Materials and Design 49 (2013) 151–159

Contents lists available at SciVerse ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Study on intra/inter-ply shear deformation of three dimensional woven preforms for composite materials

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ARTICLE INFO

Article history:
Received 1 November 2012
Accepted 1 February 2013
Available online 20 February 2013

Keywords:
3D angle interlock preform
In-plane shear
Interlaminar shear
Deformation mechanism
Mechanical property

ABSTRACT

This study presents the in-plane shear and interlaminar shear behavior of the three dimensional (3D) angle interlock preforms with different fabric densities. Picture frame shear tests for the 3D woven preform were carried out, the non-linear curves of shear stress versus shear angle and the deformation mechanism were analyzed. A new test method was designed to characterize the inter-ply shear property. The samples after interlaminar shear tests were also investigated through the yarn pulling-out and mesostructure to discover their deformation and failure mechanism. The results have shown that the fabric density has significant influence on the in-plane shear and inter-ply shear properties of 3D angle interlock preforms and the shear performance decreases with the increasing of the fabric density. The lower fabric density, the better deformability. The inter-ply shear damage mode is the binder yarn pulling out from the fabric. It is expected that the study can provide an experimental basis for building up the theoretical model.

1. Introduction

Continuous fiber reinforced polymer (CFRP) composite materials have attracted a significant amount of attention due to their advantages such as high performances, short processing cycle, possibility of repairing and welding [1–4]. Although the laminated composites have excellent in-plane mechanical properties, the application range of laminated composites is limited by the through-thickness failure due to the poor interlaminar properties. Three dimensional (3D) textile structural composites provide excellent through-thickness strength, outstanding damage tolerance and favorable impact and fatigue resistance [5–9].

As one type of the 3D textile structural reinforcements for composites, the 3D angle interlock fabric has been widely used in engineering field owing to its easy and efficient processing in a traditional loom [10–12]. In addition, the most attractive advantage of 3D angle interlock fabric has the near-net-shape forming capacity to manufacture composites [13]. The 3D angle interlock preforms have excellent mechanical properties and good formability (Fig. 1). With the development of the preforming technology, complex shape and different size of the structural parts can be produced.

In the structural integrate manufacture of composite productions, the 3D angle interlock fabric is preformed according to the shape of the final composite production that can be complex [14–16]. As to the 3D fabrics, the in-plane behavior and the interlaminar behavior are the most important deformation, and shear behavior predominates the deformation mode of the material [17–19]. It is valuable to study the inter/intra-ply shear behavior of 3D angle interlock fabric because of their wide application in production especially in the case of forming process.

The in-plane shear behavior of 2D fabric has been comparatively well investigated. Zhu et al. [20,21] carefully investigated the in-plane shear characterization of 2D fabric by experimental test, and found that the reduction of yarn was a key to wrinkling. Hivet et al. [22,23] studied the shear property of 2D fabric using picture-frame test method, and pointed out that the shear results were sensitive to the tensions in the yarns during the experiment. The tensile force increased with the shear angle increasing. Lomov et al. [24,25] presented shear tests of unbalanced 2/2 twill glass/PP fabric on picture frame in three different pretension states and studied the influence of tensile load in the yarn direction on the shear resistance for the fabric and the repeatability of the test method. Lin et al. [26] established the finite element model based on the geometry of 2D fabric to simulate the in-plane shear deformation, the simulation results were identical with experiments. Cao et al. [27] compared the picture frame shear test results from different seven labs for developing a standard test setup and obtaining accurate and appropriate material properties. Chen et al. [28] developed a FEM model to predict in-plane and interlaminar shear properties of laminates. However, the intra/inter-ply

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http://dx.doi.org/10.1016/j.matdes.2013.02.025

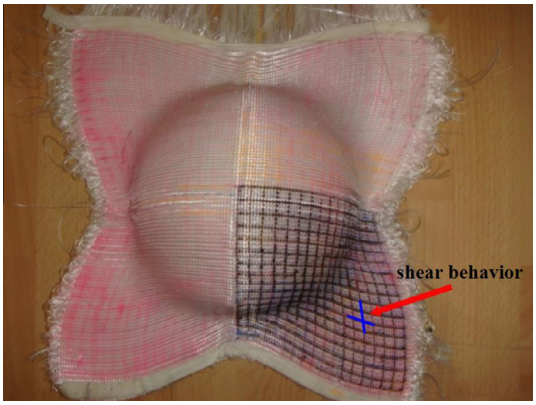


Fig. 1. Hemispherical forming of 3D angle interlock fabric.

shear behavior of 3D angle interlock fabric were rarely reported. Charmetant et al. [29] built a hyperelastic model to simulated the formability of 3D fabric.

