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Tensile properties of multilayer-connected biaxial weft knitted fabric reinforced composites for carbon fibers

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ABSTRACT

Multilayered-connected biaxial weft knitted (MBWK) fabric reinforced composites have excellent tensile properties. Three kinds of different fabrics reinforced composites are used in this paper, which are three-layer-connected biaxial weft knitted fabric, four-layer-connected biaxial weft knitted fabric and five-layer-connected biaxial weft knitted fabric. The tensile properties of MBWK fabrics reinforced composites are studied with 0° and 90° directional testing with different carbon fiber volume fractions. The results show that the carbon fiber volume fraction has significant effect on tensile strength of MBWK fabrics reinforced composites. The linear correlation between tensile strength and carbon fiber volume fraction is very well in the certain range, and failure analyses are also available by means of sample debris examination to identify the failure modes and the fracture surfaces.

1. Introduction

Multilayer-connected biaxial weft knitted (MBWK) fabric is a kind of special non-crimp fabrics (NCFs). In MBWK fabric, it consists of exactly parallel and straight high performance fibers and well deformable 1 + 1 rib loops, which makes it having good in-plane mechanical properties and out-of-plane mechanical properties, especially excellent shear deformation, maximum shear deformation angle can reach 40° [1–3]. In addition, the composites reinforced with MBWK fabric exhibit strong capacity for bearing external load and lower production costs and production cycle short, high property/cost ratio, etc. [4,5]. For these reasons, the MBWK fabrics reinforced composites are widely used in the field of pilot helmets, wing cover and car body manufacturing. The deeper research have been developed about good formability on curved surfaces of MBWK fabrics [6,7], nevertheless, composites reinforced with MBWK fabrics are often subjected to tensile loading, compression loading and bending loading [8–10]. Furthermore, its shear and bending deformation are closely related to its tensile property, the tensile failure of reinforced fibers in the composites is the main reason regardless of the external loads. Hence, the tensile property of the MBWK fabrics reinforced composites is the most fundamental and most important property.

The inserted high-performance yarns in the through-thickness provide a possibility to enhance the out-of-plane properties of NCFs reinforced composites [11–13]. Dexter and Funk [14] compared the compression after impact (CAI) strength of the stitched laminates and the unstitched laminates through the experiment testing, the results showed that the latter have more than 80% increase than the former. Similarly, Liu [15] also revealed the delamination damage areas were markedly different under low-velocity impact loading for stitched laminates and unstitched laminates. Moreover, a Mismatch Theory based on the difference of bending stiffness between adjacent laminae was used to interpret the cause of high interlaminar stress level, which observed a reduction of the damage area by up to 40%. Compared to the unstitched laminates, the stitched laminates were reported to show about 10–20% reduced tension, compression and bending stiffness and strength properties, whereas in some cases, no alterations or even moderate increases were observed [16–19]. In actual, NCFs reinforced composites have a very range of applications because of its structural features and mechanical characteristics, however, it was reported that the stitching of NCFs during the manufacturing process already disturbs the in-plane fibers, even the in-plane fibers were damaged, which created resin-rich pockets in the composites [20,21]. The effect may induce an initiation of damage, which affected the in-plane properties of composites, such as stiffness and strength. In MBWK fabrics, the damage of high performance fibers can be avoided in knitting process, which will effectively improve the performance of the MBWK fabrics reinforced composites. Li and Bai [8] studied the multidirectional tensile properties of the MBWK fabrics reinforced composites for glass fibers. The classical laminate theory was applied to predict the tensile properties of the MBWK fabrics reinforced composites and showed good agreements with the experimental results. This is a very effective way that was used

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to predict mechanical behavior of the MBWK reinforced composites. Jiang et al. [10] fully demonstrated that the MBWK fabrics reinforced composites have excellent bending properties by using experiment test. The reinforcements include three kinds of fabrics which are made of glass fibers, UHMWPE fiber and the two type's fibers blends. Although the MBWK fabrics reinforced composites have excellent in-plane mechanical properties, there is few reports about MBWK fabrics reinforced composites because of knitting methods and equipment limits. As for the MBWK fabrics reinforced composites, we still have many details need to be further research, such as the relation between fiber volume fraction and tensile strength.

In order to further understand the relation between the structure and the tensile properties of MBWK fabrics reinforced composites, tensile tests of such composites are conducted in this paper. The MBWK fabrics contain three layers, four layers and five layers of uncrimped carbon fiber bundles. One-way analysis of variance of tensile strength is applied to analyze the relationship between the carbon fiber volume fraction and the tensile strength. Furthermore, the relationship between the carbon fiber volume fraction and the tensile strength can be conducted through one-dimensional linear regression that is a common method of mathematical statistics. Failure modes are identified from the sample debris, and the microscopic mechanisms are got by the scanning electron microscope. The study may provide a desired base for building a firm base for future use of the MBWK fabric reinforced composite material in engineering applications.

