Analysis of Non-Isotropic Composite Pipes by Using Finite Element Method

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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 maximum deflection is analyzed. Maximum deflection was objective function. Beam length, beam radius, elastic modulus, shear modulus and poisson ratio of epoxy graphite in XY, YZ, XZ, ply angles of hollow circular section and force are randomly varied within effective range and their effect on Maximum Deflection 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 maximum deflection under static loading condition. 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.

Key words: Hollow circular beam, Monte Carlo simulation, composite materials, static, Iran

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 (Lee and Lee, 2004).Thin-walled structures are integral part of an aircraft (Mitra *et al.*, 2004). 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 Demirhan (2000) 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 continued the research with an elliptical cross section thin-walled composite beam. Later, Syed and Chan included hat-sectioned composite beams. And most recently, Rao and Chan expanded the work to consider laminated tapered tubes. Ascione *et al.* (2000) 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.* (2001) 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 ofstructures 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.* (2002) 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 (Chuanxian, 1985; Chandra *et al.*, 1990; Fei, 1994; Jeon *et al.*, 1995). Therefore, analysis of hollow circular composite under varying loading condition is key to improve the design and provide good agreement in results.

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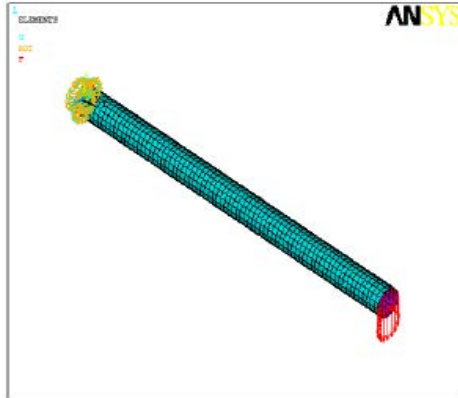
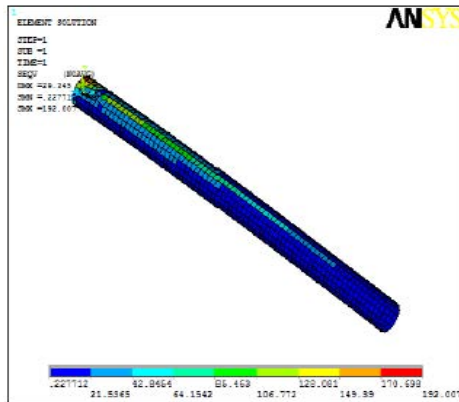Fig. 1: Meshed geometry with SHELL 181 elements; boundary conditions

Fig. 2: Contour plot of maximum deflection distribution

MATERIALS AND METHODS

Simulation: The Monte Carlo Simulation method is the most common and traditional method for a probabilistic analysis (Shinde *et al.*, 2013). 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 circularshape. All input parameter for base model are given in Table 1 and 2. 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 1178 number of nodesand 1162 number of elements.

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 1 mm. Mapped type of meshing is used. Meshed Model of specimen is shown in Fig. 2.

Table 1: Input parameter specifications (Jiang and Ruziicka, 2006)

Parameters	Values
Geometry	Length = 1524 mm
	OD = 101.6 mm
	T_{wall} = 15.2 mm
Material	E_{11} = 146.85 GPa
	E_{22} = E_{33} = 11.03 GPa
	G_{12} = G_{13} = 6.21 GPa
	G_{23} = 3.86 GPa
	T_{layer} = 0.127 mm
	$\theta = [+20_{30}/\_70_{30}]_s$
Load	4.45 N

Table 2: Comparison of literature and ANSYS results (Jiang and Ruziicka, 2006)

	Displacement (mm)		
	Literature study	Current	Error (%)
Hollow circular beam	30	29.35	2.17

RESULTS AND DISCUSSION

Figure 3 shows maximum deflection distribution and displacement in composite hallow circular beam. Scatter plot is obtained at end of static analysis. Maximum value of Maximum Deflection is 192.007 N mm^{-2} and deflection is 29.35 mm 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 (Jiang and Ruziicka, 2006; Shinde, 2014).

