DESIGN, ANALYSIS AND MANUFACTURING OF STIFFENED COMPOSITE DEFLECTOR FOR AEROSPACE APPLICATIONS

P. Ramesh Babu[1]*, P. Ravinder[2]
[1,2] Dept. of Mechanical Engineering, University College of Engineering,
Osmania University, Hyderabad- 500 007. India

Keywords: Composite stiffened panel, deflector and Structural testing

1 Introduction

Elastic behavior of circular composite plates transversely loaded at the center [1] revealed that the Hertzian contact plays a significant role in affecting the plate behavior. Taking into account both the local deformation and non-linearity due to large deflections, a very accurate prediction of the load–deflection curve was obtained. Damage and residual strength of laminated carbon–epoxy composite circular plates loaded at the centre [2] dealt with the characterization of damage in quasi-isotropic carbon fiber reinforced epoxy resin laminate loaded at the centre. Post buckling of composite panels with iso-grid stiffeners [3] is studied to perform instability analysis of composite and isotropic panels supported by stiffeners whose configurations form an isogrid pattern. Particularly, the effect of varying shell thickness and eccentric location of stiffeners on the pre- and post buckling responses of an isogrid stiffened spherical cap is investigated. Object-Oriented approach to Optimize Composite laminated plate stiffness with discrete ply angle [3] deals with two optimization approaches. In the first approach, the ply that most drastically reduces the actual strain of a composite plate is stacked one by one on the laminate. This approach is called the sequential decision approach in this study. In the second approach, the optimal solution to the stacking sequence problem was efficiently obtained by the branch-and-bound procedure. By using these approaches, the optimized stacking sequences were successfully obtained.

Manufacturing theory for advanced grid stiffened structures [4] proposes a theory governing the behavior of both tooling types during the cure cycle in order to minimize the trial and error required to understand tooling expansion during cure. Damage and residual strength of laminated carbon–epoxy composite circular plates loaded at the centre [5] dealt with the characterization of damage in quasi-isotropic carbon fibre reinforced epoxy resin laminate loaded at the centre. Load was applied by means of a servo hydraulic machine and it was supposed to simulate a low velocity impact. The acoustic emission (AE) technique was used to detect damage progression. The objectives of the present work is to reduce the weight of overall mounting frame for better performance. The deflector which contributes to majority of the weight has been decided to be replaced by composite stiffened deflector.

2 Design and Analysis

For in-plane loads, the elastic constants are used in the normal way. Under uniform transverse load, a plate is likely to buckle at some critical load N_x'. Buckling loads depend on geometry, edge conditions and flexural properties. Thin plates may fail by shear buckling before shear failure load [6]. Transverse Loading of Composite Panels

2.1 Design Constrains, Loads and Allowable

Diameter of deflector : 900mm;
Depth of deflector : 150mm
Weight of payload : 500 kg;
Weight of mounting frame: 110 kg

Design Loads

Weight of payload = 500kg;
Design load = 1.33x500 = 6650N

Design Allowable

Allowable for metal**:**
Factor of safety on UTS : 1.25;
Factor of safety on YS : 1.125
Allowable stress: Min [UTS/1.25, YS/1.125]
Allowable for composites**:**
Tensile strength : Min of ring test specimen;
Tensile modulus: Average value
Other properties: 3σ value is taken

2.2 **Configuration Design of deflector**

Thickness of skin : 3mm;
Ply sequence of skin: $(0/45/-45/0/45/-45)_s$
Size of stiffener : Width =10mm,
thickness=20mm
Weight of deflector: 3 kg;
Total weight of assembly: 60 kg

Table 1: Material Data – Composite Materials

Parameter	Carbon Fiber /Epoxy	Carbon fabric/Phenolic
E_1, (GPa)	144	66
E_2, (GPa)	7.5	67
G_{12}, (GPa)	6.5G	4.5
$\nu12$	0.2	0.25
X_t(MPa)	1600	630
X_c, (MPa)	1200	315
Y_t, (MPa)	28	652
Y_c, (MPa)	100	326
S (MPa)	40	26
ρ (kg/m3)	1450	1540

2.3 Finite Element Analysis

The geometric model of the composite deflector is shown in fig. 1 respectively. Finite element model of the composite deflector with boundary conditions is shown in fig.2.

