Effect of yarn twist on mechanical properties of glass fibre reinforced composite rods

A Jebastin Rajwin ¹, V R Giridev & M Renukadevi
Department of Textile Technology, Anna University, Chennai 600 025, India

Received 28 April 2011; revised received and accepted 1 December 2011

Effect of twist of glass yarns on the tensile, flexural and interfacial shear properties of composites has been studied. The glass fibre reinforced composite rods have been prepared by hand pultrusion technique with various twist levels. It is found that with the increase in twist level in yarns, the tensile, flexural and interfacial shear strength properties of the composites increase up to 0.25 TPI, 1.0 TPI and 0.75 TPI respectively, followed by decrease in the properties of the composites.

Keywords: Composite rod, Flexural strength, Glass fibres, Interfacial shear strength, Tensile strength, Yarn twist

1 Introduction

Composites are engineered materials formed by a combination of two or more components namely reinforcement and matrix. The reinforcement material is the hardest, strongest and stiffest component which is embedded in the matrix. The purpose of matrix is to aid in transmission of applied loads to the reinforcement and protect the latter from external damage¹. As the composites is comprised both reinforcement and matrix, the properties of the composites is influenced by the type of fibre, type of resin, ratio of fibre to resin and geometry and orientation of the reinforcement in the composites. It has been well established by the researchers that the fibre volume fraction plays a significant role in contribution to the strength of the composites². It should be nevertheless not forgotten that the interaction between the reinforcement and the matrix at the interface also plays a crucial role in mechanical performance of the composite³.

In a composite with constant fibre volume fraction, studies have shown that the decrease in fibre diameter has resulted in increase in strength of the composites which is attributed to the high surface to volume ratio⁴. Generally, all the reinforcement is made from filaments which exist as straight strands having their own inherent disadvantages. As all the filaments in the strand do not possess uniform properties, the strength of the composites is dependent upon the weak spot in the filaments (broken filament in a strand). Twisting of the strands will help to overcome the above limitations as it makes the yarn monolithic. Twisting of yarns will induce lateral cohesion leading to ease of handling of the yarns during preform fabrication. A twisted yarn under tension will induce an internal force in the transverse direction, which, in turn, generates frictional forces among the fibres. Twisting of yarns aids in localizing the micro damage and aids in the improvement in the failure strength of the yarns⁵-⁸.

A weak interface generally results in low strength and stiffness but high resistance to fracture, whereas a strong interface produces high strength and stiffness, but often low resistance to fracture⁷-⁸. Moreover, in composites the interface plays a key role in transferring the stress from the matrix to the fibres⁹-¹¹. Studies on the effect of twisting on the interfacial properties and mechanical properties of the composites are limited even though lot of researchers have carried out studies on the effect of twist on the mechanical performance of yarns. The present paper aims at studying the effect of twist on the tensile, flexural and interfacial shear strength characteristics of the glass fibre reinforced composites.

2 Materials and Methods

2.1 Materials

Commercial grade of epoxy resin along with hardener (Araldite LY556/HY 951) was procured from Javanthi Enterprises, Chennai. E–Glass
multifilament strands of count 66 tex were procured from United Technologists, Chennai.

2.2 Methods

2.2.1 Twisting of Glass Strands
Twist required for the strand was given by single yarn twist tester as per ASTM D 11423 standard. The glass strands were twisted about five twist levels (0.25, 0.50, 0.75, 1.00 and 1.25 TPI) by using the above method.

2.2.2 Composite Preparation
The glass composite rods were produced by hand pultrusion technique (Fig. 1). Hollow cylindrical polypropylene tubes of diameter 5 mm were taken as mold. Schematic diagram of the process along with the photograph of the specimen is also given in Fig. 1.

The glass strands were inserted through the hollow tube and resin was pultruded into the hollow tube. The pultruded samples within the hollow tube were cured at room temperature for 24 h and the composite specimens were removed from the tube for further testing. The fibre volume fraction of the composite was kept constant at 60% for all specimens.

2.3 Test Methods

2.3.1 Tensile Strength
The tensile properties of the twisted yarns and impregnated twisted yarns were tested in universal tester (Instron 3369 model, USA) according to ASTM D638 standard.

2.3.2 Flexural Strength
The flexural strength of the composite rods was tested according ASTM D790 standard. The flexural strength for cylindrical rods was calculated using the following formula:

\[ \text{Flexural strength} = \frac{8FL}{\pi d^3} \]

where \( F \) is the maximum load acting on the specimen (N); \( L \), the span length (mm); and \( d \), the diameter of the specimen (mm).

2.3.3 Interfacial Shear Strength
The setup used for the measurement of IFSS using single fibre pull out test is given in Fig. 2(a). The embedded length of the reinforcement in the matrix was about 3mm. The reinforced shear strength (\( \tau \)) is calculated using the following relationship:

\[ \tau = \frac{F_{\text{max}}}{\pi dl_e} \]

where \( \tau \) is the interfacial shear strength (MPa); \( F_{\text{max}} \), the maximum debonding force (N); \( l_e \), the embedded length (mm); and \( d \), the diameter of the fibre (mm).

