BENDING STIFFNESS BEHAVIOR OF THICK-WALLED COMPOSITE TUBES

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Keywords: bending stiffness, composite tubes, thermoplastic composites

1 Abstract

Thick-walled tubes have been used in engineering applications for many years. In aerospace industry, one of the applications of thick-walled tubes is landing gear of the helicopter which conventionally is made of aluminum alloy. There is an interest to replace this aluminum thick-walled tube with composite counterpart due to manufacturing cost and weight saving reasons. This motivates us to study the bending stiffness behavior of thick-walled composite tubes. An interesting bending stiffness behavior of thick-walled composite tubes is discovered. The bending stiffness formula, derived in [1] has been rearranged to be used in the analysis, and a novel parametric study is performed to explain this interesting behavior. A thick-walled thermoplastic composite tube is manufactured using automated fiber placement technique (AFP) and a pure bending test is conducted using a pure bending test setup [2] to validate the theory.

2 Bending behavior analysis

An interesting bending stiffness behavior is observed for a thick-walled composite tube made of two layers of equal thickness, and having [θ/θ] laminate configuration, comparing to that of an isotropic counterpart as shown in Fig. 1; When the tube wall thickness (t) increases, fixing the outer diameter value (Do), the bending stiffness decreases after specific value of t/Do. This result counters the usual thought of adding more thickness to have stiffer structure, encouraging us for more investigation.

The formula of bending stiffness calculation is based on the three-dimensional elasticity theory, presented in [1]. This formula is rearranged to have the following form

\[
\langle EI \rangle = \sum_{n=1}^{2} (\text{Coef}_n E_{x,n}) I_n = \sum_{n=1}^{2} E_{\text{eff},n} I_n
\]

I_n is the area moment of inertia of layer (n), E_x,n is the layer extensional modulus in tube axial direction, and Coef_n is a dimensionless parameter function of the geometric parameters, material properties, and the orientation angle of the composite layer with the layers interaction parameters. The multiplication of Coef_n with E_x,n forms a new term E_{\text{eff},n} denoted as the effective extensional stiffness of the composite layer (n). This term represents the contribution of the extensional stiffness of the composite layer in the bending stiffness of the composite tube.

A parametric study is carried out for both isotropic and composite tubes. It is observed that the same interesting bending behavior is obtained for isotropic tubes made of two different isotropic layers having the same thickness; where the inner layer of the tube is the stiffer one, Fig. 2. R_E is the ratio of modulus of elasticity of the outer layer to that of the tube inner layer (E_2/E_1). For composite tubes of equal layer thickness and [θ/θ] configuration, it is shown that E_{\text{eff}} of the inner layer is greater than that of the outer one, the same situation when R_E is less than unity in Fig. 2.

3 Specimen manufacturing

Carbon-PEEK is used to make the test specimen. This material is supplied from TenCate Advanced Composites, Cetex TC1200 PEEK AS-4. The specimen is manufactured using AFP technique at CONCOM. Fig.3 shows specimen manufacturing using a robotic AFP machine supplied from ADC Company. The thermoplastic head of the machine uses one tow at the time and is equipped with nitrogen Hot Gas Torch as the heating system. A steel mandrel is used for the manufacturing process.
4 Experimental results and comparison with theory

A recently developed pure bending test setup [2], at CONCOM, is used to apply the bending loading for the thick-walled composite tube using an enhanced mechanism compared to the conventional 3 or 4 point bending test, and more accurate results are achieved. Adaptor rings are designed to permit testing of the thick-walled composite tube on this bending test setup.

The pure bending test is carried out and the experimentally-obtained value of the bending stiffness agrees well with the theoretical value.

Fig. 1 Bending stiffness behavior of composite tube versus aluminum counterpart

Fig. 2 Bending stiffness behavior of isotropic tubes made of two layers of different isotropic materials

References
