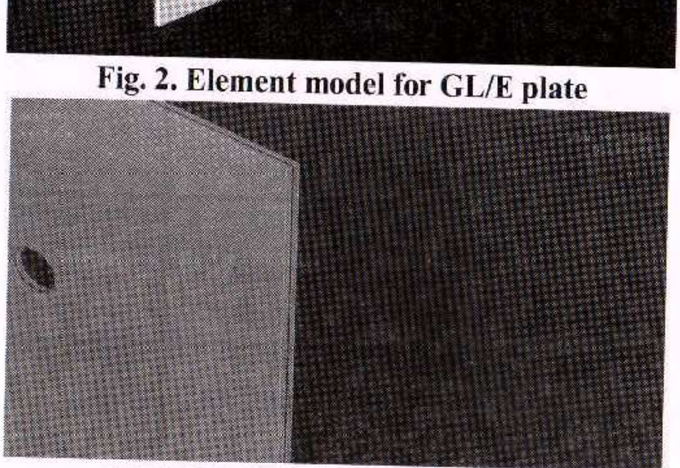


Fig 3. Layer model for GL/E plate

Fig 4. Deformation for GL/E plate

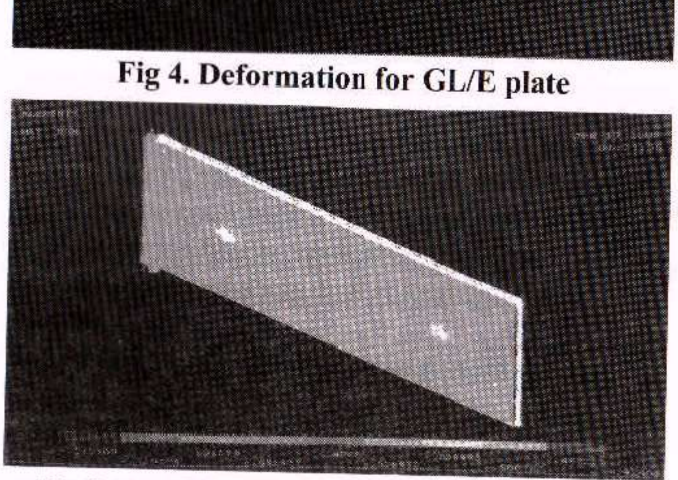


Fig 5. Load bearing condition for GL/E plate

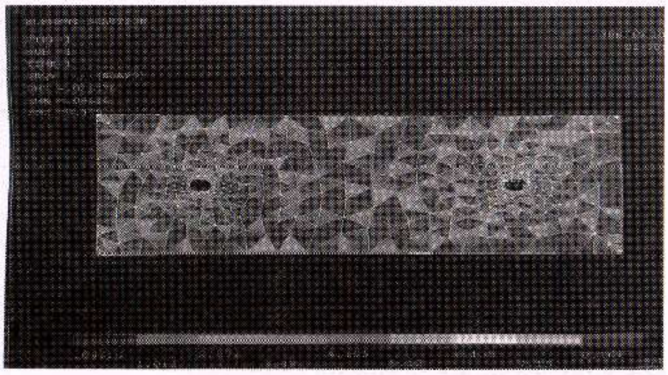


Fig 6. Stress distribution for GL/E plate

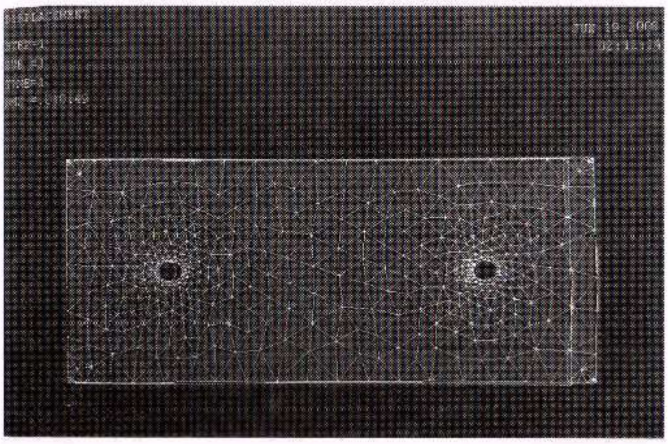


Fig 7. Deformation for GR/E plate

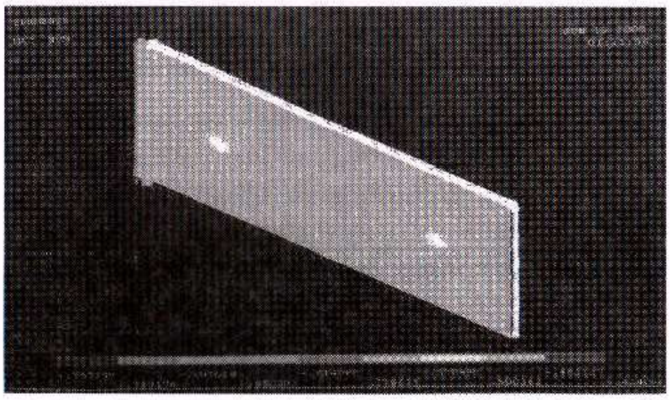


Fig 8. Load bearing condition for GR/E plate

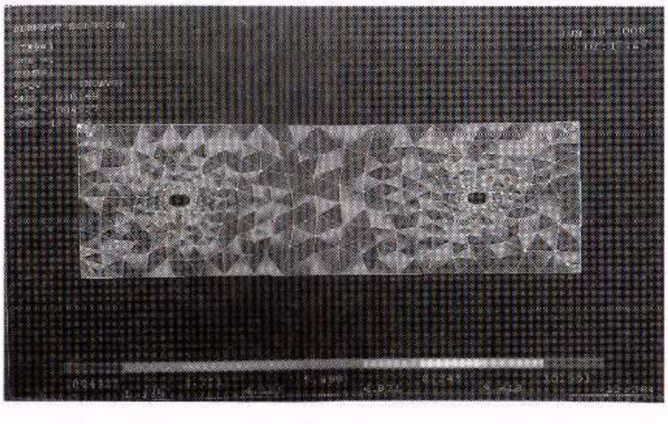


Fig 9. Stress distribution for GR/E plate