3 Results and Discussion

3.1 Effect of Twist on Tensile Properties of Glass Strands and Composite Rods
The tensile properties of glass strands depend upon the strength of unidirectional filament and the weak spot present in the filament. Table 1 and Fig. 3 show the effect of twist on tensile properties of glass strands and composite rods. It can be observed from the Table 1 that with increase in twist imported to the yarns, the tensile strength increases up to 0.25 TPI and then decreases. The increase in strength can be attributed to the better interfilament cohesion and localization of micro damage of the filaments. After 0.25 TPI, the

---

Fig. 1 — Preparation of composite rod (a) schematic diagram of the process, (b) composite rod specimen, and (c) fractured composite specimen

Fig. 2 — Single fibre pull-out test (a) experiment setup, and (b) specimen preparation
tensile strength decreases due to failure of individual filaments in the strands. The twisting of glass strands provides ease of handling and prevents damage during composite fabrication.

Figures 2 and 3 show that the tensile strength of twisted yarns reinforced composite rods increases up to 0.75 TPI. With further increase in twist level, the tensile properties of the composites drop down. It can also be observed from the Table 1 that the tensile properties of composites are higher as compared to the yarns. Moreover, the increased tensile strength of the composites is observed at higher twist levels of yarns compared to the tensile strength of raw yarns.

When twisted yarns are impregnated in resin, apart from lateral cohesion between filaments, the bonding shear strength between the fibre and the matrix in composite and transverse pressure play a vital contribution of the composite. The higher strength at 0.75 TPI may be due to the better interfacial adhesion of filament and matrix. Further increase in twist level leads to decrease in tensile strength.

3.3 Effect of Twist on Interface Properties of Composite Rod

Interfacial bonding plays a significant role in improving the tensile and flexural properties of the twisted yarn impregnated composites. The most common parameter to describe the interfacial strength is interfacial shear strength.

Single fibre pull-out test has been one of the most advantageous methods for determining interfacial strength, as it provides an understanding of debonding force as a function of displacement. The analysis of typical load-displacement curve can be seen in Fig. 5 and classified into following three stages:

- Stage I (0 < F < F_d) — Depicts zone where linear elastic behaviour of the fibre-matrix system was observed and the fibre-matrix remains intact.

Table 1 — Characteristics of twisted yarn and impregnated composites

<table>
<thead>
<tr>
<th>Twist level, TPI</th>
<th>Yarn tenacity, gf/tex</th>
<th>Tensile strength, MPa</th>
<th>Flexural strength, MPa</th>
<th>Interfacial shear strength, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28.92 (4.02)</td>
<td>117.89 (3.12)</td>
<td>147.95 (3.19)</td>
<td>5.55 (4.10)</td>
</tr>
<tr>
<td>0.25</td>
<td>31.05 (5.58)</td>
<td>135.50 (3.02)</td>
<td>201.66 (5.25)</td>
<td>7.04 (5.48)</td>
</tr>
<tr>
<td>0.50</td>
<td>30.59 (4.92)</td>
<td>166.56 (5.21)</td>
<td>295.74 (3.38)</td>
<td>8.33 (4.68)</td>
</tr>
<tr>
<td>0.75</td>
<td>29.26 (3.65)</td>
<td>203.32 (5.03)</td>
<td>396.28 (4.24)</td>
<td>9.40 (3.30)</td>
</tr>
<tr>
<td>1.00</td>
<td>28.29 (4.32)</td>
<td>117.72 (3.77)</td>
<td>424.08 (5.51)</td>
<td>7.03 (3.25)</td>
</tr>
<tr>
<td>1.25</td>
<td>27.33 (3.35)</td>
<td>71.94 (5.39)</td>
<td>365.37 (3.55)</td>
<td>5.35 (2.40)</td>
</tr>
</tbody>
</table>

Values in parentheses are CV%.
Stage II ($F_d < F < F_{\text{max}}$) — Zone shows where debonding occurs by means of crack propagation along the embedded fibre length.

Stage III ($F_{\text{max}}$) — Zone shows where crack propagation becomes unstable and the whole embedded fibre length becomes fully debonded.

From Figs 4 and 5, it can be seen that the pull out force increases with the increase in twist upto 0.75 TPI and with further increase in twist level there is a drop in pull out force, indicating poor interfacial bonding. This is better correlated with the tensile properties of the composites. The average IFSS ($\tau$) of twisted yarn impregnated composites is given in Table 1. From the table, it can be seen that $\tau$ values increase upto 0.75 TPI. This is attributed to increased mechanical interlocking thereby providing better interfacial bonding.

4 Conclusion

4.1 Twisted yarns display higher tensile strength upto 0.25 TPI. Further increase in twist leads to reduction in tensile properties.

4.2 Tensile properties of twisted yarn impregnated composite rods were found to increase upto 0.75 TPI and flexural properties increase upto 1.0 TPI, followed by decrease in tensile and flexural properties.

4.3 The pull out force increases with increase in twist in yarns upto 0.75 TPI and further increase in twist leads to decrease in pull out force.

4.4 The interfacial shear strength ($\tau$) is found to be maximum at 0.75 TPI, indicating better bonding between reinforcement and matrix.

Acknowledgement

The authors thankfully acknowledge the support given under UGC-DRS-Phase I program for the instrumental facilities to carry this work.

References