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Shear behavior of architectural coated fabrics under biaxial bias-extension

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HIGHLIGHTS

- Shear behavior of four kinds of architectural coated fabrics is studied.
- The distribution of shear stress and shear strain was analyzed by finite element method.
- The novel test method of biaxial bias-extension method was proposed.
- Shear stress-strain relation was summarized in different loading stage.

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ABSTRACT

As two typical kinds of architectural coated fabrics, PVDF coated polyester fabrics and PTFE coated glass-fiber fabrics have been prevalently used in tensile structures. Shear behaviors of architectural coated fabric is generally regarded as an unneglectable factor when analyzing and simulating mechanical response of tensile structures. This paper employed two approaches to investigate the shear stress-strain characteristics to understand the shear properties of these two common coated fabrics. At first, a finite element model of the cruciform specimen was developed to calculate the shear stress-strain distribution. The results of finite element analysis showed uniform shear stress field and uniform shear strain field in octagonal core area. Then, biaxial bias-extension test was carried out to study the shear behaviors of architectural fabrics. Experimental results showed viscoelastic-plastic property of architectural coated fabrics and the shear stiffness of PTFE coated glass-fiber fabrics greater than that of PVDF coated polyester fabrics.

1. Introduction

Fabric structures have been widely used in state-of-the-art landmark buildings in the past four decades all over the world, such as airport, stadium, and convention center [1,2]. The mechanical properties of membrane material were essential for fabric structure to realize the economical and safe architecture [3]. Two commonly used materials were polyesters fabrics coated with polyvinylchloride (PVC) or polyvinylidene fluoride (PVDF), and glass-fiber fabrics coated with polytetrafluoroethylene (PTFE). These two typical membrane fabrics deliver excellent performance in virtue of their mechanical properties, chemical stability and durability. Bridgens [4] carried out uniaxial and biaxial tensile tests on a wide range of PVC coated polyester fabrics and PTFE coated glass-fiber fabrics, found that PTFE coated glass-fiber fabrics had a higher tensile strength, but worse folding endurance than PVC coated polyester fabrics. Ansell [5] investigated the performance of PTFE coated glass fabrics by scanning electron microscopy, uniaxial tensile testing and weathering in artificial and natural environments. Ambroziak [6] identified the mechanical properties of polyester coated fabrics Precontraint 1202S with PVDF surface treatment on the basis of the biaxial cyclic test under different load ratio conditions. Zhang [7] carried out a series of mechanical test: off-axial and biaxial tensile test, uniaxial test with different strain rate and uniaxial test with different temperature. Meng [8] described the viscoelasticity of coated fabrics including PVC coated fabrics and PTFE coated fabrics and the parameters in the constitutive equation are determined through uniaxial and biaxial stress relaxation tests. However, the mentioned research primarily focused on the tensile properties of coated fabrics and the research on shear response of coated fabrics was failed to attract enough attention.

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Shear response is a crucial aspect worth considering in structural analysis. For example, the shear deformation always appeared during installation when the flat fabrics were distorted into double curved surfaces [9,10]. Additionally, increasingly architects were moving away from conventional structural forms and utilizing lower levels of curvature that was less inefficient and more sensitive to shear deformation [3]. Moreover, the load direction was always not paralleled to the yarn's direction due to different loads in service condition, such as wind pressure, wind suction and snow leaded to further complex distortion, wrinkle or tear [3]. Because of no routinely accepted method for accurately determining estimation of shear behavior [6–8], shear stiffness was usually neglected or assumed as 1/20 of the tensile stiffness in fabric structure design [1]. Therefore, an accurate estimation of the shear stiffness was urgently required to predict the structural performance of fabric structures.

