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Probabilistic Design of Hollow Circular Composite Structure by using Finite Element Method

Mr. Sachin M. Shinde*, Dr .B. P. Ronge**, Dr. P. M. Pawar**
*(Assistant Professor, Department of Mechanical Engineering, Karmayogi Engineering College, Pandharpur)
** (Professor, Department of Mechanical Engineering, SVERI's College of Engineering, Pandharpur)

ABSTRACT

This study represents simulation of hollow circular composite beam by using Monte Carlo method. A three dimensional static analysis of large displacement type has been carried out. Finite element analysis of hollow circular composite structure has been carried out and uncertainty in bending stress is analyzed. Bending stress was objective function. Beam length, beam radius, elastic modulus, shear modulus and Poisson ratio of epoxy graphite, ply angles of hollow circular section and force are randomly varied within effective range and their effect on bending stress has been analyzed. In order to validate the results, one loop of simulation is benchmarked from results in literature. Ultimately, best set of probabilistic design variable is proposed to reduce bending stress under static loading condition.

Keywords— Hollow circular beam, Monte Carlo Simulation.

I. INTRODUCTION

Composite materials have found increasing use in aerospace and civil engineering construction. One of the common areas of application is panels and hollow circulars construction where composite materials with complex lay-ups are used. The hollow composite properties can be improved when composite materials are used: specific strength, specific stiffness, weight, and fatigue life. The thin-walled beams of open cross-sections are used extensively in space systems as space erectable booms installed on spacecraft; in aeronautical industry both as direct load-carrying members and as stiffener members. In addition, they are used as well in marine and civil engineering, whereas the I-beams, in the fabrication of flex beams of bearing less helicopter rotor [1]. Thin-walled structures are integral part of an aircraft [2]. That is the reason why many researchers consider it in their studies and published it in scholarly articles. Chan and his students focused on thin-walled beams with different cross-sections. Among their studies, Chan and Dermirhan [3] considered first a circular cross section thin-walled composite beam. They developed a new and simple closed-form method to calculate it's bending stiffness. Then, Lin and Chan [4] continued the work with an elliptical cross section thin-walled composite beam. Later, Syed and Chan [5] included hat-sectioned composite beams. And most recently, Rao and Chan [6] expanded the work to consider laminated tapered tubes. Ascione et al. [7] presented a method that formulates one-dimensional kinematical model that is able to study the static behavior reinforced polymer thin-walled beams. It's well known that the statics of composite beam is strongly influenced by shear deformability because of the low values of the elastic shear module. Such a feature cannot be analyzed by Vlasov's theory, which assumes that the shear strains are negligible along the middle line of the cross-section. Ferrero et al. [8] proposed that the stress field in thin-walled composite beams due to a twisting moment is not correctly modeled by classical analytical theories, so numerical modeling is essential. Therefore, they developed a method with a simple way of determining stress and stiffness in this type of structures where the constrained warping effect can be taken into account. They worked with both open and closed cross sections. Also, to check the validity of the method for structures made of composite materials, a beam with thin, composite walls were studied. Wu et al. [9] presented a procedure for analyzing the mechanical behavior of laminated thin-walled composite box beam under torsional load without external restraint. Some analysis has been formulated to analyzed composite box beam with varying levels of assumptions [10-13]. Therefore, analysis of hollow circular composite under varying loading condition is key to improve the design and provide good agreement in results.

II .SIMULATION

The Monte Carlo Simulation method is the most common and traditional method for a probabilistic analysis [14]. This method simulates how virtual components behave the way they are built. Present work uses FEM package ANSYS for analyses of composite beam of hollow circular shape. All input parameter for base model are given in table1. Element selected for meshing the geometry of the specimen is shell 181. Material properties of epoxy graphite are entered. Figure 1 shows meshed model contains 3549 number of nodes and 3360 number of elements.

