ON VISCOELASTIC PROPERTIES OF 3-D BRAIDED COMPOSITES[a)]

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Summary Based on the three-cell division scheme, a two-scale model for braided composites was proposed. The viscoelastic properties of yarns were obtained by the finite element method and Prony series fitting. The viscoelastic constitutive relationship of interior cells was derived based on the viscoelastic properties of yarns and the viscoelastic parameters of resin matrix. The influence of braiding angles and fiber volume fractions on viscoelastic properties of 3-D braided composites was investigated.

INTRODUCTION

Three-dimensionally braided composite materials are widely used in many industries, 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.

MULTI-SCALE MODEL AND PERIODIC BOUNDARY

The complex spatial topological structure of three-dimensionally braided composites consists of three kinds of cells, *i.e*. interior cells, surface cells and corner cells [3] (Fig.1). The viscoelastic properties of three-dimensionally braided

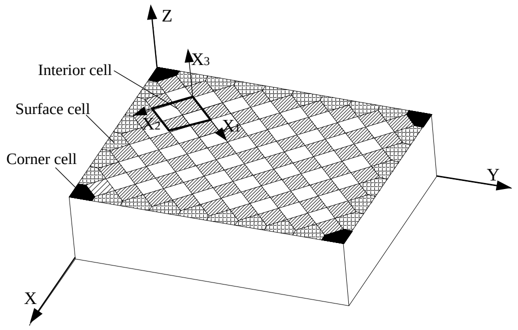

Fig.1. Three-cell structure division of 3-D braided composites

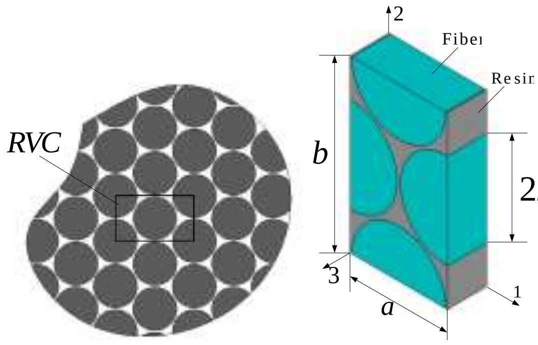

Fig.2. Micro-structure of yarns

composites are determined mainly by the interior cell which takes a main proportion. Therefore, only the interior cell is considered in this study. In micro-scale, assuming that the fibers are uniformly distributed, the yarns can be regarded as unidirectional fiber composites (Fig.2). A periodic part of the yarn, called representative volume cell (RVC), is analyzed. From structural analysis of three-dimensionally braided composites and yarns, it is obvious that the interior cell of three-dimensionally braided composites and the RVC of yarns are periodically arranged. The deformation on the interfaces between unit cells should be continuous, in other words, intrusion and separation are not allowed. So a periodic boundary condition is applied for the displacement on the interfaces.

VISCOELASTIC PROPERTIES OF YARNS AND INTERIOR CELLS

3-D viscoelastic constitutive equation at constant temperature is expressed in the form of hereditary integral as

$$\varepsilon_i(t)=\int_0^t D_{ij}(t-\tau)\frac{d\sigma_j(\tau)}{d\tau}d\tau \qquad i, j=1, 2, \ldots, 6 \tag{1}$$

where D_{ij} is creep compliance. Because the interior cell of 3-D braided composites and the RVC of yarns are symmetric structures, their viscoelastic properties are orthotropic.

For the resin matrix of 3-D braided composites, three-parameter solid model is used to describe its viscoelastic behaviours. In the model, the volume deformation is linear elastic, while the shear deformation is linear viscoelastic.

