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Effect of Stiffener Size on Ultimate Strength of GFRP Blade Stiffened Composite Plates

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Abstract*: The ultimate strength of blade stiffened composite plates with various sizes of the stiffener is studied numerically using ANSYS software. The GFRP stiffened composite plates were modeled in ANSYS as SHELL elements with orthotropic properties. The finite element model of the GFRP stiffened composite plates was analysed to obtain deflection, axial deformation and stress contours and the ultimate load values. The obtained results of the finite element model were validated with that of available experimental data. The validated finite element model was used to study the effect of stiffener size. The stiffener size was varied from 10mm to 100mm. It was observed that smaller size of stiffeners were ineffective in stiffening the plate. The optimum size of stiffener was found to be 50mm to 75 mm. .

Keywords **: Blade stiffener, GFRP, Stiffened Plates, Strength.**

I. INTRODUCTION

GFRP composites have properties of better corrosion resistance and high strength to weight ratio. Stiffened plates are used for application in ship structures and bridge decks. Plates are thin compression members and hence are prone to buckling. The presence of stiffeners in the plate helps in subdividing the plate into smaller units, thereby decreasing the b/t ratio of the plate and increasing the load carrying capacity. Blade stiffeners are simple rectangular flats which are either attached to the plate by co-curing or fabricated integrally with the plate.

Studies have been done of GFRP stiffened composite plates by many researchers. Boni et al (2012) compared numerical and experimental results of buckling and post-buckling behavior. Akula (2014) analyzed composite stiffened panel subjected to axial compression using FEM. Shi et al (2014) studied the failure of stiffened composite panels subjected to environmental effects under axial compression. Bhaskar and Pydah (2014) analyzed orthotropic stiffened plates. Pydah and Bhaskar (2015) presented an analytical approach for simply supported blade-stiffened rectangular plates accounting for transverse shear deformation and rotary inertia.

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Yetman et al (2015) investigated the skin stiffener debonding of hat stiffened panels under compressive loading. Sudirsastry et al (2015) analysed stiffened composite panels with straight, T and I shaped stiffeners under uniform axial compression. Jin et al (2015) analyzed hat stiffened composite panels. Zhu et al (2015) studied the effect of stiffener stiffeness on buckling and post buckling behavior of stiffened composite panel. Ricco et al (2015) studied the skin-stringer debonding in stiffened composite panels under compression. Mo et al (2016) studied buckling and post-buckling behavior of hat-stringer stiffened composite panel subjected to axial compression. Kolanu et al (2016) studied the compression behavior of GFRP blade, T and hat stiffened panels. Vosoughi et al (2017) analyzed stiffened laminated composite panels with the aim of optimizing the buckling load. Tan et al (2018) studied the effect of impact damage on single T-stiffened composite panels.Anita et al (2017) studied the behavior of GFRP stiffened composite plates with rectangular cutouts. Ravikumar et al (2018) predicted the buckling load of stiffened and unstiffened composite panels using ANSYS 14.0. Zhang et al (2018) analyzed eccentrically stiffened plates. Behera et al (2018) analyzed stiffened composite plates.

The aim of this paper is to study the ultimate load and failure mode of blade stiffened composite plates with different sizes of stiffeners.

II. FINITE ELEMENT ANALYSIS

A. Specimen Details

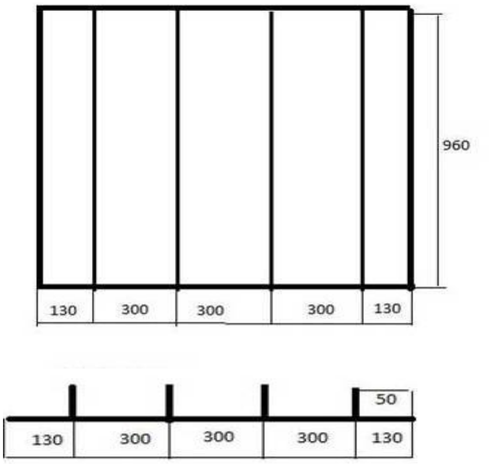
GFRP stiffened composite plates with blade stiffeners were considered for the study. The experimental data available in literature (1) is considered for the present numerical study. The size of the stiffened composite plate considered is 1160 mm (Breadth) x 960mm (Length). The spacing between the stiffeners is 300 mm. The layup structure was $[0]_6$. The material properties of GFRP laminate were also taken from literature (1) and are given in Table I.