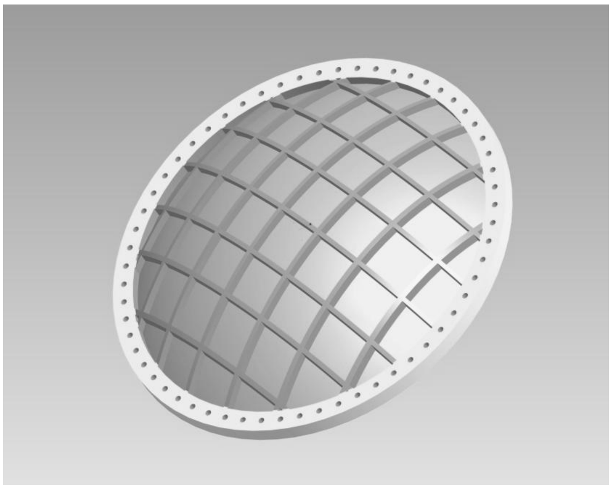

Fig. 1 Geometric Model of composite deflector.

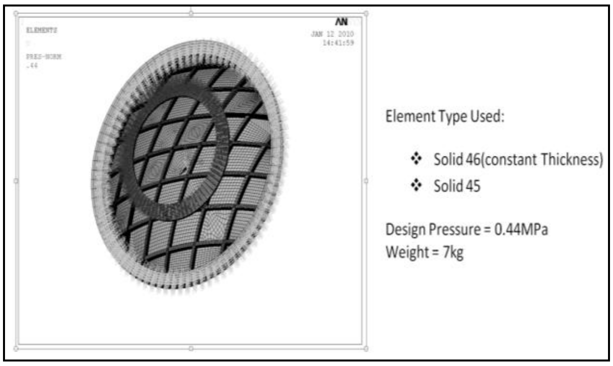

Fig. 2 Finite element model of the composite deflector with boundary conditions

3 Manufacturing and Testing

3.1 Manufacturing of foam mould

The most convenient way of realizing a composite stiffened deflector is by on a foam mould. On The metal plate with PU foam discs of 80mm thick were bonded by using adhesive AW106 and HV953 by the ratio of 10:8 by weight and allowed to cure 24 Hr. Foam profile machining was done on lathe machine with the help of template. On the curved foam, grooves was cut by sharp edge blade by help of 1:1 scale auto cad drawing print out and apply resin on the surface to make smooth and hard. Male plate was made by using E-glass/Epoxy 5mm thick and cut to required diameter to fit on the female mould. Foam moulds and composite male mould are given in Fig 3.

Fig. 3 Foam mould and composite male mould

3.2 Manufacturing of stiffened deflector

In the manufacturing of stiffened deflector a polythene is wrapped on the mandrel and winding is carried up to 1mm thickness by carbon fiber, two No. roving's and epoxy resin LY556/HT951 by 100:27 (by wt) and place another polythene. After UD winding cut along the mandrel to form UD filament prepeg. Cut required width of UD prepeg to suite groove. Prepare the epoxy resin LY-556 with hardener HY-5200 mix at the ratio of 100 parts (by wt.) of resin: 24 parts (by wt.) of hardener.

Fig. 4 Carbon/epoxy prepeg

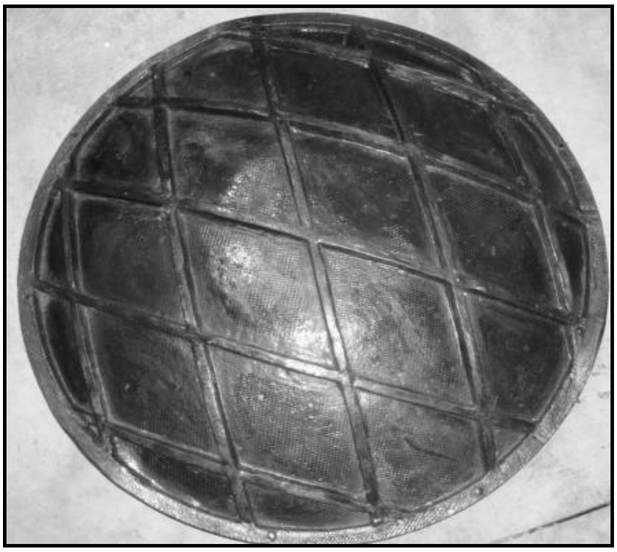

Fig. 5 Finished Model of the Composite Deflector

The carbon fabric is placed on the working table and wet the epoxy resin mix and cut fabric developments as per template. Lay-up sequence begins with filling the groove by dolly (1mm thick) uni-direction prepeg (10 No.) After filling the groove, carry-out the skin lay-up by carbon/ epoxy prepeg shown in fig. 4 (8 No.). To release the component placed one layer of release fabric and closed by male composite plate. Carried out the curing i.e cure temperature is 120° for 2hrs + 180° for 4hrs. The finished Model of the Composite Deflector is shown in fig. 5

4 Experimental Setup and Qualification Test

The composite stiffened deflector under compression load tested in INSTRON TESTING MACHINE the machine is 10 tons capacity. The strain gauges are bonded (6 No.) in the component.