Probabilistic design system for hollow circular 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

All the parameters are considered as varying with Gaussian (and or normal) distribution (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 Maximum Deflection. PDS within ANSYS uses Monte Carlo Simulation approach and analysis was looped through 1000 sample

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

Parameters	Mean	SD
Lenght	1524 mm	15.24
Radius	50.8 mm	2.54
EXX	146850 MPa	14685 MPa
EYY = EZZ	11030 MPa	1103 MPa
PRXY = PRXZ	0.28	0.056
PRYZ	0.5	0.1
GXY = GXZ = GYZ layer	6210 MPa	621 MPa
Thickness	0.127	0.0127
Teta 1	20 deg	2 deg
Teta 2	70 deg	7 deg
Force	-4450 N	-445 N

Fig. 4: Scatter plot of maximum deflection vs. beam length of hollow circular composite beam

Fig. 3: Scatter plot of maximum deflection vs. beam radius of hollow circular composite beam

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. Figure 4-18 show scatter plots of each input and output parameters. Scatter plots show uncertainty in maximum deflection. Polynomial distribution of C1 powers is indicated by red colored line. As degree of polynomial distribution is small, there is more uncertainty in maximum deflection. If linear correlation coefficient of scatter plot is small then there is less uncertainty in maximum deflection and if larger then there is more uncertainty in maximum deflection. Similarly, it is also same for rank order correlation coefficient. Figure 19 shows variatiation in maximum deflection due
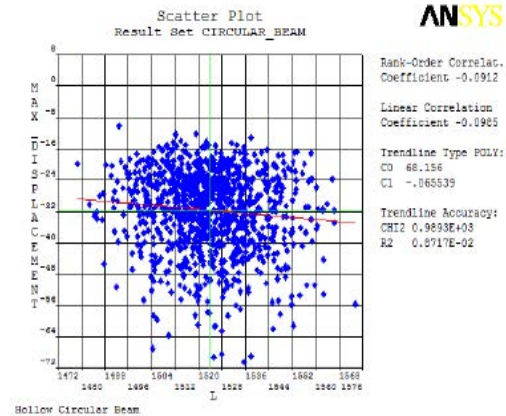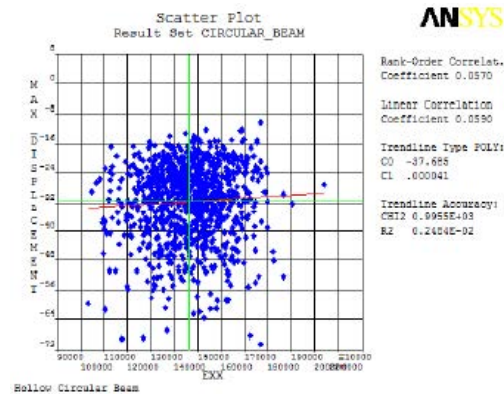

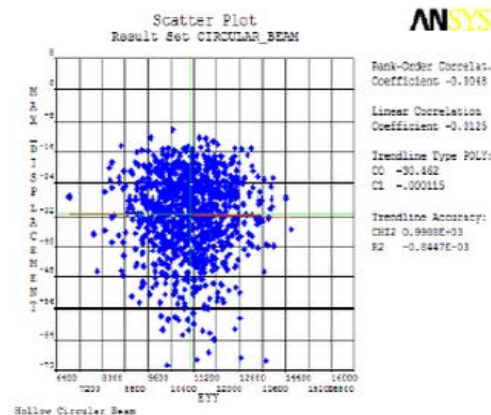Fig. 5: Scatter plot of maximum deflection vs. EXX of hollow circular composite

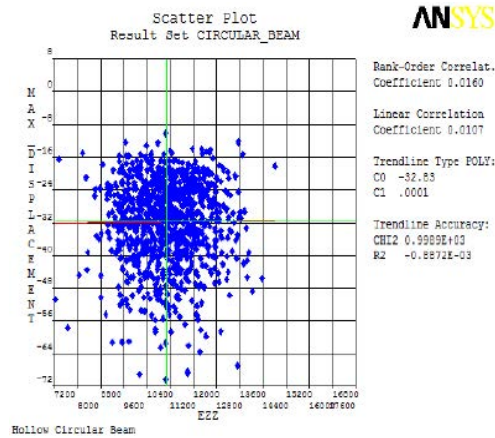Fig. 6: Scatter Plot of maximum deflection vs. EYY of hollow circular composite beam