B. Finite Element Modeling

The stiffened composite plate was modeled in ANSYS, finite element software. The plate and the stiffener were modeled as SHELL181. SHELL181 is a 4–noded shell element with finite rotation capabilities. The plate and the stiffener were divided into rectangular elements with aspect ratio 0.8 to 1.0. The plate and the stiffener were considered integral and hence were joined by careful positioning of coincident nodes. The plates were first subjected to buckling analysis. The buckling load was used to introduce imperfection in the model for non-linear analysis.

The edges of the plate were considered as simply supported. The longitudinal edges and one of the transverse edges were restrained against translational motion in the z- and y-axis. The x-axis was kept unrestrained to allow axial compression of the plate during axial loading.

The other transverse edge was restrained against translational motion in x, y and z- direction. Load was applied along the axial direction as pressure load. The FE model is shown in Fig. 2. Large displacement static analysis method is used because FRP plate when subjected to loads suffers large displacement. For the final solution, Arc-length method is chosen by giving the maximum and minimum multiplier values.



All dimensions in mm

Fig. 1. Geometry of Stiffened Composite Plate

Table- I: GFRP Material Properties

Properties	Values
Tensile strength -warp direction	250 MPa
Tensile strength - weft direction	211 MPa
Longitudinal modulus, E_1	15800 MPa
Transverse modulus, E_2	15333 MPa
Shear modulus (G_{12})	2806 MPa
Flexural modulus	15388 N/mm^2
Major Poisson's ratio (ν_{12})	0.1386
Minor Poisson's ratio (ν_{21})	0.1248

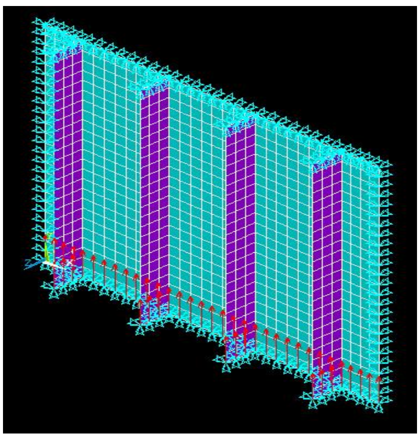


Fig. 2. FE Model of Stiffened Composite Plate

C. Validation

The data available in literature was used for validation of the model. The Ultimate load obtained from experiment and FE analysis is shown in Table II. The out-plane deformation contours are shown in Fig. 2. It is observed that the FE model predicts the ultimate load behavior of stiffened composite plate very well and hence can be used for further analysis.

Table- II: GFRP Material Properties

Description	Experiment	Finite Element Analysis
Failure Load	252 kN	250 kN
Type of Failure	Plate buckling between Stiffener	Plate buckling between stiffener

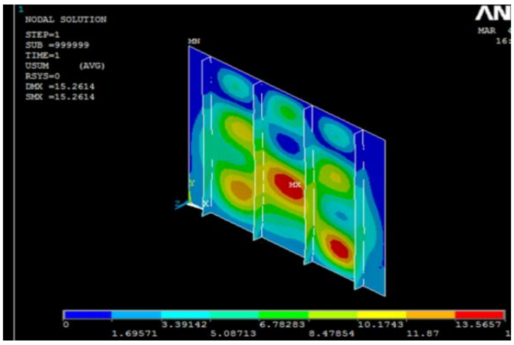


Fig. 2. Out of plane Deformation of FE A50

D. Parametric Study

The validated finite element model is used to predict the effect of stiffener size on the ultimate load and failure mode. The parametric study is conducted on stiffened composite of same the overall size : 1160mm (B) x 960 mm (L) and stiffener spacing of 300mm. The thickness of the stiffener is kept constant at 5mm and the height of the the stiffener is varied as 10mm, 25mm, 75mm, and 100mm. The dimensions of the plates considered for parametric study is shown in Table 2.

Table- II: Details of Specimens

Specimen	Stiffener height	Thickness	h/t
A10	10 mm	5 mm	2
A25	25 mm	5 mm	5
A50*	50 mm	5 mm	10
A75	75 mm	5 mm	15
A100	100 mm	5 mm	20

*validated based on experimental data

III. RESULTS AND DISCUSSIONS

The ultimate load of plates with various stiffener size is shown in Table III. The ultimate load increases by almost twice when the size of the stiffener is increased from 10 mm to 50 mm. When the size of the stiffener is increased from 50 mm to 75mm and 75 mm to 100mm, there is a marginal increase in ultimate load. The out-of-plane deformation contours and stress contours for specimen A10 is shown in Fig. 3 and Fig. 4 respectively. It is observed that the stiffened plate buckles under overall buckling. The stiffener seems inadequate to stiffened the plate and subdivide into smaller units.

