ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 2, February 2017

Analysis of effect of Fiber Orientation & Stacking Sequence on Bending Strength of I-Section Composite Beam

[1] Ashish A. Desai, [2] Sagar D. Patil, [3] Pravin H. Yadav, [4] Sadanand M. Ghanvat,
[5] Milind A. Patil
[1],[2],[3],[4] Assistant Professor Sharad Institute of Technology College of Engineering, Yadrav
[5] Lecturer Sharad Institute of Technology Polytechnic, Yadrav

Abstract- **The composite thin-walled beams like I-beams are extensively used as chief structural elements. Composite load carrying structures like aircraft wings, skin, tail planes have solid stiffeners for efficient load bearing abilities. This paper is intended to provide tools that ensure better designing options for composite laminates of I -beam. In this Paper an analytical method & FEM approach calculating bending stiffness, bending stress, bending strain of flange and web laminates. The results show the stacking sequence and fiber angle orientation strongly affects strength of composite I-beam.**

I. INTRODUCTION

Composite materials are extending the horizons of designers in all branches of engineering In composites, materials are combined in such a way as to enable us to make better use of their virtues while minimizing to some extent the effects of their deficiencies. This process of optimization can release a designer from the constraints associated with the selection and manufacture of conventional materials. Designer can make use of tougher and lighter materials, with properties that can be tailored to suit particular design requirements. And because of the ease with which complex shapes can be manufactured, the complete rethinking of an established design in terms of composites can often lead to both cheaper and better solutions.

The main advantages for the use composite materials are high strength, high stiffness to weight ratio, long fatigue life, resistance to electrochemical corrosion, and other superior material properties of composites. Those advantages are why composite materials are used in many fields of industry.

II. PRESENT THEORIES & PRACTICES:

Liu et al. [1] 2014 have performed, the progressive failure analysis using explicit finite element method is performed to predict the failure properties and burst strengths of aluminum–carbon fiber/epoxy composite cylindrical laminate structures in terms of three composite pressure vessels with different geometry sizes. The failure analysis employs the Hashin damage initiation criterion and the fracture energy-based damage evolution law for composite layers.

Badie et al. [2] 2011 have examined the effect of fiber orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength, fatigue life and failure modes of composite tubes. Finite element analysis (FEA) has been used to predict the fatigue life of composite drive shaft (CDS) using linear dynamic analysis for different stacking sequence.

G. Zhou et .al. [3] have carried out design, fabrication, testing and evaluation quasi-isotropic carbon-epoxy I-beams co-cured by using a purpose-made open mould with a hot press and low temperature moulding prepregs. The Prepregs means that, a fibrous material pre-impregnated with a particular synthetic resin, used in making reinforced structure. The evaluation of the mechanical behavior of these I-beams in bending was carried out both experimentally and analytically by the authors. Damage characteristics and load-bearing capacity of the I-beams were examined with focus on flange-web joint reinforcement, length-to-depth ratio and manufacturing quality. This paper represents the first attempt to examine both experimentally and analytically the potential change of the damage characteristics induced by a variation of the length-to-depth ratios of these co-cured I-beams.

K.D. Potter et. al. [4] have proposed design, manufacture, testing and post-test evaluation of the beams bonded `I' beams were designed, manufactured under conditions and predictions were made of their failure loads and modes. The beams were then tested in three- and fourpoint bending and the outcomes of these tests were compared to predictions. Thus, the use of adhesive bonding in advanced composite structures offers the potential for considerable weight and cost saving compared to the use of mechanical fasteners. A 3D FEA model which included the material non-linearity was able to substantiate the failure load with good accuracy**.**

W. S. Chan et al. [5] focused on classical lamination theory and determined the locations of the centroid and the shear center for composite beams with box cross-section. The aluminum beam analyzed with five web angles in both symmetric and unsymmetrical layups. For a symmetrical laminate layup of box beams, the both centroid and shear center locations move toward the bottom flange laminates as web angle is increased. For an unsymmetrical laminate layup of box beam, the centroid location is closer to the bottom flange laminate as compared with the symmetric case.