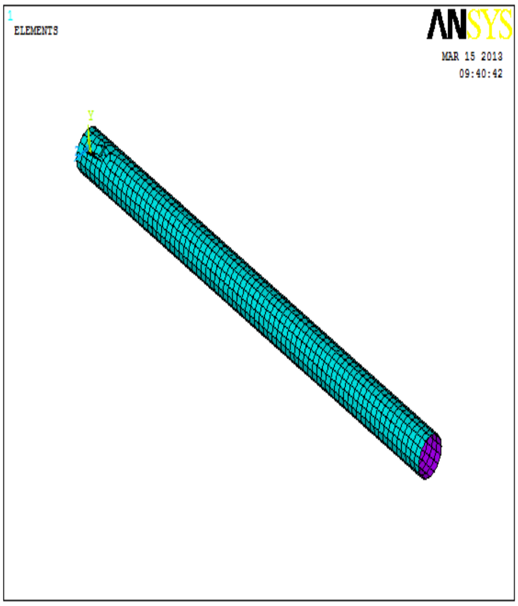

Figure 1: Meshed model of composite with SHELL 181 elements .

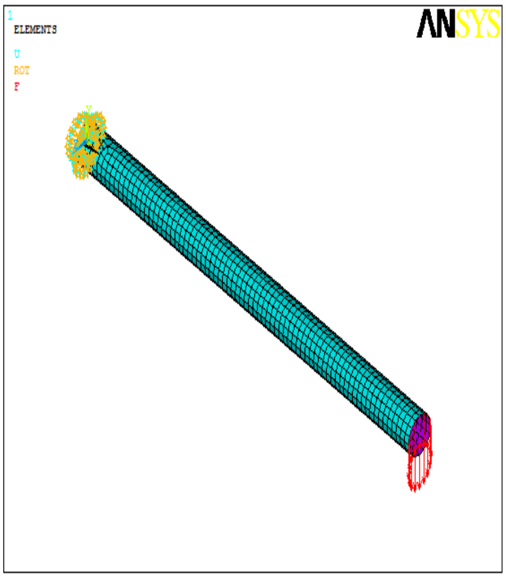

Figure 2: Meshed geometry with boundary conditions

The mesh size is reasonably small to obtain fairly accurate results. Figure 2 shows model with applied loads and boundary conditions, stressed model and deformed shape. Geometry is meshed with element size 1mm. Mapped type of meshing is used. Meshed model of specimen is shown in above figure 2

Table 1: Input Parameter Specifications [15]

Geometry	Length = 1524 mm OD= 101.6 mm t_{wall}= 15.2 mm
Material	E11 = 146.85 GPa E22 = E33 = 11.03 GPa G12 = G13 = 6.21 GPa G23 = 3.86 GPa υ12 = υ13 = 0.28 υ23 = 0.5 t_{layer} = 0.127 mm $\theta=[+20_{30}/-70_{30}]_s$
Load	4.45 KN

III. RESULTS AND DISCUSSION FOR BASELINE MODEL

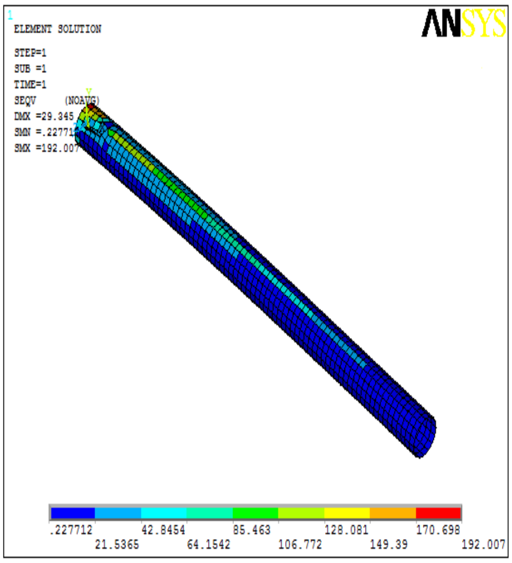

Figure 3: Contour plot of Bending stress distribution

Figure 3 shows bending stress distribution and displacement in composite hallow circular beam. Scatter plot is obtained at end of static analysis. Maximum value of bending stress is 192.007 N/mm^2 and deflection is 29.35mm and it is observed in the region at the end of beam. Base line model selected for displacement which is selected and validated from results in literature [15].

Table 2: Comparison of Literature and ANSYS results [15]

Hollow circular beam	**Displacement (mm)**		
	Literature	**Current study**	**% Error**
	30.00	29.35	2.17

IV. PROBABILISTIC DESIGN SYSTEM FOR HOLLOW CIRCULAR COMPOSITE BEAM

Probabilistic design system is used to determine the effect of one or more variables on the out come of Hollow Circular beam analysis. Present work considers:

- Geometric parameters: Length, Radius.
- Material parameters: Young modulus, Poission ratio and Shear modulus in respective direction.
- Composite properties: Layer thickness and Orientation angles.
- Load parameters: Tip load.