Table 3. Comparison *ANSYS* results (GL/E vs GR/E)

Properties to be compared	*Glass-Epoxy (GL/E)*	*Graphite-Epoxy (GR/E)*
DMX (mm)	0.026	0.010
SMN (N/mm²)	0.046	0.004
SMX (N/mm²)	9.179	12.364
Dl (mm)	0.026	0.010

and there is not very large difference in the values of stress induced in both the composites, further if the cost is considered then glass-epoxy comes as a clear winner, according to the Fig 10.

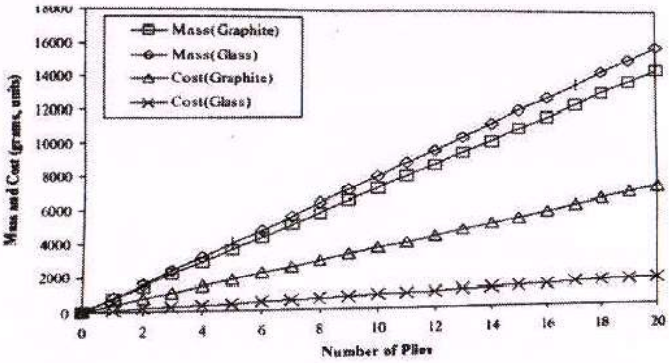


Fig 10. Cost comparison (GL/E vs. GR/E)

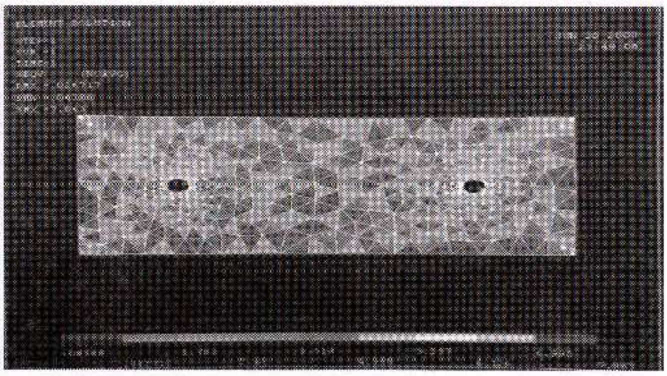


Fig 11. Deformation & stresses for GL/E at [0/30]