Vesna Savic et. al.[6] have presented the problem formulation & solution methodology for design optimization of composite I-beam. The objective of this paper is twofold. First, to formulate and design optimization problem which will include fiber orientation in a beam walls as design variables , and the second is to incorporate design issues arising from a specific manufacturing process into the optimization problem. A large number of acceptable design that satisfy some specified loading condition can be produced by varying fiber orientation in each ply and /or number plies. This presents a problem of finding the structure with the best possible combination .Optimization technique can help the designers study various dependencies between design variables & identify promising solution for a problem of interest.

Francesco Trentadue et al [7] the effects of the diagonal bars on the bending stiffness of this composite beam are investigated. Within this framework, a useful and accurate closed-form equation for calculating the equivalent bending stiffness has been proposed along with a corresponding parametric formula (even in the form of graphic charts) that should represent rapid and easy design tool for practitioners. First, a closed-form solution for the evaluation of the equivalent bending stiffness is derived. Subsequently, the influence of geometrical and mechanical characteristics of shear reinforcement is studied. Finally, results obtained from parametric and numerical analyses are discussed.

A. Catapano et al.[8] have investigated a static analysis of simply supported &cross-ply laminated composite beams. For validation, considered beams with different values of length-to-thickness ratio subjected to bending loadings. The kinematic field is imposed above the cross-section via an N-order polynomials approximation of the displacements unknown variables. The governing equations and boundary conditions are variationally obtained through the Principle of Virtual Displacements& a closed form, Navier-type solution is adopted. From this formulation, quasi three-dimensional strain and stress fields can be obtained. Classical beam models, such as Euler–Bernoulli's and Timoshenko's, are obtained as particular cases. Results are validated in terms of accuracy and computational costs towards three-dimensional FE models implemented in the commercial code ANSYS. Numerical investigations show that good results are obtained as long as the appropriate expansion order is used.

Above literature gives motivation to carry the analysis of effect of fiber orientation fiber angle orientation & stacking sequence for I beams.

III. METHODOLOGY & APPROACH:-

The finite element method is used to simulate the response of a composite laminate. To validate the model, ANSYS 13 is used to solve examples. A four-layer symmetric of flange & web laminate with a different layup, bending loading condition. The problem is first solved analytically and then with the finite element method. The results is compared to show the accuracy of the model.

3.1 Analytical analysis of composite beam:-

The following equations are used to calculate the elastic properties of an angle ply lamina in which continuous fibers are aligned at an angle ɵ with the positive x direction.

$$\frac{1}{E_{11}} = \frac{\cos^4\theta}{\mathrm{E_X}} + \frac{\sin^4\theta}{\mathrm{E_Y}} + \frac{1}{4}\left(\frac{1}{G_{XY}} - \frac{2\vartheta_{xy}}{\mathrm{E_X}}\right)\sin^2 2\theta$$

$$\frac{1}{E_{22}} = \frac{\sin^4\theta}{\mathrm{E_X}} + \frac{\cos^4\theta}{\mathrm{E_Y}} + \frac{1}{4}\left(\frac{1}{G_{XY}} - \frac{2\vartheta_{xy}}{\mathrm{E_X}}\right)\sin^2 2\theta$$

$$\frac{1}{G_{12}} = \frac{1}{\mathrm{E_X}} + \frac{2\,\vartheta_{XY}}{\mathrm{E_X}} + \frac{1}{\mathrm{E_Y}} - \left(\frac{1}{\mathrm{E_X}} + \frac{2\,\vartheta_{12}}{\mathrm{E_X}} + \frac{1}{\mathrm{E_Y}} - \frac{1}{G_{XY}}\right)\cos^2 2\theta$$

$$\vartheta_{12} = E_{11}\left[\frac{\vartheta_{12}}{E_X} - \frac{1}{4}\left(\frac{1}{E_X} + \frac{2\,\vartheta_{12}}{E_X} + \frac{1}{E_Y} - \frac{1}{G_{XY}}\right)\sin^2 2\theta\right]$$