Table 3: Parameters used in probabilistic design of hollow circular beam

Parameter	**Distribution Type**	**Mean**	**Standard Deviation**
Length	Normal	1524 mm	15.24
Radius	Normal	50.8 mm	2.54
EXX	Normal	146.85e3 MPa	14685 MPa
EYY=EZZ	Normal	11.03e3 MPa	1103 MPa
PRXY=PRXZ	Normal	0.28	0.056
PRYZ	Normal	0.50	0.1
GXY=GXZ	Normal	6.21e3 MPa	621 MPa
GYZ	Normal	6.21e3 MPa	621 MPa
Layer Thickness	Normal	0.127	0.0127
θ1	Normal	20 deg	2.0 deg
θ2	Normal	-70 deg	7.0 deg
Force	Normal	-4.45e3 N	4.45e2 N

All the parameters are considered as varying with Gaussian (or Normal) distribution (see Table 3). Baseline model inputs for beam are used as discussed in simulation section. Using uncertainties as stated above, probabilistic design system is performed using ANSYS to know sensitivity of each parameter on Bending Stress. PDS within ANSYS uses Monte Carlo Simulation approach and analysis was looped through 1000 sample points considering the variations defined in the input variables and the corresponding static analysis of the output parameters. After creating parametric model, analysis file for Circular composite beam has been created. The analysis file has been created for use during the probabilistic analysis. It is a parametric model of the problem geometry, materials, and loads. Within the analysis file, input variables are initialized and output variables are retrieved.

This section presents result of probabilistic design for Circular composite beam. Figures 4 to 18 show Scatter plots of each input and output parameters. Scatter plots show uncertainty in Bending Stress. Polynomial distribution of C1 powers is indicated by red colored line. As degree of polynomial distribution is small, there is more uncertainty in Bending Stress. If linear correlation coefficient of scatter plot is small then there is less uncertainty in Bending Stress and if larger then there is more uncertainty in Bending Stress. Similarly it is also same for rank order correlation coefficient.

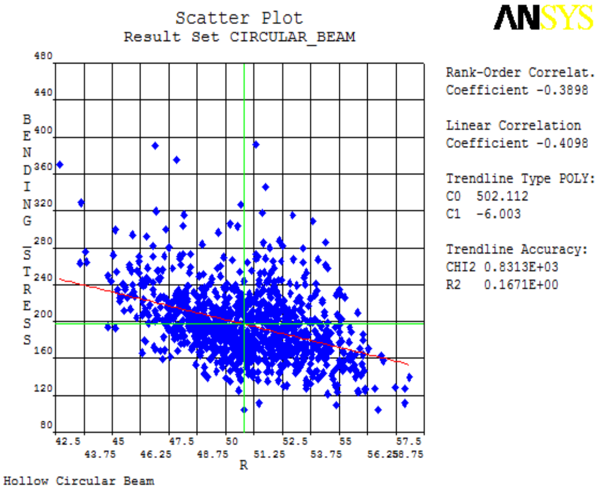

Figure 4 : Scatter plot of Bending Stress vs Beam Radius of hollow circular composite beam

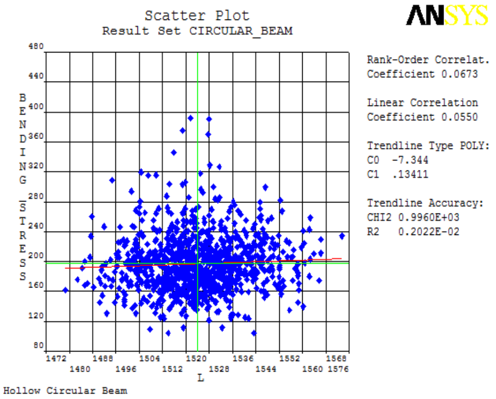

Figure 5: Scatter plot of Bending Stress vs Beam Length of hollow circular composite beam