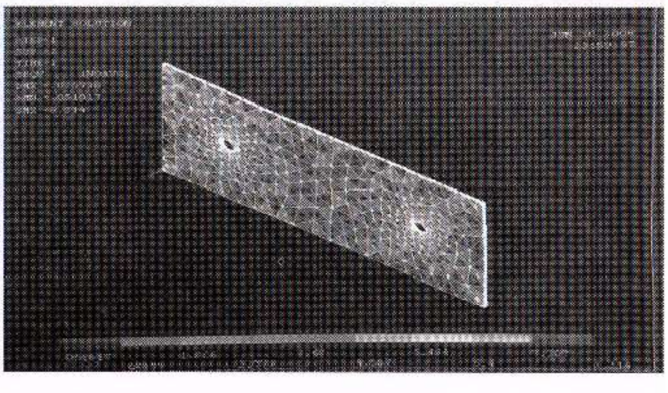


Fig 12. Deformation & stresses for GL/E at [0/60]

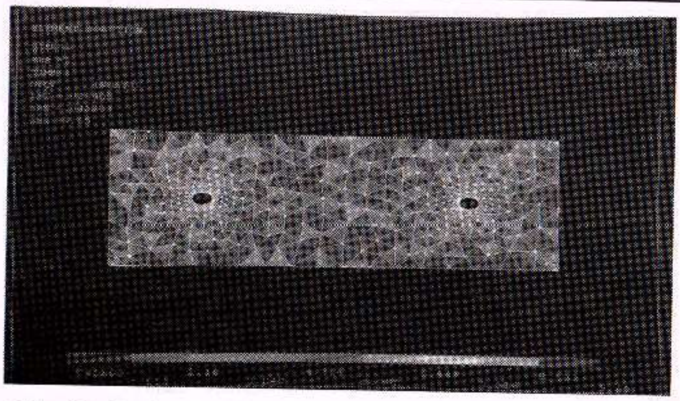


Fig 13. Deformation & stresses for GL/E at [0/90]

Table 4. Comparison of Stacking Sequence for GL/E

Stacking Sequence for Glass-Epoxy	Deformation dl (mm)	Maximum Stress (N/mm^2)	Maximum Stress (N/mm^2)
[0/30]	0.026	7.863	0.043
[0/45]	0.261	9.179	0.046
[0/60]	0.025	8.214	0.051
[0/90]	0.026	9.65	0.045

Table 5: Mass comparison of different materials

Material property	Glass–epoxy composite	Graphite-epoxy composite	Steel	Aluminum
Young's Modulus	—	—	200×10^3 N/mm^2	200×10^3 N/mm^2
Theoretical Deformation (dl/A E)	—	—	5×10^{-3} mm	14×10^{-3} mm
Density	1.785×10^{-6} kg/mm^3	1.62×10^{-6} kg/mm^3	7.85×10^{-6} kg/mm^3	2.698×10^{-6} kg/mm^3
Mass of the plate	0.8919 kg	0.8094 kg	3.9225 kg	1.3481 kg

3. Finite Element Analysis Of Steeel and Aluminium

Volume of the plate =Volume of the total plate – Volume of the holes in it

$$= (L_1 \times W \times T) - ((D/4)d^2)$$
$$= (500 \times 200 \times 5) - ((3.14/4)\ 20^2)$$
$$= 499686\ mm^3$$