3.2 Elemental Stiffness Matrix :-

$$Q = \begin{bmatrix} Q_{11} & Q_{12} & Q_{16} \\ Q_{21} & Q_{22} & Q_{26} \\ Q_{61} & Q_{62} & Q_{66} \end{bmatrix}$$

$$Q_{11} = \frac{E_{11}}{1 - \vartheta_{12}\ \vartheta_{21}}$$

$$Q_{22} = \frac{E_{22}}{1 - \vartheta_{12}\ \vartheta_{21}}$$

$$Q_{12} = \frac{v_{12} E_{22}}{1 - \vartheta_{12}\ \vartheta_{21}}$$

$$Q_{66} = G_{12}$$

3.2 $\overline{Q}$ Matrix

Using trigonometric identities, Tsai and Pagano have shown that the Elements in the $\bar{Q}$matrix can be written as,

$$\bar{Q} = \begin{bmatrix} \bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16} \\ \bar{Q}_{21} & \bar{Q}_{22} & \bar{Q}_{26} \\ \bar{Q}_{31} & \bar{Q}_{32} & \bar{Q}_{66} \end{bmatrix}$$

Where,

$$\overline{Q_{11}} = Q_{11}\ \mathrm{COS}^4\,\theta + 2(Q_{12}+2Q_{66})\sin^2\theta\ \mathrm{COS}^2\,\theta + Q22\sin 4\theta$$

$$\overline{Q_{12}} = (Q_{11} + Q_{22} - 4Q_{66})\sin^2\theta\ \mathrm{COS}^2\,\theta + Q_{12}(\sin^4\theta + \cos 4\theta\ )$$

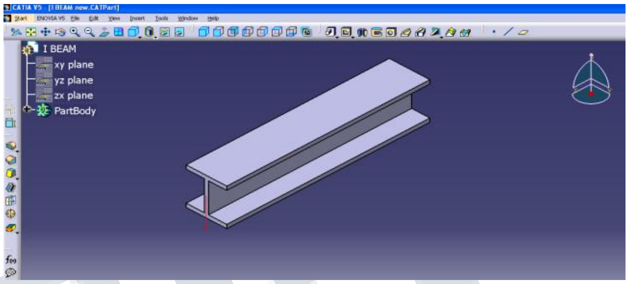
$$\overline{Q_{22}} = Q_{11}\sin^4\theta + 2(Q_{12}+2Q_{66})\sin^2\theta\ \mathrm{COS}^2\,\theta + Q22\cos 4\theta$$

$$\overline{Q_{16}} = (Q_{12} - Q_{12} - 2Q_{66})\sin\theta\ cos^3\theta + (Q_{12} - Q_{22} + 2Q_{66})sin^3\theta cos\theta$$

$$\overline{Q_{26}} = (Q_{11} - Q_{12} - 2Q_{66})sin^3\theta cos\theta + (Q_{12} - Q_{22} + 2Q_{66})\sin\theta\ cos^3\theta$$

$$\overline{Q_{66}} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})\sin^2\theta\ \mathrm{COS}^2\,\theta + Q66(\sin 4\theta + \cos 4\theta\ )$$

3.3 Stress & strain of layer of flange & web Laminates using Bending stiffness:-



Consider a load, P acting at the centroid, such that the equivalent Bending stiffness is,

Therefore,

$P = \overline{N}_x = \overline{EA}\ \varepsilon_x^c$

For flange of forces & moments per width,

$NX1 = A_{1,f}{}^{*}\varepsilon_x^c$

$MX1 = B_{1,f}{}^{*}\varepsilon_x^c$

$MXY1 = -\frac{1}{d_{66}}\left[(b_{16})\ X\ N_{X1} + (b_{16})\ X\ M_{X1}\right]$

For Web of forces & moments per width,

$NX1 = A_{1,f}{}^{*}\varepsilon_x^c$

$MX1 = B_{1,f}{}^{*}\varepsilon_x^c$

MXY1= 0 -------- (web is symmetrical)

3.4. Constitutive Equation of Laminate:-

The stress- strain relations for general orthotropic lamina can be written as,

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = [\bar{Q}] \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{bmatrix}$$

$[\bar{Q}]$ represents the stiffness matrix for the Lamina.