In the last decade, shear response of the coated fabrics attracted wide attention due to the extensive application of composite materials and the strong concern about the performance of tensile fabric structures. Galliot et al. [11,12] summarized several test methods for shear response of coated fabric, including the bias-extension test [13], picture frame test [14,15], KES-F test [16], cylinder shear device [17], biaxial test with T-shape specimen [18] and biaxial bias-extension test with cruciform specimen [19]. The bias extension and the picture frame tests were two frequently used methods, and the biaxial bias-extension test has attracted increasingly interest recently. Harrison et al. [20] gave the advantages and disadvantages of the bias extension test and the trellis frame test. Bias extension test was performed easily on uniaxial test machine, but the heterogeneous deformation appeared during the test and shear rate cannot be controlled accurately. The picture frame method can obtain a homogeneous deformation that has been recommend by MSAJ [22], but the stress condition during the test was difficult to control and measure. Cao et al. [23] organized an international group of several academic and industry researchers to do experiments of the woven fabrics and obtained the benchmark results. The results were different from each other since no standard test process of bias extension test and picture frame test in round robin exercise. Jackson et al. [24] and Colman et al. [25] proposed shear loading procedure that a cruciform specimen was clamped on a biaxial test machine and applied equal tension in warp and filling direction. The loaded specimen was then clamped in a picture frame directly. Finally, the picture frame was installed on a uniaxial test machine. This procedure investigated shear behavior at controllable tension state, but was rather complicated and inconvenient. Galliot [11,12] developed shear ramp method that the stress ramps were loaded on the four arms of cruciform specimen that fibers were paralleled to the loading directions. The main advantage of this method was that only one specimen could be used for all elastic constant measurement with biaxial test machine, the drawbacks were complex loading protocol and prerequisite of correction factor due to inhomogeneous stress distribution. Blum and Bögner [19,26] proposed a shear test method that the biaxial extension was applied on a cruciform specimen with 45° rotated fibers, and strains in three directions (warp, filling and one of load direction) were measured to calculate shear strain. This method could be carried out on biaxial tensile tester easily, but the dimension of cruciform specimen and the calculation method should be optimized to improve the accuracy of results. Besides, the shear behavior of architectural fabrics was rarely studied by biaxial bias-extension method.

In this paper, shear behavior of four plain-woven coated-fabrics were tested by a novel biaxial bias-extension method. The cruciform specimen with 45° oriented fibers was loaded under biaxial tension and the accuracy of shear strain was improved due to new calculation method. The distribution of shear stress and shear strain in cruciform specimen was investigated by finite element method to determine appropriate dimension of cruciform specimen and measuring area. The main content of test procedure was specified in detail, and the corresponding experimental results were discussed in the end of paper.

2. Theoretic background

2.1. Shear strain

Shear deformation appeared in fabric structure when the yarn's direction was unparalleled to the load direction. Therefore, the shear test of coated fabrics always applied an unparalleled force to yarn's direction, such as bias-extension method and picture frame method. As shown in Fig. 1, biaxial bias-extension method utilized a cruciform specimen with 45° oriented fibers to introduce a symmetric shear deformation in central square. The loads were transferred to center square of specimen when a couple of unequal forces were applied to four arms, and then angle between warp

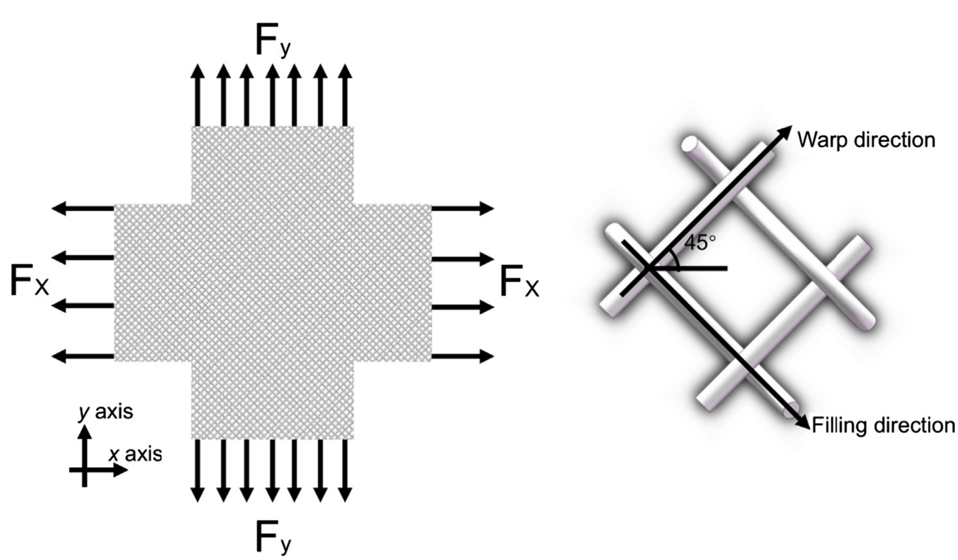

Fig. 1. Schematics of biaxial bias-extension.