Table- III: Failure Loads and Mode of Failure

Specimen	Failure Load	Type of Failure	Region of Maximum Stress
A10	106.8 kN	Overall plate buckling	On the plate
A25	176.8 kN	Overall plate buckling	On the stiffeners
A50	252 kN	Plate buckling between the stiffeners	On the stiffeners
A75	266.3 kN	Plate buckling between the stiffeners	On the stiffeners
A100	279 kN	Plate buckling between the stiffeners and Stiffener Buckling	On the stiffeners

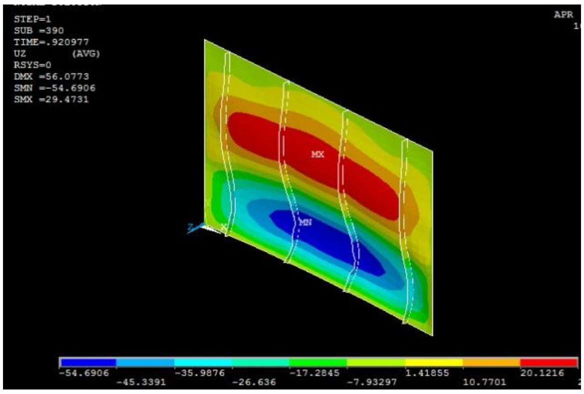


Fig. 3. Out of plane Deformation of A10

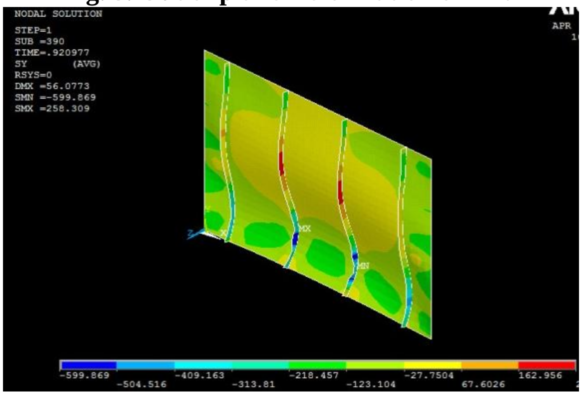


Fig. 4. Stress Contours of A10

The out-of-plane deformation contours and stress contours for specimen A25 is shown in Fig. 5 and Fig. 6 respectively. Overall buckling of the plate is observed and the stiffeners buckle along with the plate. The stiffeners do not have the adequate stiffness to subdivide the plate into plates of smaller b/t.

The out-of-plane deformation contours and stress contours for specimen B75 is shown in Fig. 7 and Fig. 8 respectively. Plate buckling between the stiffeners is observed. The Stiffeners stiffened the stiffened composite plate.