The stresses in the K^{th} ply at a distance of Z^{k} from the reference plane in terms of

strains and laminate curvatures can be expressed as,

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix} = \begin{bmatrix}\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16}\\ \bar{Q}_{21} & \bar{Q}_{22} & \bar{Q}_{26}\\ \bar{Q}_{31} & \bar{Q}_{32} & \bar{Q}_{66}\end{bmatrix}\begin{bmatrix}\epsilon_x\\ \epsilon_y\\ \gamma_{xy}\end{bmatrix}$$

Where, $\begin{bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{bmatrix} = \begin{pmatrix}\varepsilon_x^0\\ \varepsilon_y^0\\ \gamma_{xy}^0\end{pmatrix} + z_k \begin{pmatrix}k_x\\ k_y\\ k_{xy}\end{pmatrix}$

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix} = \begin{bmatrix}\bar{Q}_{11} & \bar{Q}_{12} & \bar{Q}_{16}\\ \bar{Q}_{21} & \bar{Q}_{22} & \bar{Q}_{26}\\ \bar{Q}_{31} & \bar{Q}_{32} & \bar{Q}_{66}\end{bmatrix} \left\{\begin{pmatrix}\varepsilon_x^0\\ \varepsilon_y^0\\ \gamma_{xy}^0\end{pmatrix} + z_k \begin{pmatrix}k_x\\ k_y\\ k_{xy}\end{pmatrix}\right\}$$

The strains in the laminate vary linearly through the thickness whereas the stresses
Vary discontinuously. This is due to the different material properties of the layer resulting from
different fiber orientation.
Computing bending stiffness of composite beam,

$$\mathbf{D_x^c} = \left\{\begin{matrix} \mathbf{b_{f1}\left(A_{1,f1}^{*}Z_{1,C}^{2} + 2B_{1,f,1}^{*}Z_{1,C} + D_{1,f}^{*}\right)} \\ \mathbf{+b_{f,2}\left(A_{1,f2}^{*}Z_{2,C}^{2} + 2B_{1,f2}^{*}Z_{2,C} + D_{1,f2}^{*}\right)} \\ \mathbf{+A_{1,w}^{*}\left(\frac{1}{12}h_{w}^{3} + h_{wc}^{2}h_{w}\right)} \end{matrix}\right\}$$

IV. CALCULATION OF BENDING STIFFNESS OF STEEL, ALUMINUM & COMPOSITE BEAM

A) For bending stiffness for steel & Aluminum beam $= \frac{F}{\delta}$

B) For bending stiffness for composite beam,

$$(EI)_{BEAM} = \frac{a_{11}}{a_{11}d_{11} - b_{11}^{2}}$$

V. MATERIAL PROPERTIES

Property	**Carbon Epoxy**	**Glass Epoxy**	**Steel**	**Al**
E_{11}	126.9 GPa	40.3 GPa	210 GPa	69 Gpa
E_{12}	11 GPa	6.21 GPa	-	-
G_{12}	6.6 GPa	3.07 GPa	80 GPa	26.5 GPa
μ_{12}	0.2	0.2	0.3	0.3
Density Kg/m^3	1610	1910	7810	2700

VI. FINITE ELEMENT METHOD:-

In a structural simulation, FEM helps tremendously in producing stiffness and strength visualizations and also in minimizing weight, materials, and costs.FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of both modeling and analysis of a system. It is primarily through improved initial prototype designs using FEM that testing and development have been accelerated. In summary, benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue. A number of popular brand of finite element analysis packages are now available commercially. Some of the popular packages are STAAD-PRO, GT-STRUDEL, NASTRAN, NISA and ANSYS. Using these packages one can analyze several complex structures.

VII. FINITE ELEMENT ANALYSIS

With different fiber angle orientation and Stacking sequence the analysis done in ANSYS 13.0 version for following dimension of I- section Beam.

