Mechanical Properties of Ramie Fiber Woven Composites under Biaxial Tensile Loadings

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Abstract

The objective of this work was to use a novel 3-D test analysis system for evaluating the mechanical properties of the natural fiber fabric composites under biaxial loads. Composites with three resin matrices (water-based epoxy resin, isocyanate resin, phenolic resin) were investigated, and strain-filed were characterized by using the digital speckle correlation (DSCM). The water-based epoxy resin plate and isocyanate resin plate demonstrated a characteristic of orthotropy and elastoplasticity, while the phenolic resin board revealed linear elastic and brittle-fracture simultaneously at X,Y-axial. Dissimilarities of biaxial load value were related to the orthotropy of composite structure, and load changes in fracture direction had a negative effect on the other directions at breaking moment. The degrees of dropping presented a positive correlation with the load values at rift direction. Under the linear elastic stage, the value of load and average strain at Y-direction were larger than that under X-direction within the same testing area. The strain-filed at X/Y-direction provided by isocyanate and phenolic resin plates illustrated a more smooth change than that of the water-based epoxy resin plate.

Keywords: Ramie, Natural Fiber Fabric Composite, Biaxial tension, Digital Spackle Correlation Method, Strain Filed

Introduction

Natural fibers, offered a renewable resource and a lower cost feedstock, have been extensively used for composite manufacturing. In addition, the fibers' high specific strength and stiffness, damage tolerance, and eco-friendly characteristics make them desirable for utilization (Xu *et al* 2008). These composite products suffer from uniaxial stress in practical engineering applications, but they also develop biaxial or even multi-axial stress states, in many situations, such as wind or seismic effects (Hu *et al* 2004, Luo *et al* 2008). This brings about considerable difficulty to evaluate its mechanical properties objectively. Investigating and simulating the non-liner response characteristics of stress-strain due to the complex stress state and material anisotropy have became a key part for structural design successfully or not. Experimental techniques and different kinds of material cruciform-specimens have been used to produce biaxial stress states, such as soft textile composites, notched composite and sheet molding laminates as well as fiber reinforced laminates (Arnold *et al* 1995, Smits *et al* 2006, Virginio *et al* 2008).

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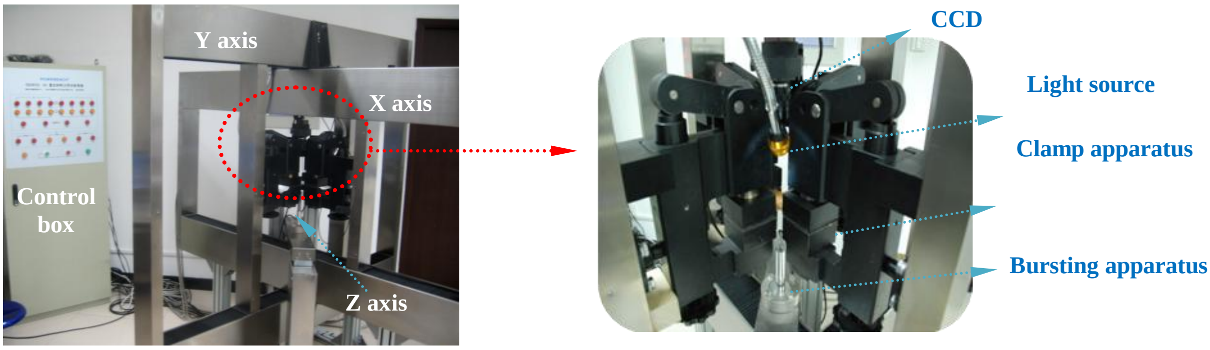


Fig. 1 3-D loading test device for composite material analysis system

In order to successfully model and simulate the behavior of materials for optimal use in structural applications, a novel testing device, the 3-D Composite Material Analysis System (Fig. 1) was developed at the International Center for Bamboo and Rattan (ICBR) in Beijing, China. The overall objective of this research was to investigate the mechanical properties of natural fiber woven composites based on three thermosetting resins under biaxial tensile loading. Meanwhile, the strain-fields were characterized by digital speckle correlation method (DSCM) during the stretching process(Chen *et al* 2009,Wang *et al* 2010).

