Determination of Mechanical Properties of Weft-Knit 1×1 Rib Glass/Epoxy Composites

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ABSTRACT

In this study, the mechanical properties of tensile and shear strength of 1×1 rib knitted fabric composite were determined in five directions: 0°, 30°, 45°, 60°, 90°, and the bearing strength of the composite were performed for the different ratio of the edge-distance-to-the-pin diameter (E/d), and the ratio of the specimen width to-the-pin diameter (W/d) in course direction. The knitted fabrics used for the study are manufactured from the 200 tex glass yarn with epoxy resin and cured in a hot press machine. The tests were carried out according to ASTM standards /1, 2, 3/. The results show that the tensile, shear and bearing properties of weft-knitted 1×1 rib glass-fiber composite material give nearly isotropic feature.

Keywords: Textile composites, Weft knitting, Glass fiber, Tensile strength, Shear strength, Bearing strength

1. INTRODUCTION

Knitting is a versatile fabrication process and a large range of knit fabrics exists. There are two different production techniques of knitted fabrics. One of them is the weft knitting technique which is the process of making a fabric by forming a set of connected loops from weft yarn inserted into successive rows across the width of the fabric /4/. The other is warp knitting, defined as a loop-forming process in which the yarn is

fed into the knitting zone, parallel to the fabric selvage /5/. When comparing with other conventional composites, knitted fabrics are situated in-between continuous fibre mats and woven or braided fabrics (Figure 1) /6/. It can be seen from the figure that the stiffness and strength of the knitted-fabrics are higher than fibre mat composites, but somewhat lower than for woven fabrics. Additionally, knitted fabric composites are usually more isotropic than woven fabric composites, and one of the outstanding features is the interlaminar fracture toughness /6/. These aspects of the knitted composite have attracted attention from many composite researchers. Among them, Leong *et al.* /7/ have analyzed the mechanical performance of resin transfer molded composites comprising a weft-knit glass fabric of Milano rib architecture. A number of mechanical properties i.e. tension, compression, bearing etc. were considered for laminates containing up to 12 layers of knitted fabric by them. They found that the knitted composites have relatively poor tension and compression properties but comparable bearing performance with respect to conventional composites. Gommers *et al.* /8/ have studied the fiber orientation distributions in different types of warp knitted fabric via the orientation tensors in the first part of their investigations. In the second part, they have analyzed the influence of the knit structure on the stiffness and strength in tensile and shear loading of glass warp knitted fabric epoxy composites. Luo *et al.* /9/ have investigated the behavior under biaxial tension of two types of glass knitted fabrics, a rib and a Milano weft

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Fig. 1: Comparison of some composite properties /6/

knit. They have determined the ultimate deformation in both wale and course directions at different displacement ratios. Xue *et al.* /10/ have investigated the large deformation tensile properties and the relevant meso-scale mechanisms of weft knitted textile composites and described the correlation between the fabric structure, matrix damage and material properties. Ramakrishna /11/, in his investigation, has determined the tensile properties of plain weft-knit glass-fiber fabric-reinforced epoxy composites experimentally in the wale and course directions and predicted the elastic properties using a cross-over model and laminated plate theory. He has expressed the crossing over of looped yarns of knitted fabric, and fiber-and resin-rich regions of composite with an analytical model. M. de Araujo *et al.* /12/ have investigated the tensile properties of different weft knitted fabrics with glass yarn, such as 1×1 rib, single Jersey, and composite plates produced with those fabrics and polyester resin.

The use of fibre-reinforced composite structures in the aerospace, marine and mass-transport industries has often been limited by their high cost of production and poor resistance to damage /7/. However, the knitted fabric reinforcements are more important in the composite industry, as they have suitable drapability and acceptable mechanical properties. Therefore in this paper, the mechanical properties including: tensile strength, young's modulus and shear strength, shear

modulus properties of the 1×1 rib knitted fabric composites were determined in five directions 0°, 30°, 45°, 60°, 90°, and the bearing strength of the material were performed for the different ratio of the edge-distance-to-the-pin diameter (E/d), and the ratio of the specimen with to-the-pin diameter (W/d) in the course directions.