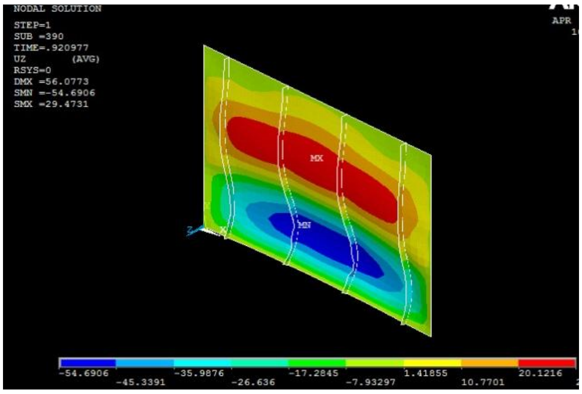


Fig. 5. Out of plane Deformation of A25

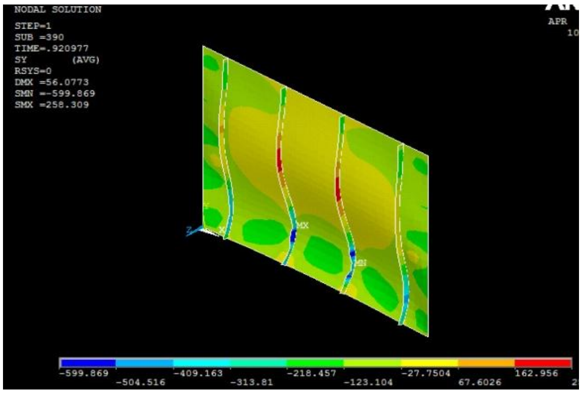


Fig. 6. Stress Contours of A25

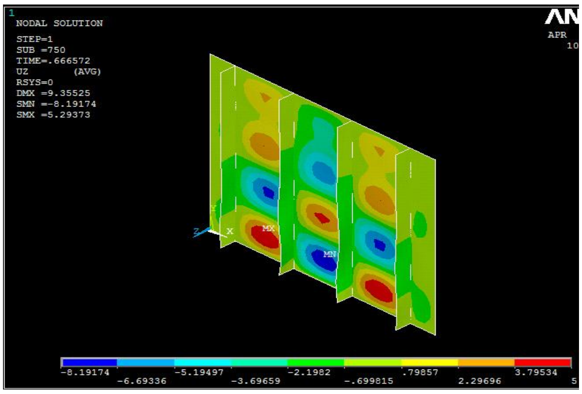


Fig. 7. Out of plane Deformation of A75

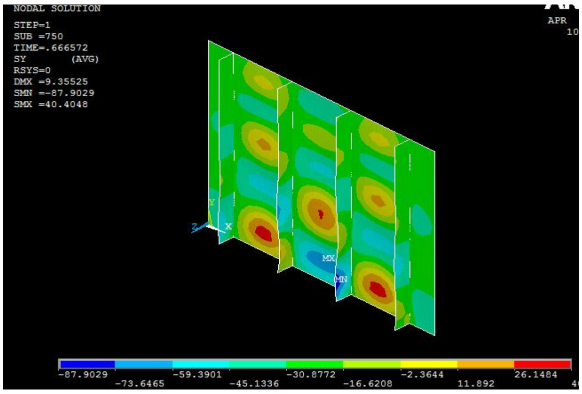


Fig. 8. Stress Contours of A75

The out-of-plane deformation contours and stress contours for specimen B100 is shown in Fig. 9 and Fig. 10 respectively. Buckling of the stiffener is observed.

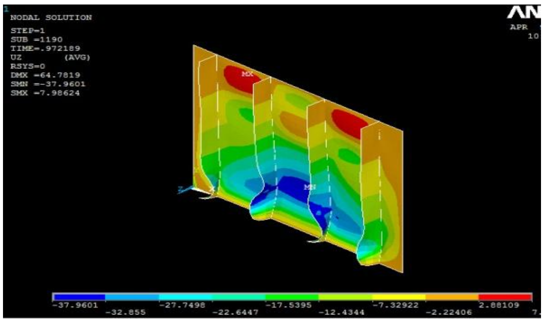


Fig. 9. Out of plane Deformation of A100

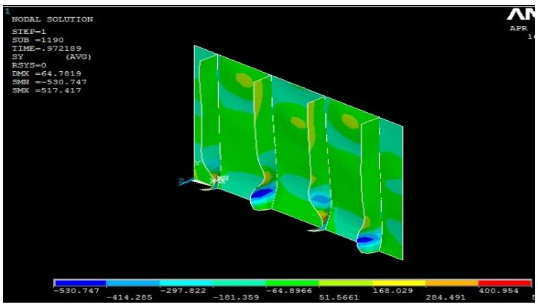


Fig. 10. Stress Contours of A100

IV. CONCLUSION

Numerical analysis of blade stiffened GFRP composite plates with various sizes of stiffeners was done using ANSYS and the following conclusions were made from the study within the limitations of the study.

1) FRP composite plate stiffened with 10mm and 25mm stiffeners undergo overall plate buckling, so the presence of stiffeners does not adequately stiffen the plate.
2) FRP composite plate stiffened with 50mm and 75mm stiffeners undergoes plate buckling in between the stiffeners.
3) Stiffener buckling is observed in FRP composite plate stiffened with 100mm stiffeners.
4) Smaller sized stiffeners are ineffective and increasing the stiffener to a larger size makes the stiffener buckle. Hence the optimum size of stiffener is 50 mm to 75mm.
5) Hence, it can be concluded that stiffener size has an influence on ultimate load and mode of failure of GFRP stiffened composite plates.

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