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Tensile Behaviour of Multilayer Knitted Fabric Composites with Different Stacking Configuration

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Abstract. In this paper, multilayer plain weft knitted glass fabric reinforced epoxy composite laminates with different stacking configurations, i.e., $[0°]_4$, $[0°/\pm45°/0°]$, $[0°/90°/90°/0°]$ and $[90°]_4$, were investigated experimentally. The laminates were uniaxially tensile loaded until final fractures occurred. The experimental results show that with the change in layer stacking structure, a corresponding variation in composite strength and stiffness was achieved. The tensile strength and modulus rank as follows: $[0°]_4 > [0°/\pm45°/0°] > [0°/90°/90°/0°] > [90°]_4$, which implicates a potential desiguability of Knitted Fabric Composites (KFC) for engineering applications. Failure behaviours of the fractured laminate specimens were examined using a 'matrix digestion and layer peeling' method, based on which the behaviour of each lamina in the laminate can be clearly shown. It was found that an angle-plied lamina in the laminate when subjected to a uniaxial tensile load has a different fracture mode from that of a single ply composite under an off-axial tensile load. This means that the lamina in the laminate is subjected to a more complicated load combination. By comparing the fractured mode of the latter lamina with that of the single ply composite, the load direction sustained by the lamina in the laminate can be identified, which provides a qualitative benchmark for verifying a theoretical simulation.

Key words: knitted fabric composites, multilayer laminate, stacking configuration, mechanical properties, fracture mode, internal load direction, experimentation.

1. Introduction

Knitting techniques are traditionally employed in clothing and apparel industry. By interlocking of loops of fibre bundles, various knitted fabrics can be produced. As one kind of textile materials, knitted fabrics possess some unique characteristics over other kinds of textile fabrics such as woven and braided fabrics, particularly in conformability and drapability which make them irreplaceable in conforming complicated contours or desired shapes. Due to these attractive features and also due to the feasibility of knitting high performance engineering fibres such as carbon/graphite, glass and aramid in current technology, there is an increasing interest in the research and development of knitted fabrics for use in composite industry [1–5]. Compared with some other kinds of fiber reinforced composites, knitted fabric composites generally have inferior in-plane stiffness and strength, as indicated in Figures 1 and 2. Hence, they are not likely to be used as primary structural

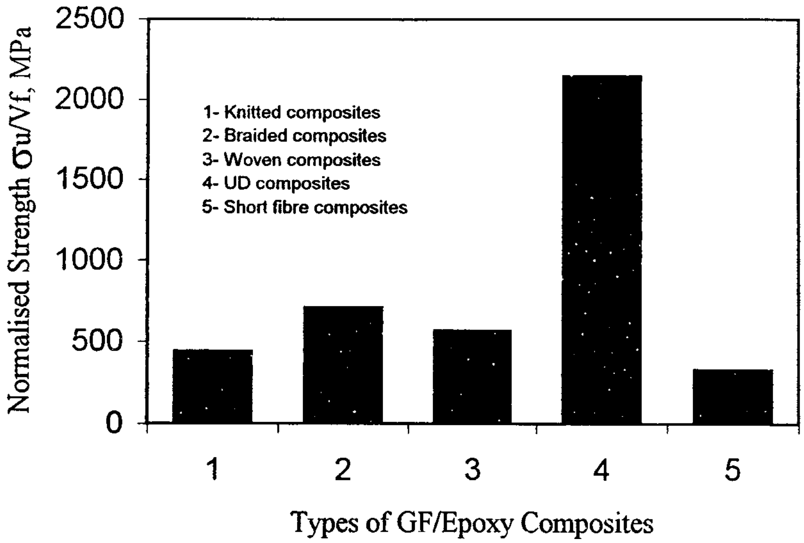

Figure 1. Normalized strength (with respect to the fibre volume fraction) of different fibrous composites in their main directions.

