Variable Stiffness BEHAVIOR INVESTIGATION OF FILAMENT WOUND TUBES

Yijin Chen[* a)], Jian Sun[*], Yanju Liu[**] & Jinsong Leng[*]
[*] *Center for Composite Materials, Harbin Institute of Technology,*
P.O. Box 3011, No.2 Yikuang Street, Harbin, People's Republic of China 150080
[**] *Department of Astronautical Science and Mechanics, Harbin Institute of Technology,*
P.O. Box 301, No. 92 West Dazhi Street, Harbin, People's Republic of China 150001

Summary In this research, two kinds of fiber reinforced composite tubes with remarkable variable stiffness properties are investigated. The first kind of variable stiffness tube is composed of flexible matrix composite (FMC) and inner liner, namely fluidic flexible matrix composite (F^2MC) tube. Significant changes in effective axial elastic modulus could be achieved through controlling the interior fluid. Base on the application of shape memory polymer (SMP), the second kind of variable stiffness tube is composed of multi-layered filament wound structures, namely shape memory polymer composite (SMPC) tube. Significant changes in effective engineering modulus can be achieved through regulating the environment temperature. Based on classical laminated-plate theory, two kinds of theory methods for both variable stiffness tubes are proposed. Moreover, the accuracy of the theory methods is demonstrated by the tensile test results. Finally, the effective axial elastic modulus and modulus ratio (variable stiffness ratio) are discussed under different fiber winding angles and fiber volume fractions for both kinds of tubes. The investigated results provide meaningful guidance to assist design and fabricate variable stiffness tubes in morphing skin applications.

INTRODUCTION

Traditionally, aircrafts are designed according to their special task, and usually optimized in the most concerned flight performance [1, 2]. However, in an integrated flight cycle with continuously varied flight parameters, the geometry of wings is not always optimal. Morphing aircrafts can solve this problem through changing their wing shapes to adapt the outside flight environment [3, 4]. Morphing skin is one of the key techniques to realizing morphing aircraft [5]. Recently, a new kind of variable stiffness skin was proposed to solve these problems [6, 7]. The skin is integrated by flexible matrix and variable stiffness tube. While the variable stiffness skin exhibits high out-of-plane stiffness, it can undergo large strain and has low in-plane stiffness. One of the key components is the variable stiffness tube.

Fluidic Flexible Matrix Composite (F^2mc) Tube

The F^2MC tube is manufactured by filament-wound FMC laminate for the outer tube and rubber material for the inner liner, as shown in Figure 1. The F^2MC tube was firstly proposed by Shan et al. [7], which would experience large axial stiffness increase when close the valves. In this study, by applying classical laminated-plate theory and three-dimensional anisotropic elasticity [8], a 3D analytical method is proposed to characterize the axial stiffness behavior of a single F^2MC tube. In comparison with the experiment result, the analysis is deemed to possess satisfying accuracy in the effective axial elastic modulus prediction of the F^2MC tube [9]. In addition, the effective axial elastic modulus and modulus ratio are discussed under different fiber winding angles and fiber volume fractions of the tube, as shown in Figure 2 and Figure 3. The analysis result shows that the modulus ratio can be regulated. The analysis results could provide references for design and fabrication of F^2MC tube.

Fig. 1 Filament wound of F^2MC tube

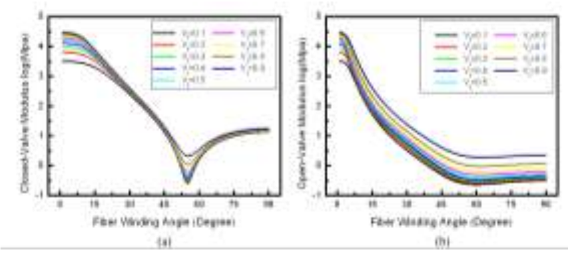

Fig. 2 Curves of modulus versus fiber angle of F^2MC tube with different fiber volume fractions: (a) closed-valve modulus; (b) open-valve modulus [6]

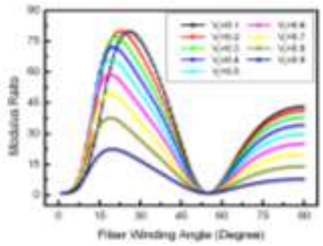

Fig. 3 Curves of effective axial ratio versus fiber angle of F^2MC tube with different fiber volume fractions [6]

