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Effect of tackification on in-plane shear behaviours of biaxial woven fabrics in bias extension test: Experiments and finite element modeling

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ABSTRACT

As one of the most reliable tests for fabric in-plane deformation characterization, bias extension test is widely accepted as following the Pin-Joint-Net assumption. Hence, researchers always take in-plane shear behaviour of tackified woven fabrics following that assumption for granted. However, it is lack of evidence. In this paper, based on the distinctive load fluctuation observed during bias extension and picture frame tests of CF3031 biaxial woven fabrics with varying tackifier content, we established a new model called "Gradual Deformation Model" as deformation assumption to describe the different bias extension behaviours of tackified woven fabrics instead of Pin-Joint-Net assumption. The model validation was implemented sufficiently via digital image correlation technology and finite element analysis. Due to the good correlation between experimental and numerical results, it is reasonable to claim that the main effect of tackification on in-plane shear behaviours is the formation of great resistance to inter-tow shear, inter-tow sliding and cross-over point sliding.

1. Introduction

Textile-reinforced composites have been widely used in aviation and aerospace engineering over the last several decades. Textile reinforcements show lower weights, better damage tolerance, improved out-of-plane mechanical properties and preferable drapability for complex geometries, compared with conventional unidirectional reinforcements [1–3]. However, fiber redistribution and reorientation induced during the process of lay-up over molds with complicated structures could lead to significant effect on mechanical properties of fabricated parts [4]. Many successful efforts have been devoted to investigating the deformation mechanism of woven fabrics during lay-up process via learning shear behaviour of woven fabrics through bias extension test and picture frame test [5–10]. Cao et al. studied the in-plane shear behaviour of woven fabrics systematically, presented the benchmark results for bias extension and picture frame tests and proposed a convenient normalization method based on the power made through clamping force, making the direct comparison between bias extension and picture frame results possible [5]. Zhu et al. mainly focused on the shear deformation of woven fabrics and its contribution to wrinkling [6]. The cross-section images of fiber yarns during the modified picture frame tests were traced, giving a comprehensive understanding about the onset of wrinkling in in-plane shear deformation.

Although being studied for decades, tackification technology is regaining attention with the trends of automation and low cost in composites manufacture. Being the most widely used low cost composite fabrication process, liquid composite modeling (LCM) composes of three major steps: preform preparation, resin injection and curing. The quality of preform affects the mechanical properties of fabricated composite parts significantly. Compared with automated preform manufacturing methods like 3D weaving [11–13], automated tape laying [14,15] etc., tackification only needs commercially available cost-effective tackified fabric reinforcements, which can work in absence of specialized equipment, performing great potential in further cost saving. Recently, with the help of tackification technology, dry preforms is manufactured by a fully automated lay-up successfully with Hexcel's HiTape® [16], which means tackification technology also shows great potential in automatic processing.

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Investigation about tackification is mainly concentrated on the effect of tackification process parameters on preform integrity, permeability and mechanical properties of composite parts [11,17–20]. Nevertheless, researchers take it for granted that the shear behaviour of tackified woven fabrics should follow the widely accepted Pin-Joint-Net (PJN) Model, which is the basic assumption for pure woven fabrics [21,22]. However, the rationalization of this assumption has never been discussed.

In preform preparation, tackified fabric plies are usually tailored, stacked and placed inside the mold cavity first. Then pressure will be applied and tackified fabric plies will deform into the designed shape at room temperature. Finally, tackified fabric plies will be heated with mold by infrared lamps or ovens with suitable process until a net-shaped preform is prepared. Herein, the majority of our work focused on the in-plane shear behaviours at room temperature of CF3031 biaxial woven fabrics with different amount of tackifier in bias extension test. The shear characteristics of woven fabrics with and without tackifier were compared with each other via load-displacement curves and digital image analysis. A novel in-plane shear deformation assumption called Gradual Deformation Model for tackified woven fabrics in bias extension test was proposed with the help of digital image correlation technology (DIC) and local shear angle measurement. In addition, a finite element model was developed to numerically predict the shear deformation behaviour of tackified CF3031 biaxial woven fabrics in bias extension test. As validated by comparing the simulated results with experiments, this model help us interpret the effect of tackification on the in-plane shear behaviours of biaxial woven fabrics in bias extension test thoroughly.

2. Material and experiments

2.1. Raw material

The 4-harness satin weave fabric CF3031 composed of 3K CCF300 carbon fiber tows was used in current work. The specifications of woven fabrics CF3031 are listed in Table 1. ET5284 epoxy resin powder with curing agent was chosen as the tackifier for preform preparation in this study, which is compatible with the matrix we will use in future study. The woven fabric CF3031 and ET5284 epoxy resin tackifier used in this work were provided by Beijing Institute of Aeronautical Materials.