2. MATERIAL PRODUCTION

Knitted fabric used in this study is weft-knit 1×1 rib fabric. The schematic diagram and photograph of the knit are shown in Figures 2a and 2b, respectively. In order to produce the fabric, a 200 tex glass yarn with a slight twisting was used and it was knitted on a 5 gauge flat bed knitting machine. Areal weight, course density and wale density of the fabric are 634gr/cm², 4 courses/cm, 3 wales/cm, respectively. The specimens used for the experimental programme were manufactured from the 3 lamina of the fabric and CY225 epoxy resin and HY225 hardener. The flat composite panels were produced using a hot press machine. In order to obtain the panels, the knitted-glass preforms were put into a mould and resin was impregnated. Then, the hot press machine was set at a temperature of 130 °C, pressure at 15 MPa and 3.5 hours for the whole pressing process. At the end of the

Fig. 2: The schematic diagram (a) and photograph of the knitted fabric (b)

process, the complete set-up was cooled to room temperature. The fiber volume fraction of the composite panels was approximately 65%, which was calculated from the weight of fabrics and panels.

3. EXPERIMENTAL PROCEDURE AND SPECIMEN PREPARATION

a) Tensile test.

Tensile strength and Young's modulus experiments were conducted according to ASTM D3039-76 standard test method for the weft-knitted glass-fibre composite panels of 2 mm thick. The test specimens were cut into rectangular blanks in five fiber orientations (0° , 30° , 45° , 60° , 90°); the variation with a constant cross section and the variation in specimen width was within ± 1 percent. Then composite tabs were bounded to the ends of the specimen to prevent failure under the grips (Figure 3). The tensile specimen was placed in the

testing machine, taking care to align the longitudinal axis of the specimen and pulled at a cross-head speed of 0.5mm/min. The specimens were loaded step by step at room temperature 20° up to failure under uni-axial tensile loading through an Instron testing machine. Three specimens were used for each experimental configuration. A continuous record of load and deflection was obtained by an extensometer (Epsilon extensometer, model: 3542-050M-050-ST).

b) Shear test.

Full characterization of a unidirectional composite requires the determination of lamina properties under in-plane shear parallel to the fibers, i.e., shear modulus G_{12} , and shear strength S . It is well known that determination of shear characteristics of advanced composites is a very difficult type of mechanical static test. One of the principal difficulties in the development of a shear test method for these materials is to induce

Dimensions in mm

Fig. 3: Tensile test specimen and its dimensions

stress of pure shear in a gauge section of specimen which has to be subjected to a shear stress of constant magnitude.

There have been numerous attempts to develop reliable test methods to determine the in-plane shear stress-strain response for composite materials, such as rail shear, cross-beam sandwich, thin-walled tube torsion, the Iosipescu shear and T tests, etc [13-19]. There has been no universal agreement on the best test for shear properties. Each of these tests has been discussed in terms of advantages, disadvantages and areas of validity and subsequently rated by the authors [20, 21]. The Iosipescu shear test was selected as one of the most popular shear test methods for characterizing the in-plane shear properties of the composites.

The necessary dimensions for each element of the Iosipescu test apparatus were determined and it was manufactured. The Iosipescu shear test method is the most practical technique currently available for testing composite materials.

The Iosipescu shear test attempts to achieve a state of pure shear stress at specimen mid-length by applying two counteracting force couples. A state of constant shear loading exists in the middle section of the test specimen, and bending moment equals zero at the mid-length of the test specimen.

The Iosipescu test specimen is tested using the Iosipescu test fixture. The specimens are placed in the Iosipescu test fixture in which the specimen is centered using the alignment pin and lightly clamped with the adjustable wedges. Then the load, at 0.5 mm/min speed, is applied to the specimen.

Specimen thickness is nominally 2mm. ASTM standard D4255-83 specifies a tolerance of ± 0.3 mm for the specimen dimensions and a tolerance of ± 0.5 mm for the notch angle. The specimen configuration and dimensions are shown in Fig. 4.

In the Iosipescu test, specimens with two symmetric V-shaped notches through the height were used. Notches in all the specimens have angles $\phi=90^\circ$ as the original Iosipescu specimen. Depths of notches were about 20% of specimen heights. The shear modulus is found from the slope of the stress-strain curve, obtained from the shear tests for different directions.

The average shear stress applied through the notched section and shear strength of the specimen is:

$$S = \frac{P_{\max}}{L.t} \quad (1)$$

where

P : applied load

L : specimen height at notch location

t : specimen thickness

Dimensions in mm

Fig. 4: Shear test specimen and its dimensions

c) Bearing test

Net tension, shear, and bearing are the main failure modes encountered in composite structural applications. A combination of these, i.e. mixed modes, may also appear. Net tension occurs catastrophically and presents the least strength. Therefore, it is an unwanted mode. Designers are required to obtain the optimum E/d and W/d ratios to get the bearing mode, which shows the highest strength in pinned-joint uses [13/.

