ANALYSIS OF VISCOELASTICITY OF 3-D BRAIDED COMPOSITE MATERIALS*

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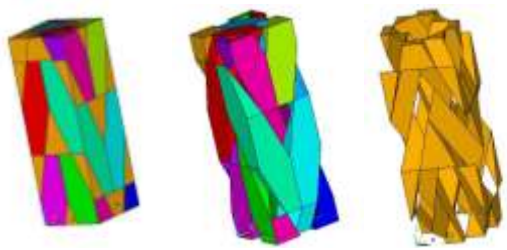
1 General Introduction

Three-dimensionally braided composite materials are widely used in many industry areas, such as airplanes, space structures, ships, and building structures. Currently the research on the mechanical properties of 3-D braided composites is focused on their stiffness and strength behaviors [1-2]. Since time and temperature always play important roles in the working condition for 3-D braided composites, viscoelasticity is one of the most important mechanical properties. However, there is little research in this subject, especially theoretical analysis of 3-D braided composites. In this paper, viscoelasticity of 3-D braided composites is studied.

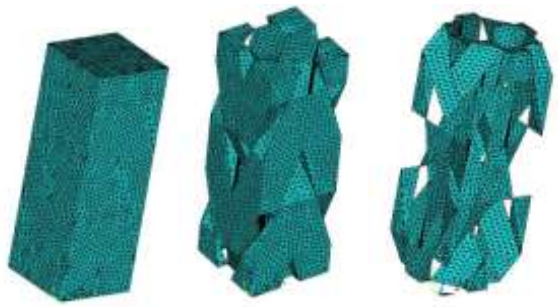
2 Mesomechanical Model

A mesoscopic geometrical periodic unit cell of 3-D braided composites is analyzed in details using a 45° unit cell division method (Fig.1). The structural



(a) Integrated model (b) fiber bundle model (c) matrix model
Fig.1 Three-dimensional model of a unit cell

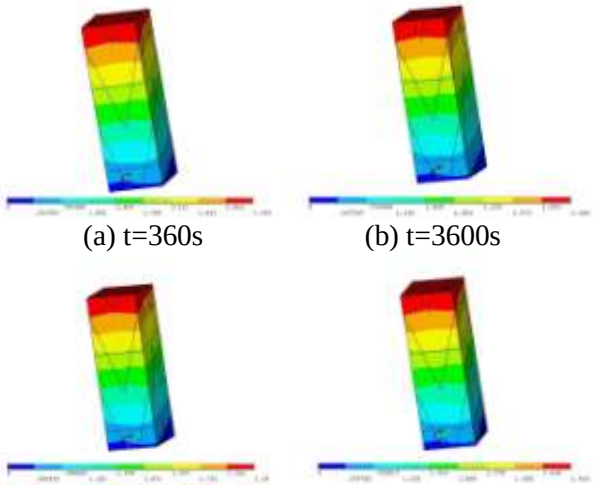
parameters are determined from braiding processes. In the model, the cross-section shape of yarns and the contact between them are considered, and the geometrical structure of unit cells is established. The finite element method is employed to analyze the mechanical behaviors of 3-D braided composites. A tetrahedron element is used to discretize the three-dimensional model of a unit cell for the composites (Fig.2). The periodic boundary conditions for displacements are applied to the unit cell.



(a) Integrated model (b) fiber bundle model (c) matrix model
Fig.2 Finite element model of a unit cell

3 Constitutive Equations

By using the finite element model mentioned above, a step stress 200 MPa is applied on the unit cell along the braiding direction. The displacements of all nodes in the unit cell along the braiding direction are obtained (Fig.3), and the average strain along the



(a) t=360s (b) t=3600s
(c) t=18000s (d) t=36000s

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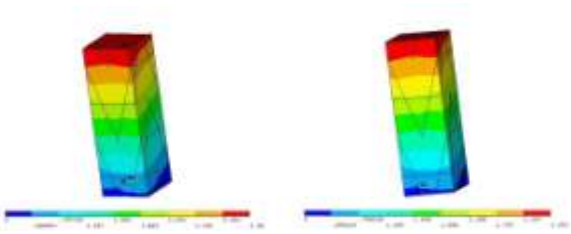

(e) t=360000s (f) t=540000s

Fig.3 Variation of displacement field with time (braiding angle θ =35°, fiber volume fraction V_f =40% and step stress σ_0 =200Mpa)

braiding direction is calculated. The creep compliance for the periodic unit cell along the braiding direction is got according the following formula

$$J(t) = \varepsilon(t) / \sigma_0 \tag{1}$$

An exponential function is used to fit a series of discrete creep compliances, and the expression for the creep compliances along the braiding direction is

$$J(t) = 0.137 - 0.0649e^{-\frac{t}{147.94}} \tag{2}$$

where the unit for $J(t)$ is Gpa^{-1}, the unit for t is hour. Along the braiding direction, the initial compliance J_0 is 0.0721Gpa^{-1}, the final compliance J_∞ is 0.137Gpa^{-1}, and the retardation time τ is 147.94h.