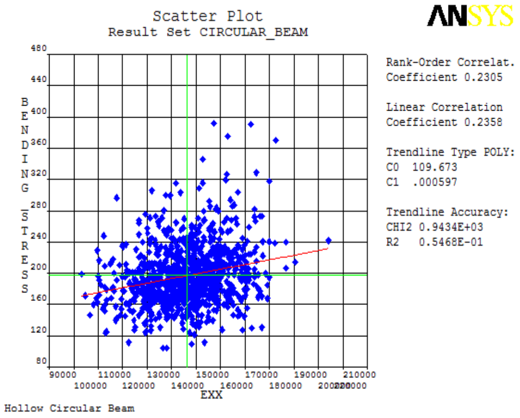

Figure 6: Scatter plot of Bending Stress vs EXX of hollow circular composite beam

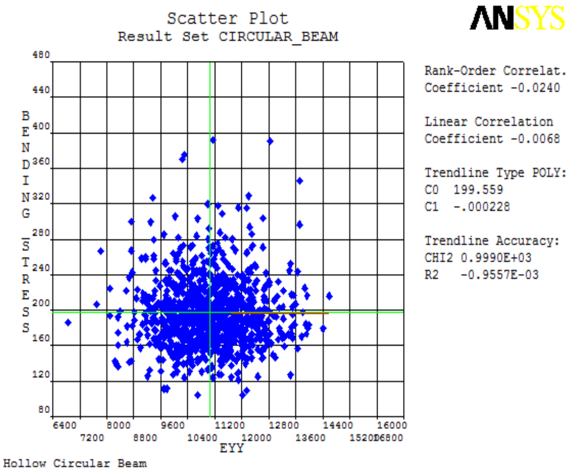

Figure 7: Scatter plot of Bending Stress vs EYY of hollow circular composite beam

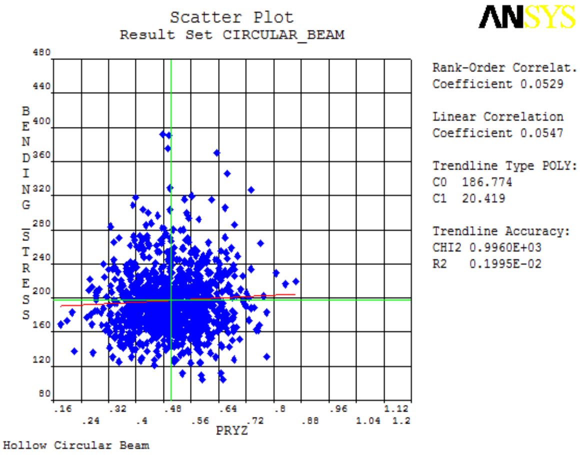

Figure 10: Scatter plot of Bending Stress vs PRYZ of hollow circular composite beam

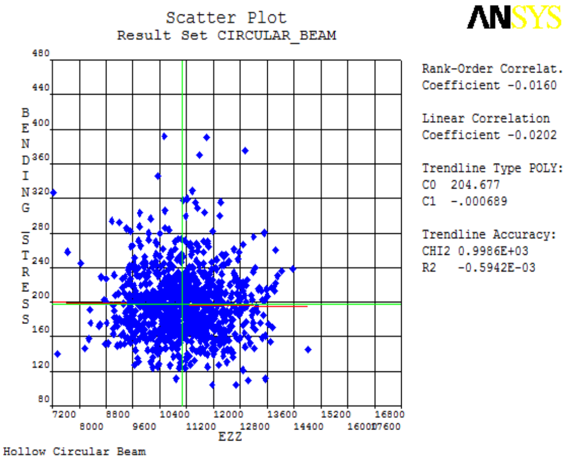

Figure 8: Scatter plot of Bending Stress vs EZZ of hollow circular composite beam

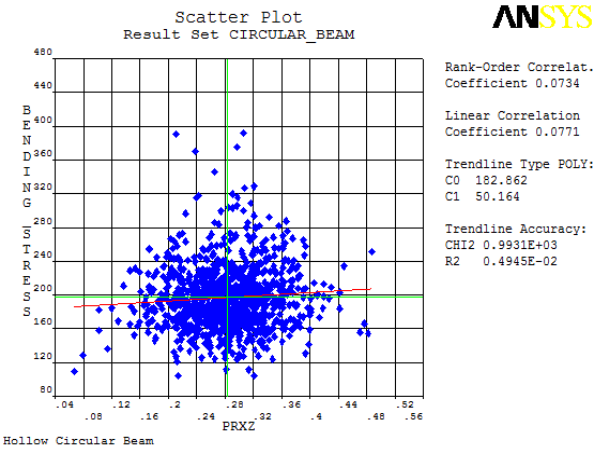

Figure 11 : Scatter plot of Bending Stress vs PRXZ of hollow circular composite beam