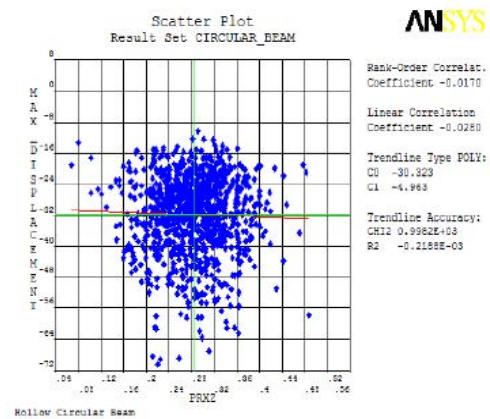Fig. 7: Scatter plot of maximum deflection vs. EZZ of hollow circular composite beam

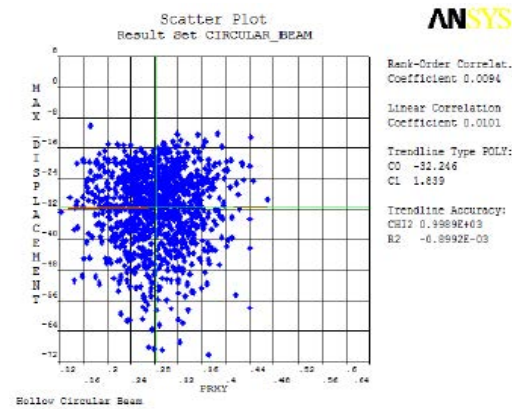Fig. 10: Scatter plot of maximum deflection vs. PRXZ of hollow circular composite beam

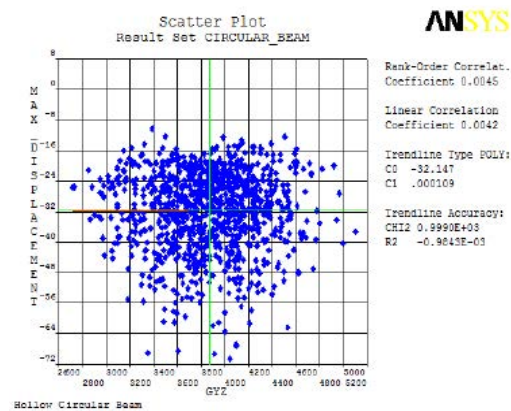Fig. 8: Scatter Plot of maximum deflection vs. PRXY of hollow circular composite beam

Fig. 11: Scatter plot of maximum deflection vs. GYZ of hollow circular composite beam
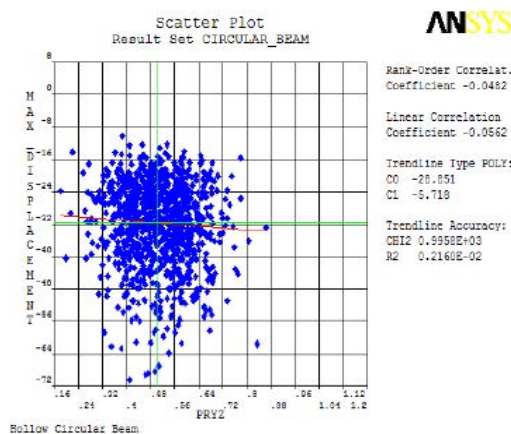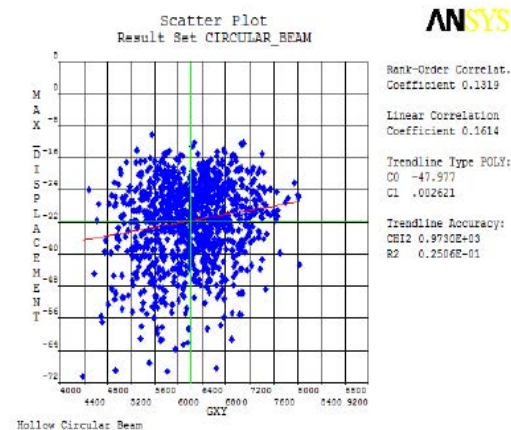