The constitutive equation for viscoelastic behaviors for the braided composites along the braiding direction is

$$\varepsilon(t) = 0.0721\sigma(t) + 4.39\times10^{-4}\int_0^t \sigma(\tau)\exp(-\frac{t-\tau}{147.94})d\tau \tag{3}$$

Through Laplacian transformation from the creep compliance the relaxation modulus for the composites is obtained as follows

$$Y(t) = 7.30 + 6.57e^{-\frac{t}{74.70}} \tag{4}$$

It is shown that the initial modulus Y_0 is 13.87GPa, the final modulus Y_∞ is 7.30GPa, and the relaxation time τ' is 74.70h.

4 Numerical results

Three-dimensionally braided composite materials with fiber volume fraction 40% and braiding angles 30°, 35°, 40°, 45°, 50°, 55° and 60° are modeled using the finite element method for their viscoelastic properties. The viscoelastic parameters are listed in the table 1. The variation of creep compliances and

Table 1. Fitting parameters for viscoelastic properties

θ (°)	$J_0(Gpa^{-1})$	$J_\infty(Gpa^{-1})$	$\tau(h)$	$Y_0(Gpa)$	$Y_\infty(Gpa)$	$\tau'(h)$
30	0.0681	0.1261	147.69	14.68	7.9302	79.76
35	0.0721	0.1370	147.94	13.87	7.2993	77.86
40	0.0759	0.1473	148.15	13.18	6.7889	76.34
45	0.0797	0.1581	148.36	12.55	6.3251	74.79
50	0.0833	0.1681	148.54	12.00	5.9488	73.61
55	0.0868	0.1782	148.71	11.52	5.6117	72.43
60	0.0901	0.1875	148.88	11.10	5.3333	71.54

relaxation moduli with time is shown in the figures 4 and 5, respectively. With the increase of braiding

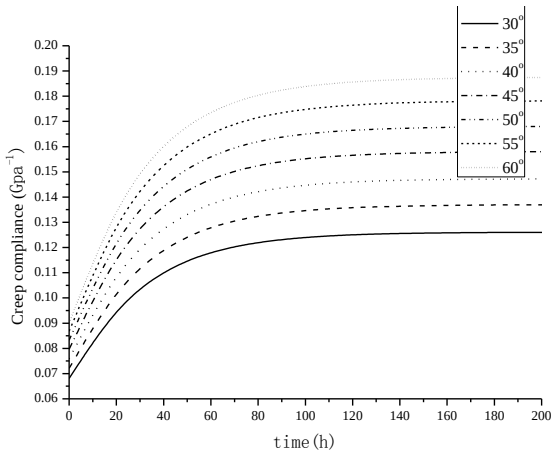

Fig.4 Creep compliances at different braiding angles

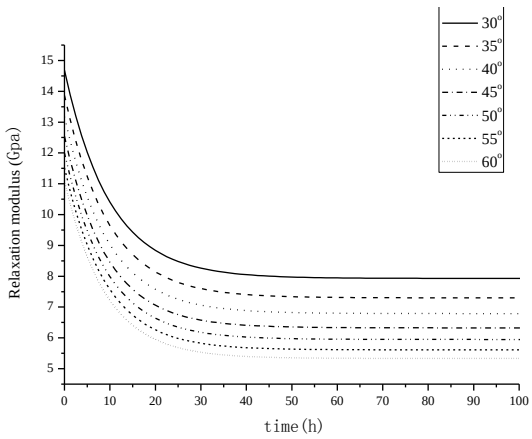

Fig.5 Relaxation moduli at different braiding angles

angles of 3-dimensionally braided composites, the viscoelastic effects decrease and the anti-viscoelastic properties increase along the braiding direction. Thus a braided composite of small braiding angles should be adopted to avoid creep failure in engineering application. In the figures 6 through 11,

