PROBABILISTIC DESIGN AND RANDOM OPTIMIZATION OF HOLLOW CIRCULAR COMPOSITE STRUCTURE BY USING FINITE ELEMENT METHOD

Mr. Shinde Sachin M.
Student, Department of Mechanical Engineering,
SVERI’s College of Engineering, Pandharpur, India

ABSTRACT

This study represents simulation of hollow circular composite beam by using Monte Carlo method i.e. direct sampling. A three dimensional transient 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. Moreover optimization of selected design variables has been carried out by using random optimization method. Bending stress was objective function. Beam length, elastic modulus of epoxy graphite, ply angles of hollow circular section, radius 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 optimized design variable is proposed to reduce bending stress under different loading condition.

Keywords: Hollow Circular Composite Beam, Monte Carlo Simulation, Random Optimization.

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 of fiber-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. Element selected for meshing the geometry of the specimen is shell 181. Material properties of epoxy graphite are entered. Fig 1 shows meshed model contains 3549 number of nodes and 3360 number of elements. The mesh size is reasonably small to obtain fairly accurate results. Figure 2 shows model with applied loads and boundary conditions.

![Figure 1: Meshed model of composite with SHELL 181 elements](image1)

![Figure 2: Meshed geometry with boundary conditions](image2)

Geometry is meshed with element size 1mm. Mapped type of meshing is used. Meshed model of specimen is shown in above figure 2.
L, R, THETA1, THETA2, Exx, F indicate beam length, radius, ply angles of hollow circular section elastic modulus of epoxy graphite and force respectively. These design parameters were varied by using uniform distribution. Maximum bending stress in composite hollow circular beam is selected as response parameter. Properties of epoxy graphite are entered. All degrees of freedom are made zero at one end of specimen while other end is subjected to displacement. Range of displacement is selected in such a way that excessive distortion of the elements can be avoided. Loading conditions are varied. So, full Transient analysis of large displacement type is executed in 4 steps. Each step is incremented by 1 step. One simulation loop of transient analysis has been defined. It is executed 1000 times by varying design parameters randomly within defined range. Scatter plot of maximum bending stress has been obtained at different combinations of selected parameters. Similarly, Optimization of selected design parameters has been carried out in order to reduce shape of composite hollow circular beam. Random optimization has been carried out. 1000 feasible sets are obtained and the best set is selected to reduce bending stress.

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 hollow circular beam. Scattered plot is obtained at 4th step of transient analysis. Maximum value of bending stress is 192.007N/mm² and deflection is 29.35mm. 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>
<thead>
<tr>
<th>Hollow circular beam</th>
<th>Displacement (mm)</th>
<th>Literature</th>
<th>Current study</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>30.00</td>
<td>29.35</td>
</tr>
</tbody>
</table>

Input variables were randomly varied with respect to output parameter bending stress. Scatter plots for the bending stress as a function of the most important random input variables are discussed as below. In figure 4, bending stress indicates probable value of bending stress with respect to hollow circular ply angle THETA1 in degree. Scattered plot shows uncertainty in bending stress. Polynomial distribution of C1 powers is indicated by red colored line. As degree of polynomial distribution is small, there is less uncertainty in bending stress. It is observed that bending stress increased when ply angle THEA1 is within the range 8 deg. to 24 deg.

![Figure 4: Scattered plot of Bending Stress Vs THETA1](image)

![Figure 5: Scattered plot of bending stress Vs THETA2](image)
Bending stress was reduced when THEA1 was within the range 72 deg. to 88 deg. It is observed that hollow circular ply angle is less significant cause of uncertainty in bending stress as compared to other design parameters.

In figure 5, bending stress indicates probable value of bending stress with respect to hollow circular ply angle THETA2 in degree. Scattered plot shows uncertainty in bending stress. Polynomial distribution of C1 powers is indicated by red colored line. It is observed that bending stress increased when ply angle THEA2 is within the range -24 deg. to -8 deg. Bending stress was reduced when THEA2 was within the range -88 deg. to -72 deg. It is observed that hollow circular ply angle THETA2 is significant cause of uncertainty in bending stress because linear correlation coefficient between bending stress and beam length is 0.0776 more as compared to other design parameters.