Fig. 9: Scatter plot of maximum deflection vs. PRYY of hollow circular composite beam

Fig. 12: Scatter plot of maximum deflection vs. GXY of hollow circular composite beam
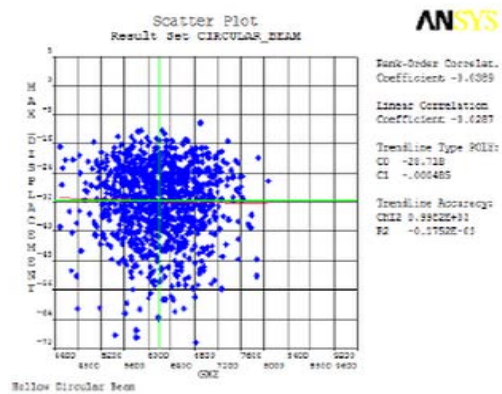
Fig. 13: Scatter plot of maximum deflection vs. GXZ of hollow circular composite beam
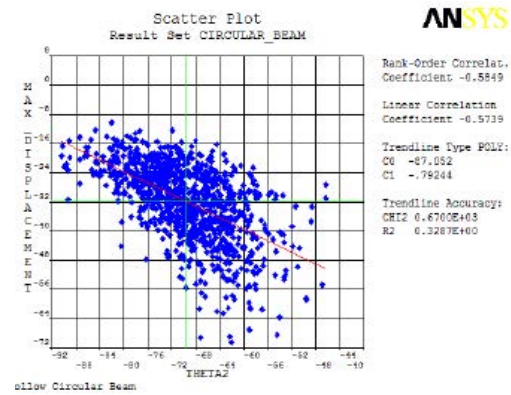

Fig. 16: Scatter plot of maximum deflection vs. ply angle 2 (THETA2) of hollow circular composite beam
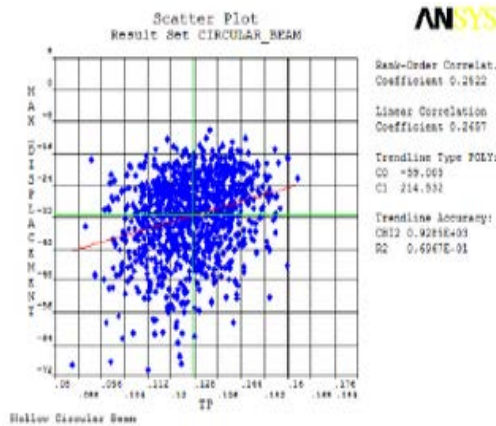

Fig. 14: Scatter plot of maximum deflection vs. ply thickness of hollow circular composite
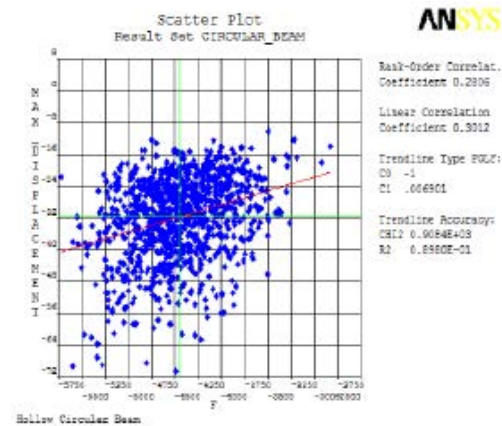

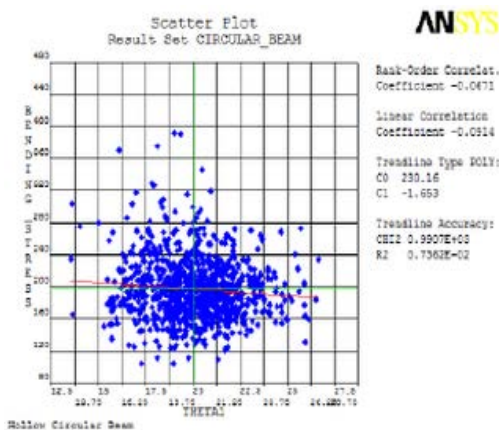Fig. 17: Scatter plot of maximum deflection vs. load of hollow circular composite beam