1) Two gauges are on stiffeners length wise on opposite side.
2) Two gauges on node (junction of the stiffeners) on opposite side.
3) Two gauges on skin on opposite diameter.

The stiffened deflector has to undergo various tests before design and fabrication process is proved and these tests form the qualification tests. Every stiffened deflector manufactured as per design has to undergo a series of tests like dimensional inspection and ultrasonic tests before it is accepted for use. These tests are called the acceptance tests. The stiffened panel that undergoes all the acceptance tests successfully will be made available for further use.

4.1 Test Objectives

The primary objective of the test is validation of design as well as fabrication process of the stiffened panel. The following are details of the objectives:

i. To prove structural integrity of stiffened deflector.
ii. To establish the design margins.

iii. To compare the predicted strains and deformations.

4.2 Load test procedure

The stiffened deflector is first loaded from 0 to 0.5 kN and remove the load back to 0 thrice so that the strain gauges stabilize. The accuracy of these load cells shall be minimum 0.5 Ton. The stiffened deflector is loaded in steps of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5,6.0, 6.5 and failure load. Strain gauge readings as well as LVDT readings, at every step, shall be recorded.

5 Results and Discussions

The comparison is based on FE analysis and load test performed on the actual composite stiffened deflector.

5.1 Strain comparisons at stiffener

The stiffeners are fabricated out of UD prepeg and gauges are bonded along the fiber direction. An applied load of 6.65kN on the stiffened panel also was used in the analysis. The FE results and test results are shown in table-2 and data was plotted in Figs.6 and 7.

5.2 Strain comparisons at Cross-over station

The cross-over station, the fiber are coming ±60°. The FE results and test results are plotted in Figs. 8 and 9.

The cross-over stations consists of stiffener with helical pattern, as a results, bending deformation of the cross-over induces stress concentration and large fiber directional stress gradient occurred. Hence failure is 6.76kN against a design load of **6.65 kN** and corresponding maximum **micro-strains is 4268** (against a failure strain in carbon epoxy composite is 4200-4600 micro-strains) observed and leads to failure of the composite in circumference direction. However, the result of the finite element analysis shows close agreement with the experimental results. Also, the design stresses were within safe limits.

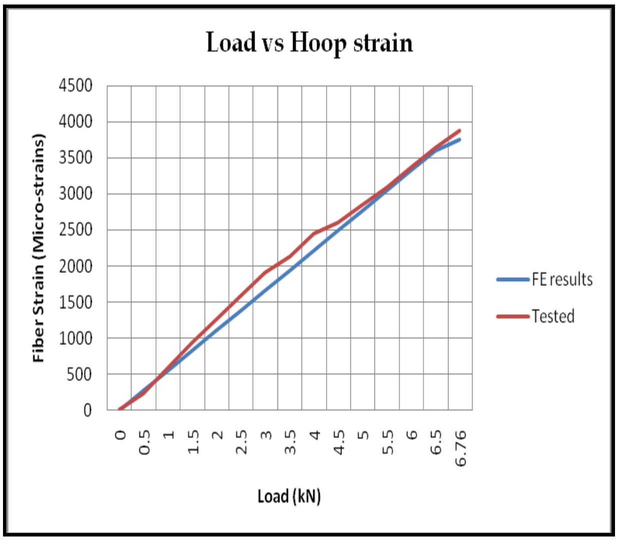

Fig. 6 Comparison of Hoop strain obtained by FE and Experiment at stiffener

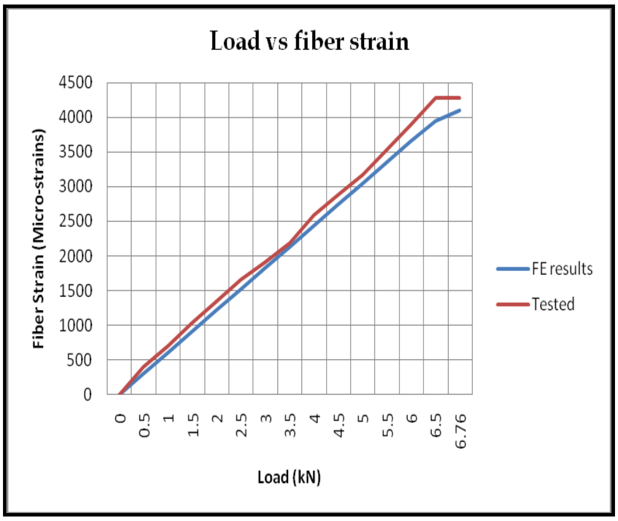

Fig. 7 Comparison of fiber strain obtained by FE and Experiment at stiffener.