It is obtained after 1000 samples (tests). Output parameter with combination of input parameters is plotted. Higher order Polynomial of 1 degree is used to plot scattering. It is observed that there is more scatter of bending stress from polynomial line within the thickness range 2200 mm to 2400 mm. Bending stress = 10 N/mm² which has rank 1 out of 1000 samples. The confidence bounds are evaluated with a confidence level of 95.00%. Figure 6 shows bending stress N/mm² vs. beam length of hollow circulars section in mm. C0 to C1 indicates degree of polynomial. As degree of polynomial distribution is 1, there is less uncertainty in bending stress.

![Figure 6: Scattered plot of bending stress Vs Beam length of hollow circular section](image)

As compared to ply angles THETA1, uncertainty is less because degree of polynomial is less by one. Linear correlation coefficient between bending stress and beam length is 0.0431. Value of bending stress is obtained at different values of beam length. Particularly, above relationship between beam length and bending stress is obtained at varying loading conditions. At the same time, bending stress is obtained at different combinations of geometrical and material parameters. At the beam length 3000 mm, bending stress is 9.5N/mm². Figure 7 shows bending stress distribution of hollow circular composite beam. Elastic modulus value is randomly varied within range 1×1005 N/mm² to 2×1005 N/mm². Scattered plot is obtained at 4th step of transient analysis. Maximum value of bending stress is 10.20 N/mm². Rank order co-relation coefficient is 0.1379 and linear co-relation coefficient is 0.1250. It is observed that there is more uncertainty because maximum order of polynomial distribution of bending stress is of 1. As compared to beam length and ply angles THETA1, THETA2, random variation in elastic modulus causes more uncertainty in bending stress.
Figure 8 shows bending stress distribution of hollow circular composite beam with respect to beam radius. Beam length value is randomly varied within range 25 mm to 75 mm. scattered plot is obtained at 4th step of transient analysis. Maximum value of bending Stress is 9.75 N/mm².

Rank order co-relation coefficient is 0.347 and linear co-relation coefficient is 0.0282. It is observed that there is more uncertainty as compared to beam length and ply angles THETA1. Because maximum order of polynomial distribution of bending stress is of C1. Nature of trend line shows that bending stress value is decreased before 36 mm beam radius and it was approximately constant when beam length was 40mm to 52mm. Also rank order coefficient value is more as compared to beam length and ply angle THETA1.

After Monte Carlo simulation, results of optimization are discussed as below. Objective function was bending stress and design variables were same as that of Monte Carlo simulation.
Table 3: Design variables for random optimization of hollow circular composite structure

<table>
<thead>
<tr>
<th>Design Parameters</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>2500 N</td>
<td>4500 N</td>
</tr>
<tr>
<td>L</td>
<td>1000 mm</td>
<td>2000 mm</td>
</tr>
<tr>
<td>R</td>
<td>25 mm</td>
<td>75 mm</td>
</tr>
<tr>
<td>THETA1</td>
<td>10 degree</td>
<td>90 degree</td>
</tr>
<tr>
<td>THETA2</td>
<td>-10 degree</td>
<td>-90 degree</td>
</tr>
<tr>
<td>EXX</td>
<td>100e3 N/mm²</td>
<td>200e3 N/mm²</td>
</tr>
</tbody>
</table>

Objective function = BS (Bending stress) N/mm²

1000 feasible sets of optimizations have been obtained and best set is proposed. Following composite figures show feasible values of design variables with respect to objective function.

Figure 9: Feasible values of THETA1 Vs Bending stress

Figure 10: Feasible values of THETA2 Vs Bending stress
Figure 11: Feasible values of Beam Length Vs Bending Stress

Figure 12: Feasible values of Beam Radius Vs Bending stress

Figure 13: Feasible values of Elastic modulus Vs bending stress
Table 4: Best set of random optimization

<table>
<thead>
<tr>
<th>SET 963 (FEASIBLE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Variables</strong></td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>L</td>
</tr>
<tr>
<td>R</td>
</tr>
<tr>
<td>THETA1</td>
</tr>
<tr>
<td>THETA2</td>
</tr>
<tr>
<td>EXX</td>
</tr>
<tr>
<td><strong>BENDING STRESS</strong></td>
</tr>
</tbody>
</table>

Table 4 shows best set among 1000 sets of feasible value of design variable of optimized design variables and reduced value of bending stress.

IV. CONCLUSION

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

- It is found that there is significant uncertainty in bending stress when beam radius, elastic modulus and hollow circular Ply angle THETA1 are randomly varied.
- 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 probable value of bending stress was to 19.79 N/mm². Bending stress value is reduced to 7.61 N/mm² after random optimization.
- Best set of design variables has been proposed when hollow circular beam is under varying loading condition.

REFERENCES