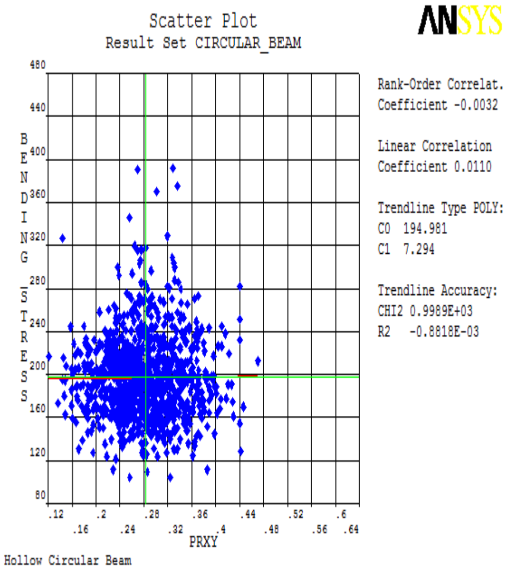

Figure 9: Scatter plot of Bending Stress vs PRXY of hollow circular composite beam

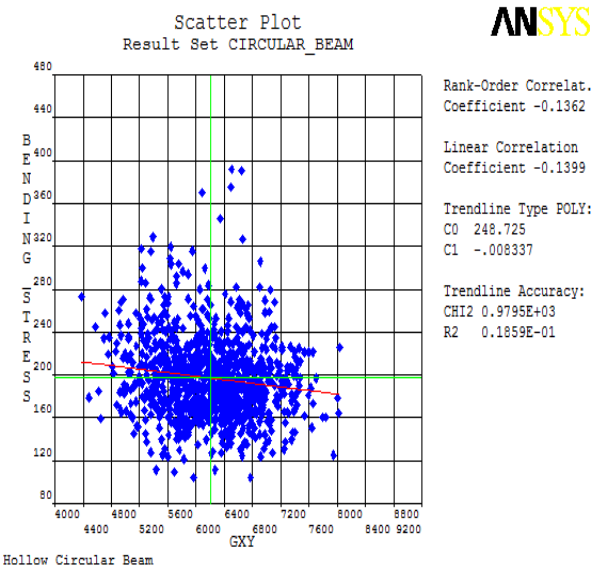

Figure 12: Scatter plot of Bending Stress vs GXY of hollow circular composite beam

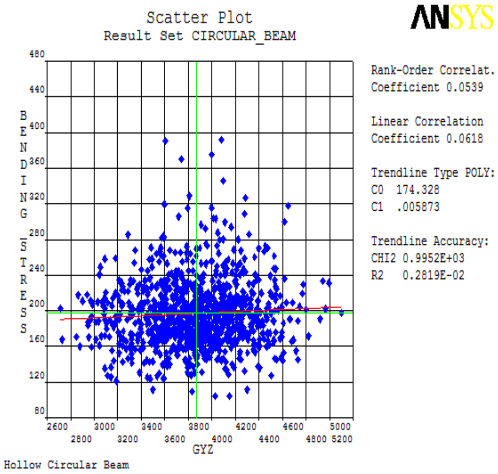

Figure 13: Scatter plot of Bending Stress vs GYZ of hollow circular composite beam

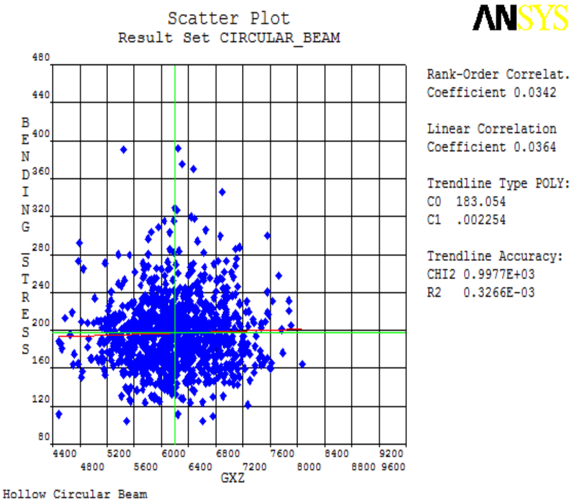

Figure 14: Scatter plot of Bending Stress vs GXZ of hollow circular composite beam