The bearing tests are performed according to ASTM D953. The specimens were produced in the following manner: While keeping the E/d ratio as 4, the W/d ratio is varied as 2, 4, 6, and 8; and maintaining W/d as 4, E/d is changed as 2, 4, 6, and 8 (Figure 5). These 2 mm thick specimens were drilled by a modified high-speed steel drilling tool with three sharp contact points to prevent fuzzy edges. In this way, a 6.5 mm diameter hole from a fixed distance of $L=80$ mm along the symmetry axis is obtained on the specimens. A hardened and polished pin was later inserted in the hole without clearance. Then, experiments were performed by means of a custom made fixture on a 100kN loading capacity Instron-8516+ universal testing machine with a speed of 1.3mm/min. The maximum load, $P_{\max}$,

Fig. 5: The geometry of the pinned-joint problem.

obtained from the tests was recorded and then the maximum bearing strength was calculated by using the following relation.

$$\sigma_b = \frac{P_{\max}}{dt} \quad (2)$$

where d is the hole diameter and t is the thickness of the plate.

4. RESULTS AND DISCUSSION

a) Tensile properties

The angular variations of the tensile strength are shown in Figure 6. It can be seen from Figure 6 that the maximum tensile strength is obtained in the wale and course directions, and the values of each direction are nearly the same. The minimum value of tensile strength

Fig. 6: Angular variation of tensile strength

is, however, obtained at around the directions of 45° and -45° . Although the tensile strength curve is roughing with respect to the plate angle θ , its values do not change considerably. As a result of this, it can be said that the tensile properties of the material show approximately isotropic feature. Some failed photographs of the specimens were given for critical points.

The properties of Young's modulus with respect to θ are shown in Figure 7. The general scene of the curve gives a similar character to that of the tensile strength curve. While the maximum values of Young's modulus

reach both $\theta=90^\circ$ and -90° , the minimum values reach $\theta=45^\circ$ and -45° .

b) Shear properties

The angular variations of shear strength and shear modulus of the specimens are shown in Figures 8 and 9. These figures reveal that maximum shear strength and shear modulus values are observed in the 60° and -60° directions while the minimum shear values are observed in the 45° and -45° directions. The variation of the shear curves are also roughing with respect to the plate angle,

Fig. 7: Angular variation of Young's modulus

Fig. 8: Angular variation of shear strength

Fig. 9: Angular variation of shear modulus

θ . It was seen from the figures that the intervals of the shear strength and shear modulus changing along the vertical axis are not very wide. It can be said that the properties of shear strength and shear modulus also give isotropic features. Two failed specimens of photography were given in Figure 8 for both $\theta=60^\circ$ and $\theta=-45^\circ$ which have the biggest and the least shear strength respectively.

c) Bearing properties

The bearing strengths in course directions are shown

in Figures 10 and 11. The bearing strength values are highly dependent on the E/d ratio. While the W/d ratio is constant ($W/d=4$), bearing strength increases with increasing E/d ratio and takes its maximum value at $E/d=4$ (Fig.10). After the $E/d=4$ ratio, bearing strength is slightly lower than the maximum value, but constant.

While the E/d ratio is constant, ($E/d=4$), bearing strength does not change considerably with increasing W/d (Fig. 11). But it takes its maximum value at the ratio of $W/d=4$. After the $W/d=4$ ratio, bearing strength is also decreased slightly. The bearing strength takes its minimum value at $W/d=8$.

Fig. 10: Effect of edge distance ratio on bearing strength

Fig. 11: Effect of side distance ratio on bearing strength

While failure modes are investigated, all the E/d and W/d points give the bearing mode, which is the best mode of resisting load, except while W/d and E/d are 4 and 2, respectively. At these points the failure mode is net-tension, which is the weakest mode.

CONCLUSION

In this paper, the mechanical properties including: tensile and shear properties of the 1×1 rib knitted fabric composites were determined in five directions at 0°, 30°, 45°, 60°, 90°, and the bearing tests were performed for the different ratio of the edge distance to the pin diameter (E/d), and the ratio of the specimen with to the pin diameter (W/d) in course directions. As a result of experimental work, the following results are found;

- Maximum tensile strength is obtained in the wale and course directions; however, the minimum value of tensile strength is obtained at around the directions of 45° and -45°.
- The maximum values of Young's modulus reach $\theta=90^\circ$ and -90° , on the other hand, minimum values at $\theta=45^\circ$ and -45° .
- Maximum shear strength and shear modulus values are observed in the 60° and -60° directions while minimum values are observed in the 45° and -45° directions.

- For all E/d and W/d points, the failure modes give bearing mode except W/d=4 and E/d=2
- Bearing strength changes considerably with increasing E/d. But it takes its maximum value at the ratio of W/d=4 and E/d=4.
- An important result is that the tensile, shear, and, bearing strength of the knitted fabric composite is reasonably isotropic.

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