2.2. Tackification process

The ET5284 epoxy resin tackifier powder was applied uniformly on one side of woven fabric by a 120 mesh sieve. Then, powder sprayed fabric was heated by an IR lamp for one half minute at 110 °C to fuse tackifier powders to fabric surface. The amount of tackifier powder applied on fabric was controlled accurately via a Mettler-Toledo analytical balance accurate to 0.0001 g. Finally, as-prepared fabrics were cooled down to room temperature for tests. CF3031 woven fabrics with 2.5 wt%, 5.0 wt% and 10.0 wt% tackifier were prepared separately. The photographs of fabric with and without tackifier are partially illustrated in Fig. 1.

Table 1
Specifications of woven fabric CF3031.

Geometry parameters	CF3031
Areal density (g/m^2)	220
Gap between fiber yarns/mm	0.26
Fiber yarn width/mm	1.59
Fabric thickness/mm	0.264

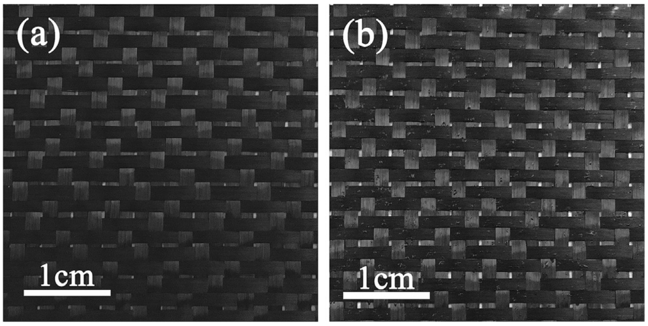

Fig. 1. Photographs of woven fabric CF3031: (a) untackified, (b) tackified.

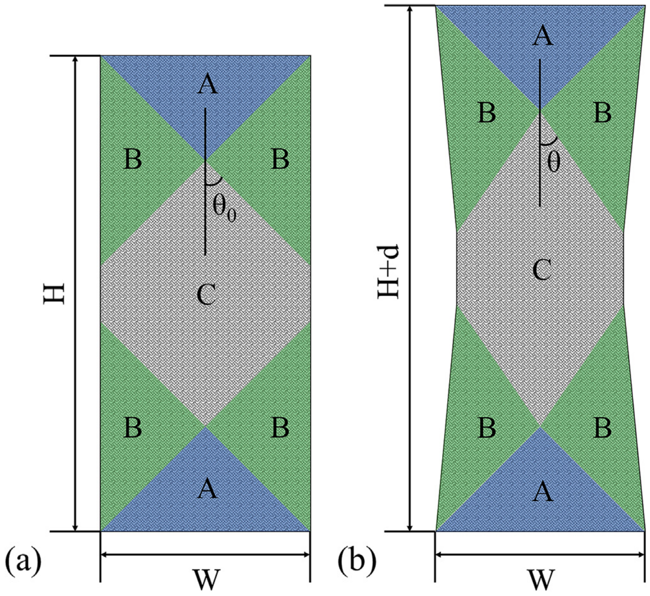

Fig. 2. Schematic of classical deformation mechanism in bias extension test: (a) before deformation, (b) after deformation.

2.3. Bias extension and picture frame tests

The in-plane shear properties of woven fabrics were characterized by bias extension and picture frame tests. The dimensions of bias extension specimens used in this work are 225 mm × 90 mm. Tensile load is applied along the longitude of rectangle specimen and carbon fiber yarns are initially orientated at ±45° to the

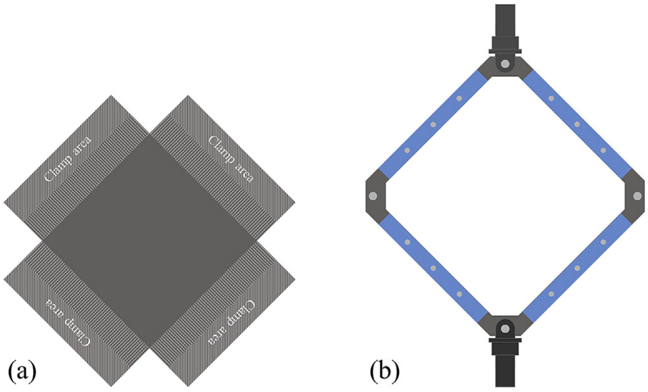

Fig. 3. Picture frame tests: (a) specimen, (b) test fixture.