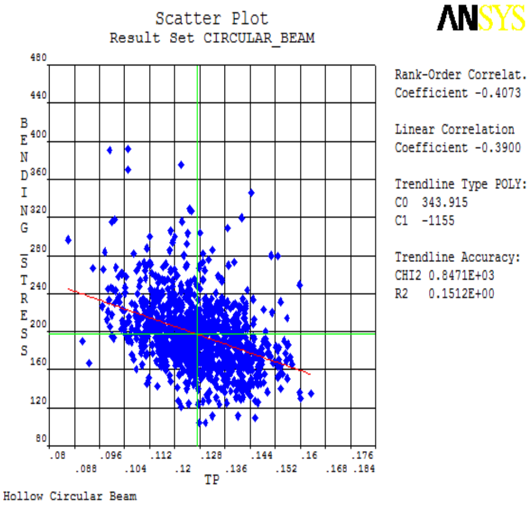

Figure 15: Scatter plot of Bending Stress vs Ply Thickness of hollow circular composite beam

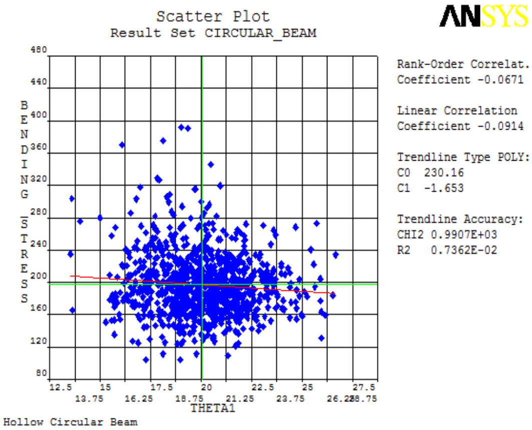

Figure 16: Scatter plot of Bending Stress vs Ply Angle1 (THETA1) of hollow circular composite beam

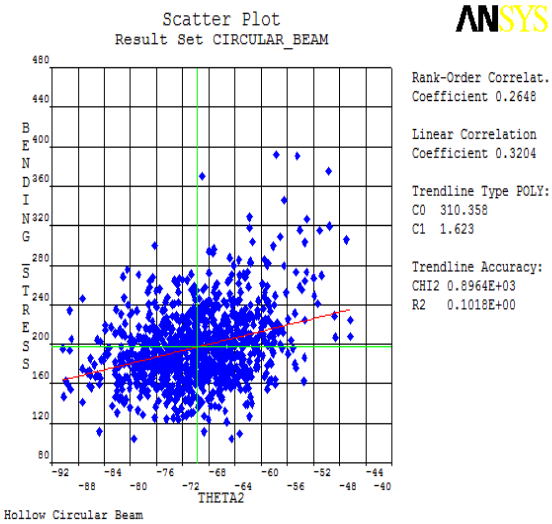

Figure 17: Scatter plot of Bending Stress vs Ply Angle2 (THETA2) of hollow circular composite beam

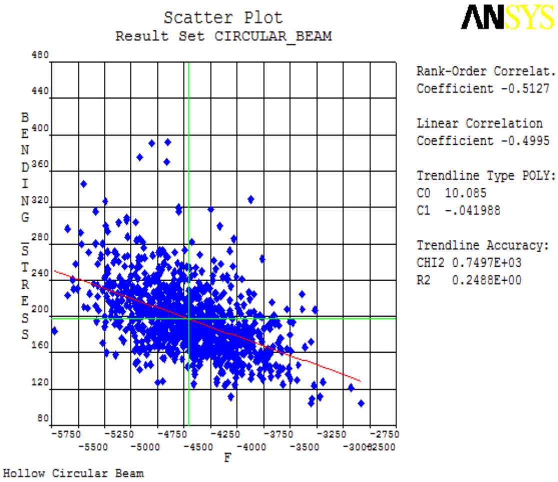

Figure 18: Scatter plot of Bending Stress vs Load of hollow circular composite beam