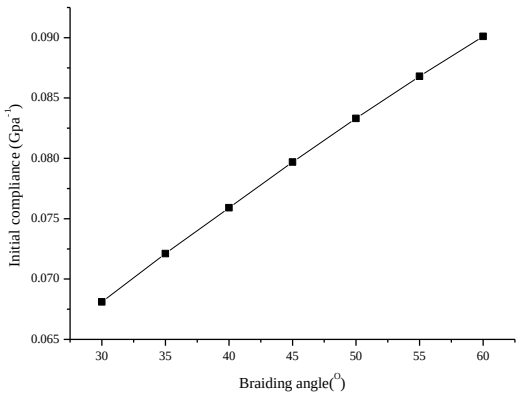

Fig. 6 Initial compliances versus braiding angles

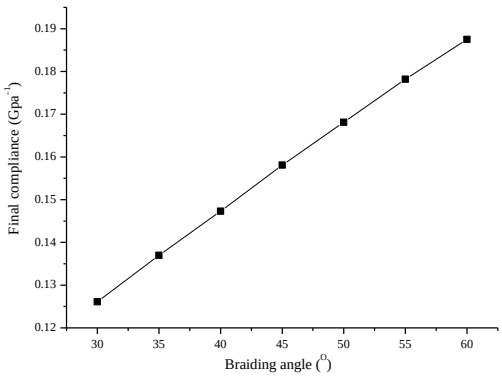

Fig. 7 Final compliances versus braiding angles

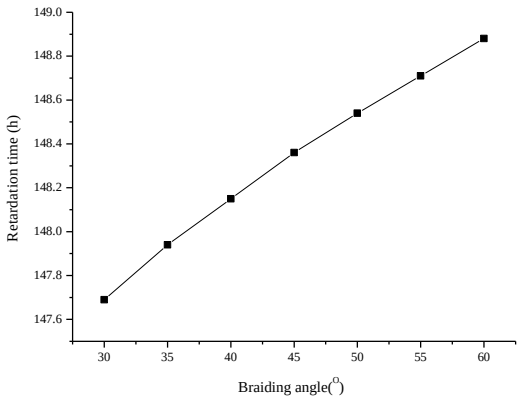

Fig. 8 Retardation time versus braiding angles

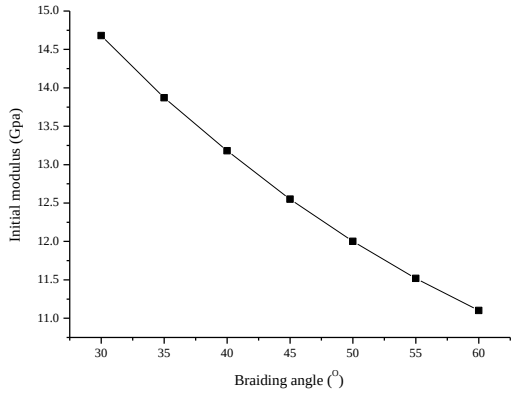

Fig. 9 Initial moduli versus braiding angles

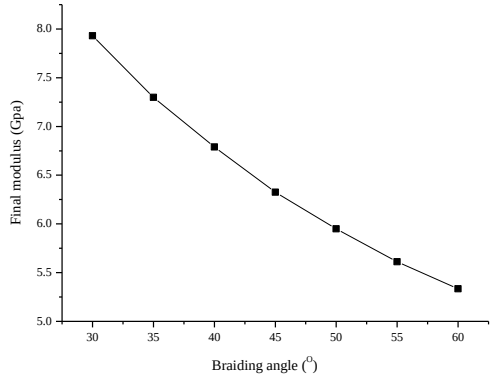

Fig. 10 Final moduli versus braiding angles

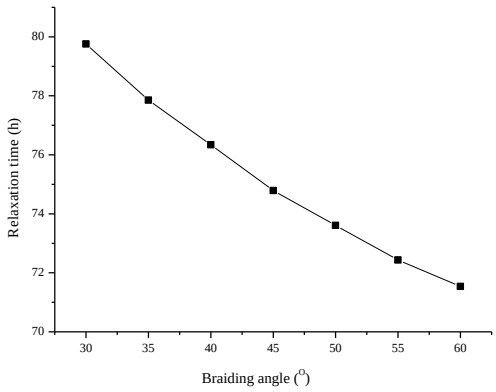

Fig. 11 Relaxation time versus braiding angles

it is shown that with the increase of braiding angles, the initial compliances, final compliances and retardation time increase, while the initial moduli, final moduli and relaxation time decrease with the increase of braiding angles. These viscoelastic

parameters are approximately linear with the braiding angle.