Sample preparation

Balanced plain woven ramie fabrics were supplied by the company Hua Sheng. The basic parameters were: surface density- 244.8 g/m2, yarn linear density- 74.1 tex, thickness- 0.4 mm, warp density 184 roots/10 cm, and weft density- 137 roots/10 cm. Resin types: water-based epoxy resin (epoxide equivalent: 1,200-1,850g/eq), phenolic resin(Solids content: 47%) and isocyanate resin (supplied by Huntsman Corporation). Firstly, ramie woven is soaked in water-based epoxy resin, phenolic resin and isocyanate resin respectively. Then, putting them in an oven (65°,3-hours) can reserve for compressing composites. Molding technological conditions: hot-pressing pressure, time and temperature are 2MPa,5min and 120° ,and paving way：$[(0/90)]_5$。

Equipment

The 3-D Composite Material Analysis System (Fig.1) can evaluate materials not only for tension or compression in the X and Y axial directions, but also bursting at the Z axis simultaneously.There are two sensors for measuring the forces in x, y direction and each direction has two clamps. Sensor accuracy is 1.0 N， maximum load value is 5.0 kN， and drawing speed is 0.013-1.066 mm/s. The system is equipped with Digital Speckle Correlation Method Analysis System software**(DSCM)**.

Biaxial Testing and Digital Speckle Correlation Methods

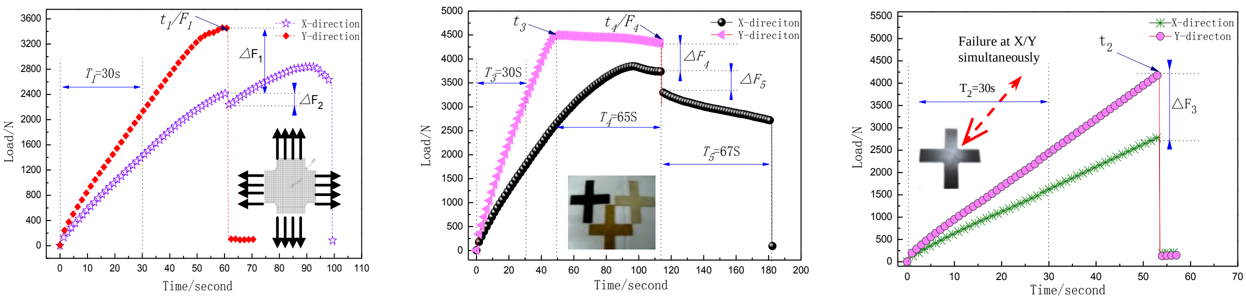
Fillet cruciform specimens were cut to shape with a laser to a total length of 300.0 mm with each arm measuring 50.0 mm wide. In order to form a uniform and randomly distributed speckle image, the surface of each cruciform specimen was sprayed with a layer of black glass bead paint layer for image enhancement. Biaxial tensile tests were conducted at stretching rates of 0.033 mm/s in each direction. The biaxial tensile test was conducted with the modulated speckle image captured by a high speed charge-coupled device (CCD) camera for description of the microscopic changes occurring on the surface. The pictures were saved in a file for analysis of the strain field. The observed speckle pattern included information on the object's surface height with the different degrees of gray reflecting the different stress-strain states of the specimens. The data were smoothed 3 pixels in both the X and Y directions. Ten samples were tested. The size of measured surface area of fabric was: 60 x 60 pixle, and the accuracy of measurement is about 0.01pixel theoretically.

Results and Discussion

Biaxial tension experiment.

Fig.2 illustrates: (1)mechanical properties at X-direction are different from Y-direction for all three types composites， namely X-direction fracture load value are smaller at than Y. This dissimilarity are linked with fiber volume fraction in X/Y-direction. Under the paving way of $[(0/90)]_5$, there are two warp-layers and three weft-layers in X-direction, while Y-direction has three warp-layers and two weft-layers. Warp yarns are fabricated to a higher density than those for weft（Y-direction）as yarns in the warp direction（X-direction）, resulting fiber volume fraction in X are less than Y-direction.

(2)Composites demonstrated variable characteristics of stress-strain behavior under biaxial tensile loads. Orthotropy and elastoplasticity were showed by water-based epoxy resin plate and isocyanate resin plate (Fig.2a,b), while phenolic resin board revealed a high-quality linear elastic in Load-Time curve and simultaneous brittle-fracture properties in X,Y-direction(Fig.2c) .



(a) (b) (c)

Fig.2 Time-load curves under biaxial loads for composites:（a）water-based epoxy resin plate; （b）isocyanate resin plate;（c）phenolic resin plate.

(3) Water-based epoxy resin composites'Y-directional failure occurred firstly at the moment of t_1, load difference value between X and Y-direction was $\triangle F_1$=875.92N. As Y-direction load became disappearance suddenly, stress state transformed from biaxial loadings (both X and Y tensile) into a

unaixal (only X-axial tension). The instant change of suffering loading way has a decreasing effect on the value of load in X-direction, and the X-load dropping value was $\triangle F_2$=210.12N(Fig.2a) .