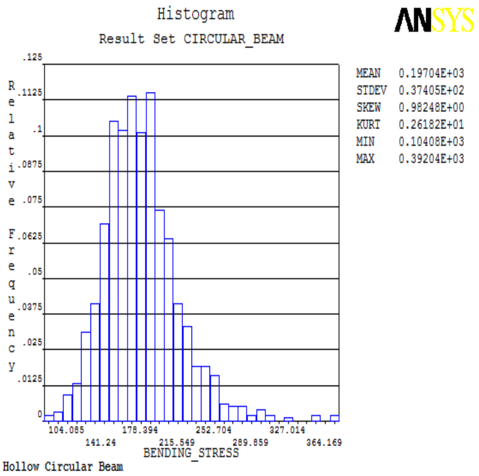

Figure 19: Histogram of output parameter Bending Stress of hollow circular composite beam

Figure 19 shows variatiation in Bending Stress due to combined variation in various input parameters. Bending Stress varies between 104 MPa to 392 MPa. Although all input parameters vary using normal distribution function but output parameters do not follow same. It can be seen from values of Kurtosis and Skewness. Value of skewness deviates from zero.

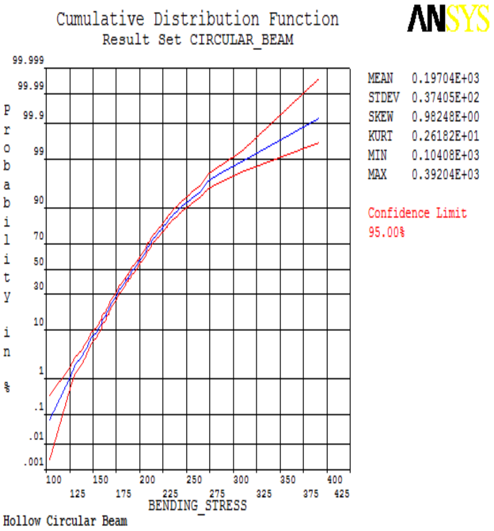

Figure 20: 95% confidence interval for Bending Stress of hollow circular composite beam

Beams are typically designed to fulfill certain design criteria based on the output parameters. For example, a design for Bending Stress will be above or below a certain limit, yet, the cumulative distribution curve for Bending Stress shows minimum 104 MPa and maximum 392 MPa. Probability of having Bending Stress less than 250 MPa is below 90% (see Figure 20).

The line in middle is the probability P that the maximum Bending Stress remains lower than a certain limit value with 95% confidence interval. The confidence interval quantifies the accuracy of the probability results. After the reliability of the beam has been quantified, it may happen that the resulting value is not sufficient. The answer to the question which input variables should be addressed to achieve a robust design and improve the quality; can be derived from probabilistic sensitivity diagrams plot. The result of the proposed method is Spearman rank-order correlation to determine which random parameters are most significant in affecting the uncertainty of the design. The sensitivity analysis results obtained are shown in Fig. 21 The sensitivities are given as relative values (bar chart) and relative to each other (pie chart).

On the other hand, variation in following seven parameters significantly affect bending stress of beam whereas variation in remaining eight parameters do not have significant effect:

- Tip load
- Ply thickness
- Beam radius
- Orientation angle – 70 deg
- Youngs modulus in XX
- Shear modulus in XY
- Poissions ration in XZ

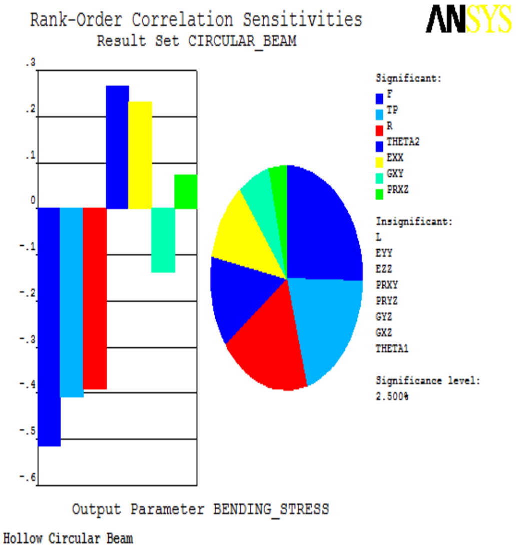

Figure 21: Sensitivity plot for bending stress

V CONCLUSION

The influence of the design parameters on bending stress under variable loading condition is studied. The conclusions obtained are summarized as follows.