Table 2 Comparison of Deflection, Stress and Strain

	Deflection	Stress	Strain
FEM-1 (7X7)	0.25 mm	92 MPa	2650
FEM-2 (5X5)	0.6 mm	108 MPa	3600µ-hoop; 4182µ-axial
Tested	1mm	248MPa-axial	3820µ -hoop; 4514µ -axial

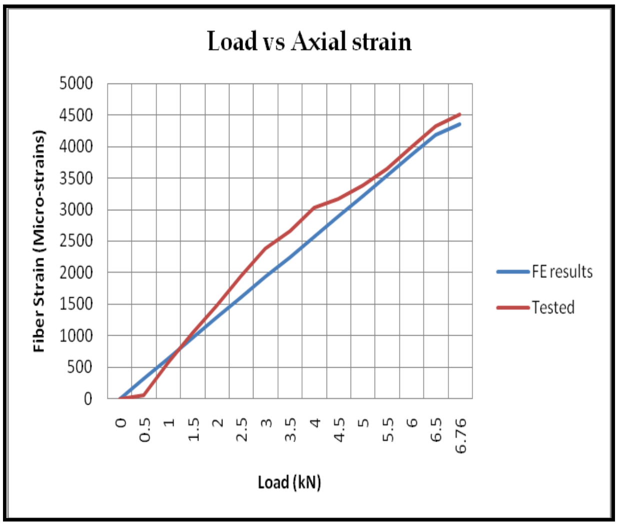

Fig. 8 Comparison of Axial strain obtained by FE and Experiment at cross-over station.

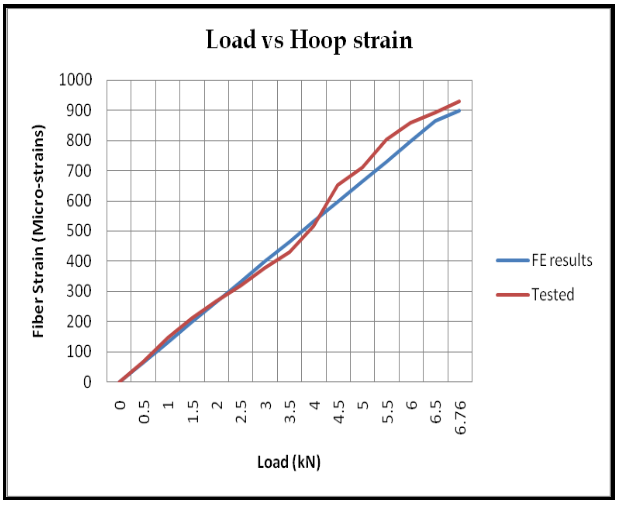

Fig. 9 Comparison of Hoop strain obtained by FE and Experiment at cross-over station.

6 Conclusions

- The composite stiffened deflectors are the best choice as compared to other stiffened structures with regards to its significant weight saving without compromising on its performance.
- The modified composite deflector (reduced no of stiffeners) is having better margin of safety.

References

[1] F. Elaldi, S. Lee and R.F.Scott "*Design, Fabrication and Compression Testing of Stiffened Composite panels for Aircraft Structures"*. NRC LTR-ST-187, 1992.

[2] J.H.Starnes, F.K.Knight and M.Rouse "*Post-buckling of selected flat stiffened graphite epoxy panels loaded in uni-axial compression*", AIAA 23(8), p.344, 1988.

[3] Marco Aurelio Rossi "*Design and Analysis of a Composite Fuselage*". Brazilian Symposium on Aerospace Eng. & Applications, 2009.

[4] G.Caprino, A. Langella and V. Lopresto "*Elastic behavior of circular composite plates transversely loaded at the center*". Composites: Part A, Vol. 33, pp 1191–1197, 2002.

[5] F. Cesari, V. Dal Re, G. Minak and A. Zucchelli "*Damage and residual strength of laminated carbon–epoxy composite circular plates loaded at the centre*". Composites: Part A, vol. 38, pp 1163–1173, 2007.

[6] Atila Barut and Erdogan Madenci "*Post buckling of composite panels with iso-grid stiffeners*". AIAA, pp 7-10, 2008

[7] Akira Todoroki, Nanonobu Sasada and Mitsunori Miki "*Object-Oriented approach to Optimize Composite laminated plate stiffness with discrete ply angle*". Composite Materials: Vol. 30,No.9, 1996.

[8] M. Steven Huybrechts, E. Troy Meink, M. Peter Wegner and M. Jeff Ganley "*Manufacturing theory for advanced grid stiffened structures*". Composites: Part A , vol.33, pp 155–161, 2002.