Ahead of t_3, isocyanate resin plate showed a generally linear variation curve of load-time under biaxial tension. However, plastic deformation began at t_3 and formed necking down gradually after the moment of t_3,the lasting time was T_4=65S,the loading value reduced to F_4= 4322 N, $F_4 > F_1$. At the moment of t_4, Y-direction failure happened and load difference value between X and Y-direction was $\triangle F_4$=588.59 N,with $\triangle F_1 > \triangle F_4$; the X-load dropping value was $\triangle F_5$=309.48 N (Fig.2b) .
These analysis above indicates that the load instant variation at breaking-direction has a negative effect on the other directions' load values, and the dropping degrees were linked with breaking load as well as load difference value between X and Y-direction.

Strain-filed by DSCM.

We can see in Fig .2 the curves of time-load represent a high quality linear during 0-30seconds in biaxial tensile process, so their linear variation stage are correctly selected for investigating information of strain-filed(Fig. 3) by using DSCM.

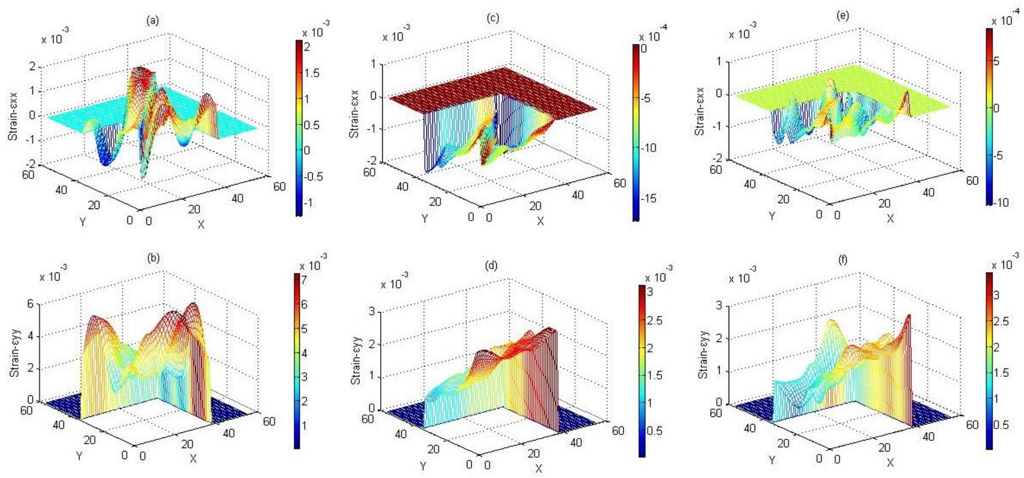


Fig. 3 Strain-fields for composites during 0-30seconds under biaxial tensile loads: a),b) for X ,Y- direction of water-based epoxy resin plate; c),d) for X ,Y- direction of isocyanate resin plate; e),f) for X and Y- direction of phenolic resin plate.

Values of field-strains revealed for Figure 3 shows: ε yy> ε xx ,and X,Y-directions' strain mean value of water-based epoxy resin plate, phenolic resin and isocyanate resin plate are respectively e_{xx}=0.67， -0.86， -0.15, and e_{yy}=4.42， 2.08， 1.82(unit-10-3) during T1,T2,T3.The loads for 0-30seconds are within the limit in the elastic proportion and the value of loads in Y-direction are larger than X-direction, therefore the strain in Y-direction are larger than X-direction for elastic modulus unchanged and the same testing cross sectional area.

Fig. 3a and 3b show that the values of water-based epoxy resin plate' strain has a larger fluctuating range with a distribution range of -1.38 to -2.03 in X-direction and 0 to 7.13 in Y-direction, while strain-filed for phenolic resin plate and isocyanate resin plate are comparatively gently, with a distribution range of -1.81～0.01 and 0～3.21 in X-direction, and -1.01～0.92,0～3.52 in Y-direction respectively,Figures 3c,d,e,f. Analysis of the strain-field accounted for characteristics of orthogonal anisotropy of water-based epoxy resin plate.

Results and Discussion

1) Under thebiaxial tensile loads, the mechanical behavior for the composites from three resin matrices have different properties. The water-based epoxy resin plate and isocyanate resin plate represented orthogonal anisotropy and elastoplasticity, while phenolic resin board revealed a high-quality linear elastic and simultaneous brittle-fracture properties at X,Y-direction. Instant load change at the breaking-direction had a negative effect on the other direction. The dropping degrees were positively related to breaking load as well as load difference value between X and Y-direction.

2) Within the limit in the elastic proportion of biaxial tension, the mean value of strain-field are larger in Y-direction than X because of material anisotropy. Variation of strain-filed for phenolic resin plate and isocyanate resin plate are moderately gently and smoothly, while water-based epoxy resin plate' strain fluctuation are comparatively large.

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