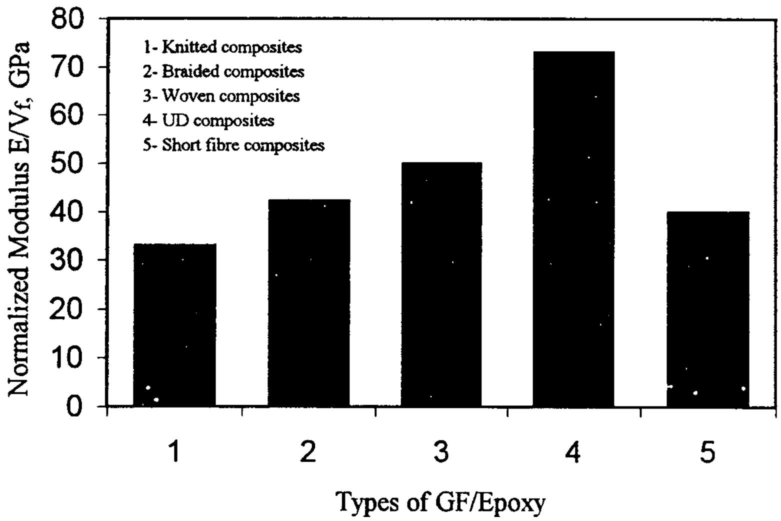

Figure 2. Normalized modulus (with respect to the fibre volume fraction) of different fibrous composites in their main directions.

materials in high performance structure components. However, it is possible to make them secondary load-sharing structures, due to their feasibility of net or near to net shape contours [6] and some other superior mechanical performances such as high resistance to impact [7, 8]. A “flexible composite” with a much larger useable range of deformation than conventional laminated composites could be achieved by combining tougher resins with knitted fabrics [9].

The mechanical properties of knitted fabric composites (KFC) varied with variables such as knit architecture, stitch density, pre-stretching percentage on fabrics, inlay fiber bundles, tow size of fibers etc. have been experimentally investigated by previous researchers [10–18]. The anisotropy feature of KFC has already been recognized. These investigations were mainly carried out based on single layer or equivalent single layer knitted fabric reinforced composites. On the other hand, limited work has been done so far on the mechanical behaviour of knitted fabric composites with varied stacking structures. The present paper focuses on investigation of the tensile behaviours of multilayer plain weft knitted glass fabric reinforced epoxy composites with different stacking configurations. Following laminates have been considered: $[0°]_4$, $[0°/\pm45°/0°]$, $[0°/90°/90°/0°]$ and $[90°]_4$, where 0° refers to the fabric wale direction and 90° to the fabric course direction. With the variation in the stacking arrangements, different tensile moduli and ultimate strengths have been found. The tensile strength and modulus rank as follows: $[0°]_4 > [0°/\pm 45°/0°] > [0°/90°/90°/0°] > [90°]_4$.

A special attention has been focused on the fracture mode of each lamina layer in the laminate. This was achieved in the present paper by using a special technique, called "matrix digestion and layer peeling" method. The resin matrix in the fractured laminate specimen was digested and each fabric layer was peeled off. The fracture surface of each layer was thus clearly shown. A comparative study was also carried out using a single layer fabric reinforced composite under an off-axial tensile load. It was found that the fracture mode of an angle-plied lamina in the multilayer laminate is different from that of single layer composite subjected to the off-axial tensile load. Hence, the angle-plied lamina in the laminate is subjected to a more complicated load combination. By comparing the two fracture modes, the load direction sustained by the angle-plied lamina can be determined. These experimental evidences are useful for verifying a theoretical simulation on the multilayer knitted fabric reinforced composites.

2. Experimental

2.1. PLAIN WEFT-KNIT FABRIC

Plain weft-knit fabrics were produced on a Flying Tiger knitting machine manually, using CPR407 glass fiber yarns made by ACI Fibreglass, Australia. The linear density of the yarn is 600 Tex (grams per 1000 m in length). Schematic diagram of a plain weft knitted fabric is shown in Figure 3.

The row of loops in the longitudinal direction of the fabric is called "wale", whereas the row of knit loops in the width direction is named as "course". In this study, the wale direction is taken as the reference (0°) direction. Thus, 90° direction is along the course direction. The fabric stitch density was characterized as 3.4 loops/cm in the wale and 3.8 loops/cm in the course directions, respectively.

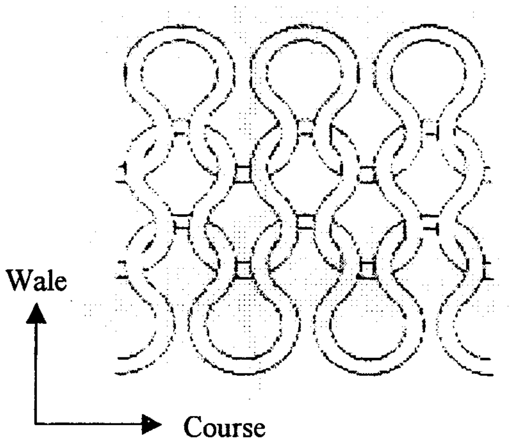

Figure 3. Schematic diagram of a plain weft-knit glass fabric.