Fig. 15: Scatter plot of maximum deflection vs. ply angle1 (THETA1) of hollow circular composite beam
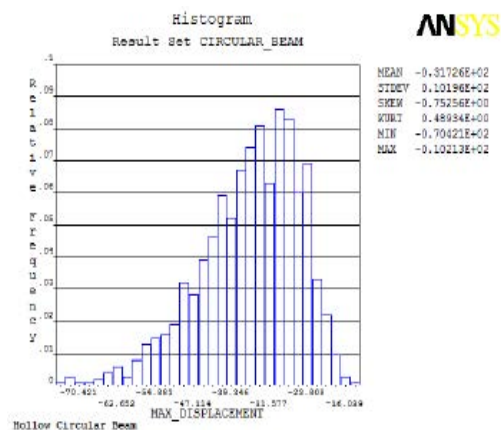

Fig. 18: Histogram of output parameter maximum deflection of hollow circular composite beam
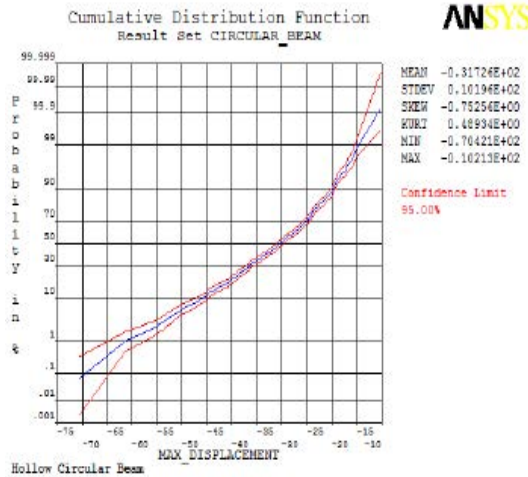
Fig. 19: The 95% confidence interval for maximum deflection of hollow circular composite beam
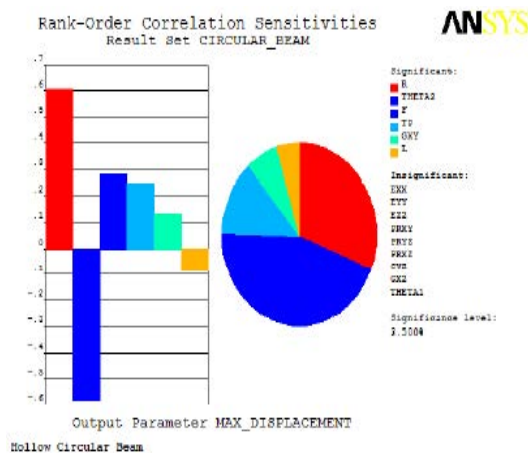

Fig. 20: Sensitivity plot for maximum deflection

to combined variation in various input parameters. Maximum deflection varies between the cumulative distribution curve for deflection shows minimum 10 and maximum 70 mm. 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.

Beams are typically designed to fulfill certain design criteria based on the output parameters. For example, a design for maximum deflection will be above or below a certain limit, yet, the cumulative distribution curve for maximum. The cumulative distribution curve for deflection shows minimum 10 mm and maximum 70 mm. Probability of

having deflection >35 mm is below 50% (Fig. 20). The line in middle is the probability p that the maximum maximum deflection 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 sensitivities are given as relative values (bar chart) and relative to each other (pie chart).

- Beam radius
- Orientation angle-70°
- Tip load
- Ply thickness
- Shear modulus in XY
- Beam length

CONCLUSION

The influence of the design parameters on maximum deflection under variable loading condition is studied. The conclusions obtained are summarized as follows. Baseline analysis deflection results perfectly match with literature results for above case and percentage error is <3%. Successfully carried out probabilistic analysis to study effect of input uncertainties on maximum deflection of static analysis for circular composite beam. From analysis it appears that not all input uncertainties affect maximum deflection:

- Co-relation coefficients and rank order coefficients of selected parameters are obtained to know the relationship between maximum deflection and design variables
- In monte carlo simulation, it was observed that maximum probable value of the cumulative distribution curve for deflection shows minimum 10 mm and maximum 70 mm

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