For the viscoelastic properties of yarns (Fig.3), the finite element method is employed to obtain the creep compliance

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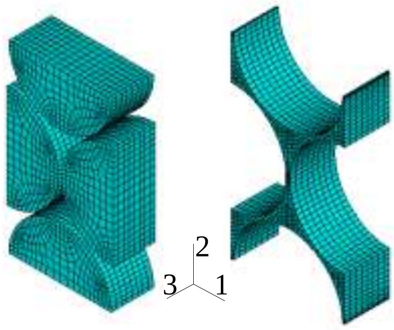
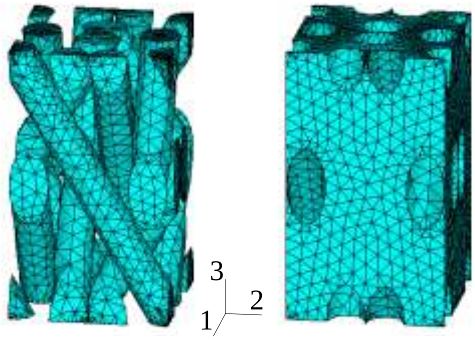


(a) Fibers (b) Resin matrix
Fig.3. Finite element model of the RVC

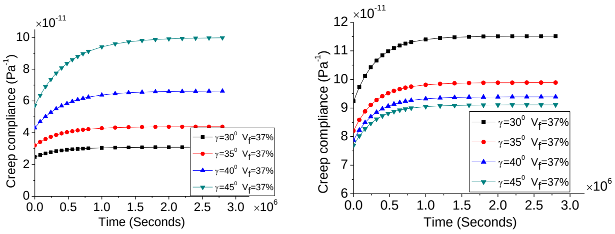


(a) Yarns (b) Resin matrix
Fig.4. Finite element model of the interior cell

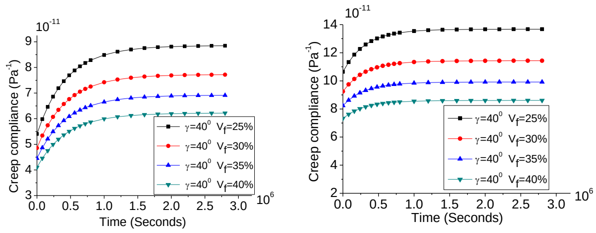
Matrix. Since the viscoelastic properties are described as functions of time, Prony series is applied to fit the functions of time from the discrete data.
For the viscoelastic properties of interior cells (Fig.4), the finite element method is used again to obtain the creep compliance, and Prony series is applied to fit the functions of time from the discrete data.

EFFECTS OF BRAIDING ANGLES AND FIBER VOLUME FRACTIONS ON VISCOELASTICITY

The interior cell of 4-step 3-D braided composites with 1×1 pattern can be characterized by two independent parameters, braiding angles and fiber volume fractions. The effects of braiding angles and fiber volume fractions on the viscoelastic properties are studied (Fig.5~6). It is shown that the creep compliances in the braiding direction increase with the



(a) direction-3 tension (D_{33}) (b) plane-13 shear (D_{55})
Fig.5. Creep compliance with different braiding angles



(a) direction-3 tension (D_{33}) (b) plane-13 shear (D_{55})
Fig.6. Creep compliance with different fiber volume fractions

increase of braiding angles, while the shear creep compliances in plane-13 decrease with the increase of braiding angles. The creep compliances in the braiding direction decrease with the increase of fiber volume fractions and the shear creep compliances in plane-13 also decrease with the increase of fiber volume fractions.

CONCLUSIONS

In the paper three-dimensional viscoelastic properties of braided composites were analyzed. Based on three-cell division method, a multi-scale model in which the unit cell is composed of yarns and resin matrix, and the yarn is composed of fibers and resin matrix, was proposed. A periodic boundary condition was applied to the unit cell and the yarn.
In the yarn scale, given the viscoelastic parameters of the resin matrix and the elastic constants of the fiber, the viscoelastic properties of yarns were obtained by the finite element method and Prony series fitting. In the interior cell scale, given the viscoelastic parameters of the resin matrix and the viscoelastic properties of the yarn, the viscoelastic properties of interior cell were obtained by again the finite element method and Prony series fitting.
Furthermore, the effects of braiding angles and fiber volume fractions on the viscoelastic behaviors of 4-step braided composites with 1×1 pattern were investigated. With the increase of braiding angles, the viscoelastic deformation in the braiding direction increases, while the viscoelastic shear deformation decreases. The viscoelastic deformation in the braiding direction and the viscoelastic shear deformation both decrease with the increase of fiber volume fractions.

References

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