2.2. SPECIMENS

Composite laminates were fabricated by a hand lay-up method. The matrix material used was a mixture of epoxy resin R-50 and hardener H-64 (Chemicrete Enterprises Pte. Ltd, Singapore) in a ratio of 100 : 48 by weight. Prior to commencing composite fabrication, the knitted fabrics were dried in an oven at 100°C for 2 h to remove moisture that may influence adhesion between the epoxy matrix and the glass fibers. The epoxy resin and the hardener were separately preheated at 45°C for 30 min to reduce viscosity. Then, the resin and the hardener were thoroughly mixed together, followed by a vacuum treatment for 3 $\sim$ 5 minutes to remove entrapped air bubbles. The composite fabrication was begun by attaching the fabrics with pushpins onto a wooden plank that was covered with a PP (Polypropylene) sheet. The PP sheet was used as a release agent to ensure the surface quality of the final composite laminate. Straight aluminum rods of 2 mm diameter were inserted into the fabric edges to make the curling fabrics flat during the fabrication. The resin mixture was then poured into the fabrics and another PP sheet was placed on the fabric surface. A delicate brush was used to push any air cavities to sides, before applying another wooden plank and heavy weights. The resin-impregnated fabrics were cured at room temperature for 24 hrs. Multilayer laminates of four stacking configurations, i.e., $[0°]_4$, $[0°/\pm45°/0°]$, $[0°/90°/90°/0°]$ and $[90°]_4$, were prepared. To facilitate comparison, single layer knitted fabric composite panels were also fabricated. The fiber volume fractions, V_f, were 22.2% for the multilayer laminates and 17.1% for the single layer composites, which were determined with a combustion method. Tensile specimens were cut carefully using a water-cooled diamond saw in parallel to the wale or course direction. All specimens have the same width of 25 mm. Aluminum end tabs of 45 mm in length were glued to the both ends of the specimens, leaving a testing gauge length of 120 mm.

2.3. TESTS

Tensile tests were carried out on an Instron testing machine (Type 8516) at a cross-head speed of 1.5 mm/min. Tensile strains were calculated based on the cross-head displacements. Macrostructure of failed specimens was observed using optical microscopy, whereas microstructure of the specimens was examined under a Jeol Scanning Electron Microscope (JSM-5800LV). To identify the fracture mode of an internal layer in the fractured laminate specimen, a resin digestion process was employed. Details will be described in the following section.

3. Results and Discussions

3.1. MECHANICAL PROPERTIES

Figure 4 plots the stress–strain curves of single layer knitted fabric composites subjected to a uniaxial tensile load at loading directions of 0°, 45° and 90° off-axis (with respect to the wale direction). Averaged properties of the single layered composites are summarized in Table I. The composite anisotropy in strength and

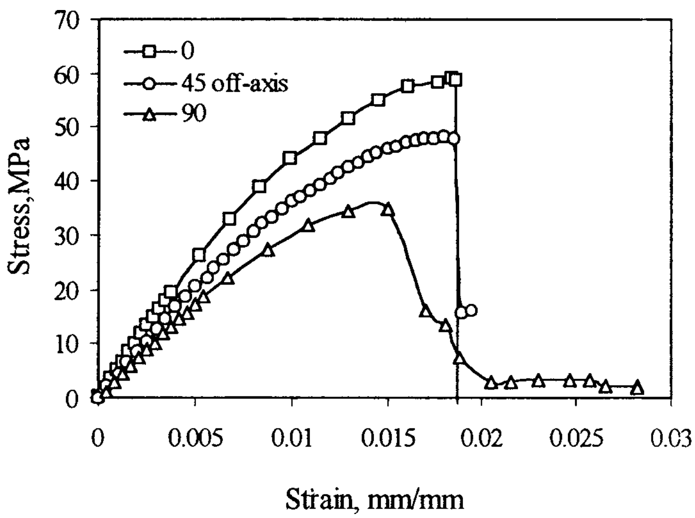

Figure 4. Typical stress-strain curves of single layer GF/Epoxy KFCs.

Table I. Tensile properties of single layer GF/Epoxy KFC.

	0° direction	45° direction	90° direction
Ultimate strength, MPa	59.1	41.3	34.9
Young's modulus, GPa	4.85	4.44	3.63
Failure strain, %	2.2	1.9	1.6

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