First of all, problem is first solved analytically and then with the finite element method. The geometry (Refer fig.7.1) to assume that bf1 = 20mm, $b_{f\,2}$ =20 mm,h_w =16 mm, $t_1 = t_2 = t_3 = 2mm$, Length of the Beam is 100 mm, Applied bending force at centroid is 500 N. For, I-section composite beam, four-lamina symmetric of flange & web laminate with a layup (0-90-90-0) & bending loading condition. (HM Carbon Epoxy lamina four laminas &Thickness each lamina is 0.5mm)

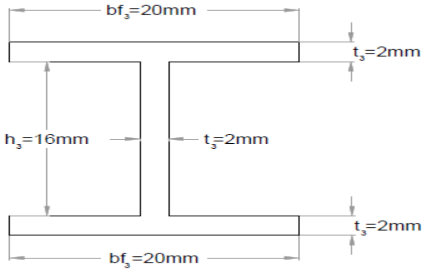
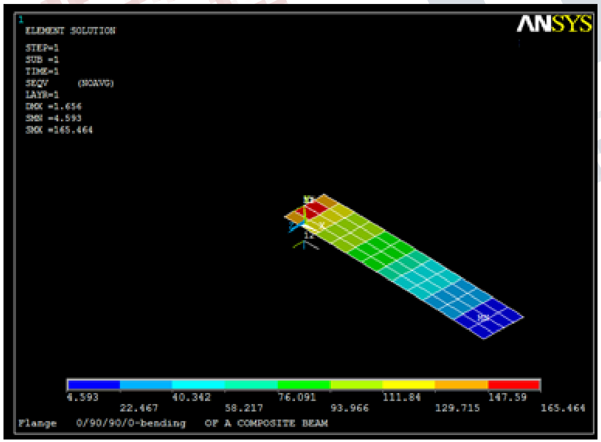


Fig. 7.1.Geometry of I-section Beam

7.1 SHELL 181 Element:-

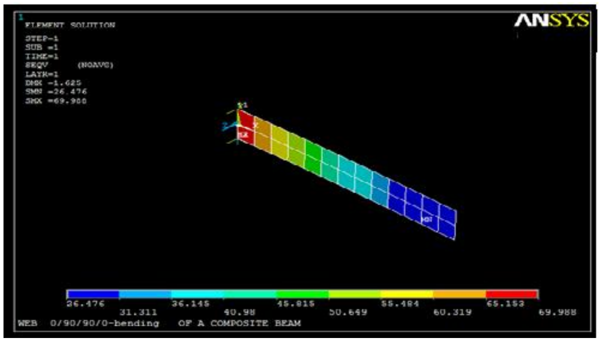
An 4-node element with six degrees of freedom at each node is selected. The element is suitable for analyzing thin to moderately-thick shell structures and is appropriate for linear, large rotation, and/or large strain nonlinear applications. The layer information is input using the section commands rather than real constants. Shell 181 suitable for analyzing thin to moderately-thick shell structures. It is a four-node element with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes.



```
ELEMENT SOLUTION

STEP=1
SUB =1
TIME=1
SEQV     (NOAVG)
LAYR=1
DMX =1.656
SMN =4.593
SMX =165.464
```

Fig.7.1. Flange Bending stress for 1st Layer (applying Bending load at centroid)



```
ELEMENT SOLUTION

STEP=1
SUB =1
TIME=1
SEQV     (NOAVG)
LAYR=1
DMX =1.625
SMN =26.476
SMX =69.988
```

Fig.7.2. Web Bending stress for 1st Layer (applying Bending load at centroid)

VIII RESULT & DISCUSSION

If fiber angle orientation of any one layer is changed and it is kept constant in other layers. For optimum composite I-section composite beam is obtained. To verify the analytical results & ANSYS result. For optimum composite I-section composite beam, obtained by changing orientation of stacking sequence & Orientation angle.