Three-dimensionally braided composites with the braiding angle 40° and fiber volume fractions 25%, 30%, 35%, 40%, 45%, 50% and 55% are also modeled using the finite element method for their viscoelastic properties. The viscoelastic parameters are listed in the table 2. The variation of creep

Table 2. Fitting parameters for viscoelastic properties

V_f (%)	$J_0(Gpa^{-1})$	$J_\infty(Gpa^{-1})$	$\tau(h)$	$Y_0(Gpa)$	$Y_\infty(Gpa)$	$\tau'(h)$
25	0.0819	0.1771	148.66	12.2110	5.6497	68.79
30	0.0788	0.1632	148.45	12.6902	6.1350	71.77
35	0.0755	0.1490	148.19	13.2503	6.7114	75.09
40	0.0721	0.1372	147.94	13.8699	7.2993	77.86
45	0.0688	0.1260	147.71	14.5302	7.9365	80.65
50	0.0655	0.1159	147.52	15.2698	8.6207	83.30
55	0.0625	0.1071	147.32	16.0000	9.3458	86.05

compliances and relaxation moduli with time is shown in the figures 12 and 13, respectively. It is shown that with the increase of the fiber volume fractions of 3-dimensionally braided composites, the viscoelastic effects increase and the anti-viscoelastic properties decrease along the braiding direction.

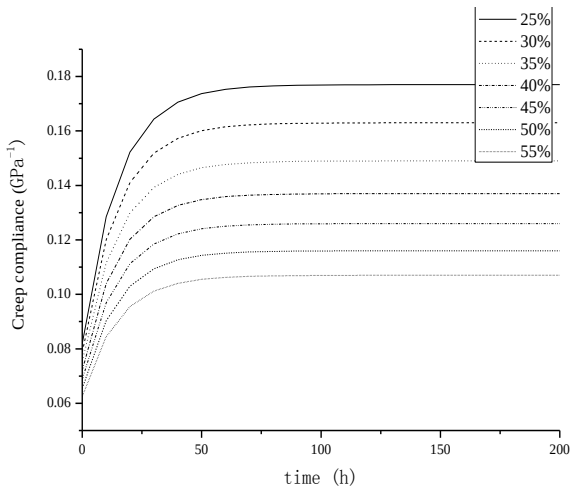

Fig.12 Creep compliances at different fiber fractions

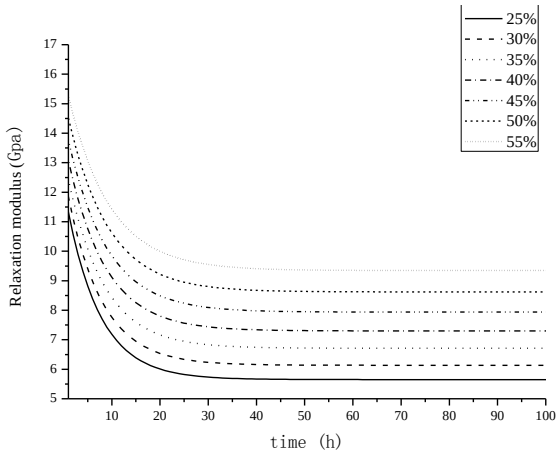

Fig.13 Relaxation moduli at different fiber fractions

5 Conclusions

The effects of braiding angles and fiber volume fractions on the viscoelastic properties are analyzed through the numerical simulation for 3-D braided composites. A 3-D braided composite with a smaller braiding angle and a higher fiber volume fraction has better creep-resistance ability.

6 References

[1] J.-M. Yang, C.-L. Ma and T.-W. Chou "Fiber inclination model of three-dimensional textile structural composite". *Journal of Composite Materials*, 1986, 20(5):472～484.

[2] J.-H. Byun, T.-W. Chou, "Process-microstructure relationships of 2-step and 4-step braided composites". *Composites Science and Technology* 1996, 56:235～251.

[3] L. Chen, X.M. Tao, C.L. Choy "On the microstructure of three-dimensional braided perform". *Composites Science and Technology*, 1999(59):391～404.

[4] Z. Hashin "Viscoelastic behavior of hetemgeneous media". *Journal of Applied Mechanics*, 1965, 29:630～636.

[5] R. Luciano, E. Barber "Analytical expression for the relaxation modulo of the linear viscoelastic composites with periodic microstructure". *Journal of Applied Mechanics*, 1995, 62:786～793.

[6] C. C. Chamis "Mechanics materials: past, preset and future". *Journal of Composites Technology and Research*, 1989, 11(1):3～14.