- Baseline analysis deflection results perfectly match with literature results for all three cases and percentage error is less than 3%.

-Successfully carried out probabilistic analysis to study effect of input uncertainties on Bending Stress of static analysis for circular composite beam. From analysis it appears that not all input uncertainties affect Bending stress.

- Co-relation coefficients and rank order coefficients of selected parameters are obtained to know the relationship between Bending Stress and design variables.
- In Monte Carlo simulation, it was observed that maximum probable value of Bending Stress was 392 MPa and minimum probable value was104 MPa.

REFERENCES

[1]. Lee, J., and Lee, S., “Flexural-torsional behavior of thin-walled composite beams”, ELSEVIER, Thin-walled Structures, vol. 42, 2004, pp. 1293-1305.
[2]. Mitra, M., Gopalakrishnan, S., and Seetharama, M., “A new super convergent thin walled composite beam element for analysis of box beam structures”, ELSEVIER, International Journal of Solids and Structures, vol. 41, 2004, pp. 1491-1518.
[3]. Chan, W. S., and Demirhan K. C., “A Simple Closed-Form Solution of Bending Stiffness for Laminated Composite Tubes”, Journal of Reinforced Plastic & Composites, vol. 19, 2000, pp. 278-291.
[4]. Lin, C. Y., and Chan, W. S., “A Simple Analytical Method for Analyzing Laminated Composites Elliptical Tubes”, Proceedings of the 17th Technical Conference of American Society of Composites.
[5]. Syed, K. A., and Chan, W. S., “Analysis of Hat-Sectioned Reinforced Composite Beams”, Proceedings of American Society for Composites Conference.
[6]. Rao, C., and Chan, W. S., “Analysis of Laminated Composites Tapered Tubes", Department of Mechanical and Aerospace Engineering, University of Texas at Arlington.
[7]. Ascione, L., Feo, L., and Mancusi, G., “On the statical behavior of fiber-reinforced polymer thin-walled beams”, ELSEVIER, Composites, Part B, vol. 31, 2000, pp. 643-654.
[8]. Ferrero, J. F. , Barrau, J. J. , Segura, J. M. , Castanie, B. , and Sudre, M., “Torsion of thin-walled composite beams with midplane symmetry",ELSEVIER,Composite Structures, vol. 54, 2001, pp. 111-120.251
[9]. Wu, Y., Zhu, Y., Lai, Y., Zhang, X., and Liu, S., “Analysis of thin-walled composite box beam under Torsional load without external restraint”,ELSEVIER Thin-walled Structures, vol. 40, 2002, pp. 385-397.
[10]. Chuanxian, C., “Researches on bending and torsional stiffness of thin-walled carbon epoxy box beam”, Mechanics and Practice, Beijing University Press, 1985.
[11]. Chandra, R., Stemple, A. D., and Chopra I., “Thin-walled composite beams under bending, torsional and extensional loads”, Journal Aircraft, 1990, vol. 27, 619-626.
[12]. Fei, Y., “A theory for bending and torsion of the composite single cell thin-walled beam", Mechanics and Practice, 1994, vol. 16, pp. 37-40.
[13]. Min, J. S., Hyo, C. M., and In, L., “Static and dynamic analysis of composite box beams using large deflection theory. Computer & Structures, 1995, vol. 57, pp. 635-642.
[14] Shinde,S.M., Ronge,B,P, Pawar, P.P., “Probabilistic Design and Random Optimization of Aerofoil Composite by Using Finite Element Method”, www.ijera.com Vol. 3, Issue 5, Sep-Oct 2013, pp.01-05
[15] Jiang, Sun, Milan Ruziicka, “ A Calculation Method of Hollow Circular Composite Beam under General Loadings”, Bulletin of Applied Mechanics, 2006, vol.3, pp.05–114 2006
[16] Shinde S.M., “Probabilistic Design and Random Optimization of Circular Composite by Using Finite Element Method”, IJMET, Volume 5, Issue 4, April (2014), pp. 206-215