2. Experimental and testing

2.1. Materials and specimens production

In this experiment, the MBWK [22] fabrics were made in the Institute for Composite Materials in Tianjin Polytechnic University. The weft yarns and the warp yarns are made of T300-3 K carbon fibers which are knitted together by the polyester yarns (PET DTY) with the 1 + 1 rib loops as shown in Fig. 1. The first layer of the three-layer-connected biaxial weft knitted fabric is composed of the weft carbon fiber bundles, the middle layer is composed of the warp carbon fiber bundles and the last layer is the same as one. The coffee lines are weft carbon bundles, and the black lines are warp carbon fiber bundles. These carbon fiber bundles are stitched together by the white lines which are made of polyester yarns (PET DTY) with 1 + 1 rib loops. The thickness of the fabric is about 1.0 mm. The structure of the four-layer-connected biaxial weft knitted fabric is different from three-layer-connected biaxial weft knitted fabric, but all the yarns are same. The first and the forth layers of the four-layer-connected biaxial weft knitted fabric are composed of the weft carbon fiber bundles, the second and the third layers are composed of the warp carbon fiber bundles. The thickness of the fabric is about 1.25 mm. The first and the second layers of the five-layer connection biaxial weft knitted fabric are composed of the weft carbon fiber bundles, the third layer is composed of the warp carbon fiber bundles, the forth and the fifth layers are composed of the weft carbon fiber bundles. MBWK fabrics were consolidated with epoxy resin by resin transfer molding (RTM) process. The cut-out MBWK fabric after weighing is spread in the mold, and then the mold is fitted together, sealed and vacuumized. Finally, the epoxy resin of certain proportion is injected into the mold. After MBWK perform is infiltrated completely, the mold is placed in the oven to be heated, the curing process starts according to the *T-t* curve shown in Fig. 2. In the end of the processing, the plate is cooled down naturally in the oven.

2.2. Testing

The tensile properties of the MBWK fabrics reinforced composites are studied with 0° and 90° directional testing with different carbon fiber volume fraction. 0° is defined that carbon fiber direction oriented along weft direction, and 90° oriented along warp direction. The samples geometry is 250 mm × 25 mm × 4 mm [23] see Fig. 3 and Table 1, and five samples were tested in every group. 50 mm × 25 mm × 2 mm aluminum tabs are affixed to both ends of every sample on both sides. And the tensile tests were conducted at the room temperature. Since in this paper, the carbon fiber layers of the MBWK fabric are defined as layer, and the MBWK fabrics of the composite plate are defined as piece.

Now there is not the tensile test standard of MBWK fabrics reinforced composites, and because the carbon fiber of the composite material is completely straight, so the tensile test can be conducted follows the ASTM: D3039/D3039M-08 that is standard test method for tensile properties of polymer matrix composite materials. The tensile test was conducted by SHIMADZU AG-250KNE universal material testing machine. The loading speed was 2 mm/min. During tensile test, one end of the tester was fixed, the other end moved at the loading speed. The extensometer with a gauge length of 50 mm was attached in the middle of the sample. Since the extensometer measured a large region containing a number of the textile unit cells, an overall average mechanical behavior was exhibited. Note that the holding clamp of the measuring arm should be removed after the extensometer was affixed to the sample, which can prevent that both measuring arms produce elastic deformation.

In the process of the test, the relative slippage happened between the samples and the clamps, the data is inaccurate, and so the extensometer must be fixed on the samples in every test. Note that after the extensometer fixed on the samples, the holding clip of fixing the two measuring arm can be remove, it is for prevent the measuring arm producing elastic deformation. With the samples are stretched, the distance of the measuring arms increases, the signal is transmitted to the computer, the load–elongation curve is shown in the computer. When the tensile strength reaches a certain value, the extensometer must be removed in case of spring lamination happens permanent deformation in the tensile fracture.

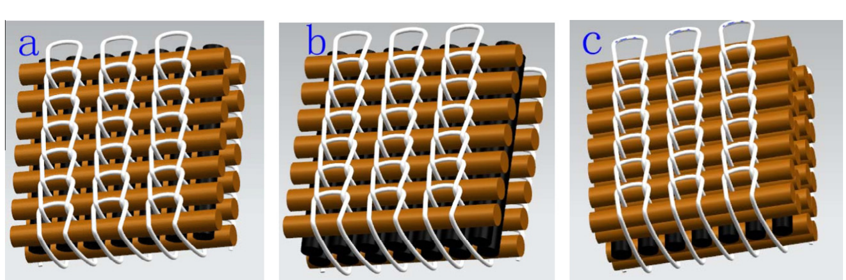

Fig. 1. The MBWK fabrics interlock structure.