Shape Memory Polymer Composite (Smpc) Tube

[a)] Corresponding author. Email: chenyijin025@126.com

As a typical smart material, shape memory polymers (SMPs) have the capability of variable stiffness to external stimuli, such as hear, electricity, magnetic and solvent, et al. In this research, a shape memory polymer composite (SMPC) tube composed of multi-layered filament wound structures is investigated as shown in Figure 4. The SMPC tube possesses the flexibility under high temperature condition and the rigidity under low temperature condition. Significant changes in effective engineering modulus can be achieved through controlling the environment temperature. A three-dimensional theory method based on classical laminated-plate theory and Sun's [10] thick laminate analysis is used to predict the theoretical effective axial engineering moduli of the SMPC tube in both cold and heated states. In order to verify the accuracy of the theory method, a tensile test is conducted on the SMPC tube. In comparison with tensile test results, the theory method is verified to possess satisfying accuracy in the effective axial engineering modulus prediction of the SMPC tube, as shown in Table 1. In addition, the effective axial engineering modulus and its modulus ratios are analyzed and discussed in different fiber winding angles and fiber volume fractions, as shown in Figure 5. The analysis results show that the modulus ratio can be regulated through changing the fiber-winding angle and fiber volume fraction.

Fig. 4 SMPC tube specimens

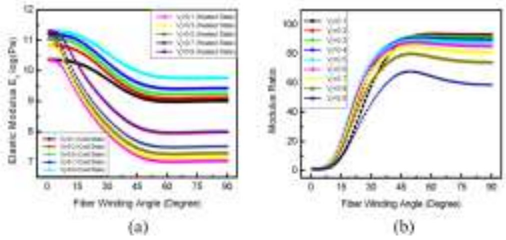

Fig. 5 Curves of elastic modulus versus fiber winding angle of SMPC tube with different fiber volume fractions: (a) cold state and heated state moduli; (b) modulus ratio

Table 1 Comparison of experiment and predicted results

	Axial elastic modulus (cold state)/ MPa	Axial elastic modulus (heated state)/ MPa	Modulus ratio
Experiment results	2692.5	34.1	79.0
Predicted results	3065.4	36.2	84.7

CONCLUSIONS

To conclude, two kinds of filament wound tubes with variable stiffness are fabricated and analyzed. Significant changes of effective axial elastic modulus can be achieved. Two kinds of theory method are proposed based on classical laminated-plate theory to describe the effective axial elastic modulus. In comparison with the tensile test results, both theory methods are deemed to possess satisfying accuracy in the effective axial elastic modulus prediction. In addition, the variable stiffness ratios are discussed under different fiber winding angles and fiber volume fractions for both kinds of tubes. The analysis results show that the variable stiffness ratios can be regulated, which also show great potential in morphing aircraft applications.

References

[1] Yin W, Sun Q, Zhang B, Liu J and Leng J.: Seamless Morphing Wing with SMP Skin. Advanced Materials Research, 47-50: 97-100, 2008.

[2] Chen Y, Yin W, Liu Y and Leng J.: Structural Design and Analysis of Morphing Skin Embedded with Pneumatic Muscle Fibers. Smart Mater. Struct., 20(8): 085033, 2011.

[3] Bubert E.A., Woods B.K.S., Lee K., Kothera C.S. and Wereley N.M.: Design and Fabrication of a Passive 1D Morphing Aircraft Skin. J. Intel. Mat. Syst. Str., 21(17):1699-1717, 2010.

[4] Thill C., Etches J., Bond I., Potter K. and Weaver P.: Morphing Skins. AERONAUT J., 112(1129):117-139, 2008.

[5] Bartley-Cho J, Wang D, Martin C, Kudva J and West M.: Development of High-rate, Adaptive Trailing Edge Control Surface for the Smart Wing Phase 2 Wind Tunnel Model. J. Intel. Mat. Syst. Str., 15(4): 279-291, 2004.

[6] Philen M., Shan Y., Bakis C.E., Wang K.W. and Rahn C.D.: Variable Stiffness Adaptive Structures Utilizing Hydraulically Pressurized Flexible Matrix Composites with Valve Control. In: Proc. 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference, Newport, Rhode Island, 2006.

[7] Shan Y., Lotfi A., Philen M., Li S.Y., Bakis C.E., Rahn C.D. and Wang K.W.: Fluidic Flexible Matrix Composites for Autonomous Structural Tailoring. In: Proc. of SPIE, the International Society for Optical Engineering, 6525:1-14, 2007.

[8] Xia M., Takayanagi H. and Kemmochi K..: Analysis of Multi-layered Filament-wound Composite Pipes under Internal Pressure. COMPOS STRUCT, 53:483-491, 2001.

[9] Chen Y, Sun J, Liu Y and Leng J.: Experiment and Analysis of Fluidic Flexible Matrix Composite (F2MC) Tube. J. Intel. Mat. Syst. Str., Sep 11, 2011, in press

[10] Sun C. and Li S.: Three Dimensional Effective Elastic Constants for Thick Laminates. J COMPOS MATER, 22(7): 629-639, 1988.