8.1 For Layer Orientation(C/C/C/C)- *($0^0/30^0/30^0/0^0$)*

Layer Orientation ($0^0/30^0/30^0/0^0$)	**Analytical Results Stress (N/mm^2)**	**ANSYS Results Stress (N/mm^2)**	**Percentage Error**
Lamina 1	119.38	121.46	1.712498
Lamina 2	68.62	69.69	1.535371
Lamina 3	68.62	69.56	1.351351
Lamina 4	102.59	101.26	1.296423

Table 8.1.1.:-comparison of Flange bending stress analysis (C/C/C/C)- ($0^0/30^0/30^0/0^0$)

Layer Orientation (0/30/30/0)	**Analytical Results Stress (N/mm2)**	**ANSYS Results Stress (N/mm2)**	**Percentage Error**
Lamina 1	64.45	67.33	4.277439
Lamina 2	58.72	61.22	4.083633
Lamina 3	58.72	58.31	0.698229
Lamina 4	64.45	67.13	3.992254

Table 8.1.2:-comparison of Web bending stress analysis (C/C/C/C)- ($0^0/30^0/30^0/0^0$)

8.2. Result of I-beam for Steel, aluminum & Composite Beam:

Types of Beam	**Applied Load In(N)**	**Bending stiffness (N/mm)**	**Weight in Kg**
Steel I-Beam Beam	500	85.20X 10^3 N/ mm	0.08742
Aluminum I-Beam	500	0.282X 10^6 N/ mm	0.0302
composite I-Beam	500	0.2538 X 10^6N/ mm	0.01932

Table-8.2.1:- Bending & weight Analysis of Steel, Aluminum & optimum composite I-Section beam.

IX. CONCLUSION & FUTURE SCOPE

A finite element model is created to obtain the stiffness of each ply Using ANSYS. The results of finite element method were compared with analytical solution. Four different cross-section configurations were used to compare and validate the analytical solution. The stress and strain in each ply of I-beam subjected to bending load at the centroid had a difference ranging from negligible to 6% compared to finite element results. For flange Laminates $0^0/30^0/30^0/0^0$ in 90^0 direction minimum stress are observed, in 0^0 directions maximum stress are observed. For flange Laminates $0^0/90^0/90^0/0^0$ in 90^0 direction minimum stress are observed, in 0^0 directions maximum stress are observed. The maximum stress in Outer two layers is observed in $0^0/30^0/30^0/0^0$ laminate. The lay-up of $0^0/45^0/45^0/0^0$ is the best as regards stresses induced. It shows that the finite element model developed in ANSYS is accurate. The next step is to analyze the response of the laminate beam under different loadings and with different fiber orientations for getting Optimum Design.

REFERENCES

1. P.F. Liu, L.J. Xing, J.Y. Zheng "Failure analysis of carbon fiber/epoxy composite cylindrical laminates using explicit finite element method" Composites: Part B 56 (2014) 54–61
2. M.A. Badie, E. Mahdi , A.M.S. Hamouda, "An investigation into hybrid carbon /glass fiber reinforced epoxy composite automotive drive shaft", Materials and Design 32 (2011), pp 1485–1500
3. G. Zhou, J. Hood, " Design, manufacture and evaluation of laminated carbon/epoxy I-beams in bending", Composites: Part A 37 (2006) 506–517
4. K.D. Potter , R. Davies , "Heavily loaded bonded composite structure: design, manufacture and test of `I' beam specimens", Composite Structures 51 (2001) 389-399
5. W. S. Chan and K.A. Syed, "Determination of Centroid and Shear Center Locations of Composite Box Beams" the University of Texas at Arlington, Texas, USA
6. Vesna Savic ,Mark Tutte, Zelda B. Zabinsky, "Optimization of composite I-section Using fiber angles as design variables" , Composites Structures 53 (2001) 265-277
7. Francesco Trentadue1, Erika Mastromarino "Bending Stiffness of Truss-Reinforced Steel-Concrete Composite Beams" scientific Research Open Journal of Civil Engineering, 2014, 4, 285-300
8. A. Catapano , G. Giunta, S. Belouettar , E. Carrera , "Static analysis of laminated beams via a unified formulation", Composite Structures (2011).
9. P.K. Mallick, "Fiber-Reinforced composite Materials", Third Edition, USA