3.1 FE Analysis of Steel & Aluminum

Loading condition 2000 N tensile, Solid 95 element for meshing

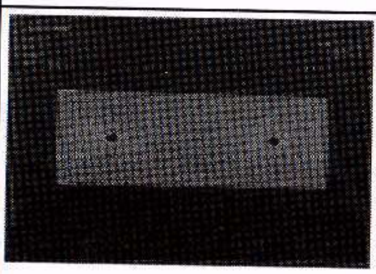
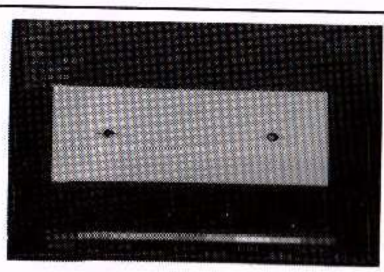
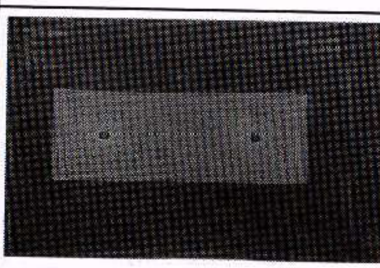
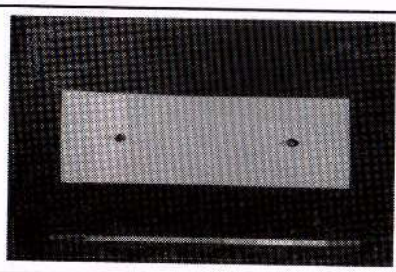
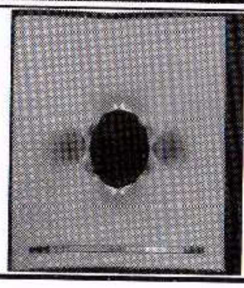
Material	*Deformation dl (mm)*	*Stress distribution across plate*	*Stress distribution across the hole*
Steel			
Aluminum			

Fig 14. FE Analysis of Steel and Aluminum

Table 6. Result comparison between Glass-Epoxy plate, Graphite-Epoxy plate, Steel plate and Aluminum plate having same dimensions

Properties to be compared	Glass-Epoxy	Graphite-Epoxy	Steel	Aluminum
Theoretical dl (mm)	—	—	5×10^{-3} mm	14×10^{-3} mm
DMX (mm)	26.176×10^{-3} mm	10.149×10^{-3} mm	9.975×10^{-3} mm	4.993×10^{-3} mm
SMN (N/mm^2)	46.16×10^{-3}	4.927×10^{-3}	401.342×10^{-3}	368.35×10^{-3}
SMX (N/mm^2)	9.179	12.364	6.913	6.887
Dl (mm)	26.176×10^{-3} mm	10.149×10^{-3} mm	4.993×10^{-3} mm	9.975×10^{-3} mm
Density	1.785×10^{-6} kg/mm^3	1.62×10^{-6} kg/mm^3	7.85×10^{-6} kg/mm^3	2.698×10^{-6} kg/mm^3
Mass of the plate	0.891 kg	0.809 kg	3.922 kg	1.348 kg

Table 7. Deformation, Max. Stress and Min. Stress with respect to the Stacking sequence of Glass-Epoxy

Stacking Sequence for Glass-Epoxy	Deformation dl (mm)	Maximum Stress (N/mm^2)	Minimum Stress (N/mm^2)
[0/30]	0.026	7.863	0.043
[0/45]	0.261	9.179	0.046
[0/60]	0.025	8.214	0.051
[0/90]	0.026	9.65	0.045

4. Conclusions

The material investigated in this paper has very less deformation for the 2000 N tensile loading, as composed to steel & aluminum has very less deformation as compared to the glass-epoxy and graphite-epoxy but the stresses induced were on higher side.

In the view of weight optimization, glass-epoxy and graphite-epoxy is best suited as the deformation is not that high. So, for the weight optimization with respect to the same tensile loading, FRP composites are the best optional materials. Among the two FRP composite, glass-epoxy has less cost (Fig. 10), so the natural choice for the weight optimization with respect to the same tensile loading will be the glass-epoxy composite material.

There are different options for going for the stacking sequence of the fiber for the composite but according to the Ansys results (Table 7) it's clear that [0/30] stacking sequence is best among all as it has the least deformation and stresses for the same tensile loading.

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