In this paper, a careful study on the in-plane shear and interlaminar shear behaviors of 3D angle interlock fabrics with different fabric density are reported. The shear stress versus shear angle curves and wrinkles position of in-plane shear test are recorded to compare with each other, and stress–displacement curves of inter-ply shear test are analyzed. In addition, the three stages of in-plane shear non-linear curves are characterized. The damage morphologies of interlaminar shear are presented and compared to obtain the structural effects of 3D woven fabrics during the shear test. It can provide the foundation for investigating the formability and theoretical analysis.

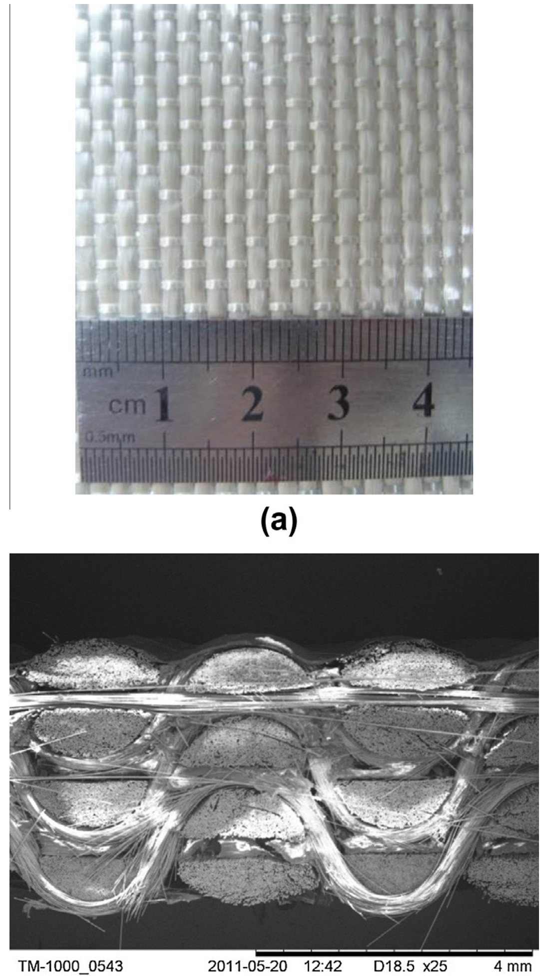
2. Experimental details

2.1. Materials

Fig. 2 gives the picture of the 3D angle interlock fabric and meso-structure of cross-section. The fabric samples were made with glass fiber filaments. Their specifications are listed in Table 1. The sketch diagram of 3D angle interlock fabric structure are shown in Fig. 3 to illustrate the specific preform structure. For this architecture which is made of three different groups of yarn systems, i.e., warp yarn, weft yarn and binder yarn, it presents a layer-to-layer angle interlock structure where the warp yarns and weft yarns are almost straight, the binder yarns show a different undulation connecting the upper layer and under layer of non-crimp weft yarns to be held together to form a stable fabric construction [10]. The non-crimp warp and weft yarns are laid in 0°/90° sequence with no weaving with each other. The linear density of binder yarn is smaller than that of warp and weft, and it only plays a part in connection in the preform. The structural characters ensure high stiffness and high strength along warp and weft direction.

2.2. Intra-ply shear test

Picture frame test was an effective way for characterizing intra-ply shear property of fabric. The 3D fabrics for shear tests were prepared according to the size of the picture frame and the characteristics of sample were described in Fig. 4. In order to prevent the pressures from imposing on the preforms by the fixture during the large deformation, the central area of shear deformation was 100 mm × 100 mm, and the four corner parts were cut off. Shear tests were conducted on a SHIMADZU 1kNE universal testing machine with a crosshead speed of 10 mm/min. Three samples were tested for each structure.



(b)

Fig. 2. Photographs of the 3D angle interlock preform; (a) surface and (b) cross section.

Picture frame test have been improved during the experiment to ensure the pure shear load, for example, to minimize the marginal restriction and facilitate the clamping of fabric, and so on [30–34]. Although the improvements has been performed for the stability of the shear results, some important influential factors also need to be considered, such as the effect of yarn position on tension in the yarn, and the friction of the frame [35,36]. In this paper, some improvement have been made based on the existing questions:

(1) The arms of picture frame are connected by the rolling bearing instead of shaft connection. The friction between the frame is an important element for shear results due to the small shear force between yarns at initial stage of shear. The friction–displacement curves of before and after improvement are given in Fig. 5. It can be seen that the frame friction retains stable and small, the value is within the range of 0.04–0.08 N after improvement and the friction cannot influence the test results.
(2) The yarns positioning has been improved. The shear results are highly sensitive to sample positioning, especially for fabrics with lower crimp. Fig. 6 shows that the improper positioning can cause large tension in the yarn or the yarn relaxation during shear test. So the yarns in the sample should be parallel with the arm. The four arms are grooved