The Effect of Fiber Twist on the Mechanical Properties of Natural Fiber Reinforced Composites

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Abstract: The use of natural fibers as reinforcements in polymers, gives interesting alternatives for production of low cost and ecologically friendly composites. In this paper, the effect of fiber twist on the mechanical properties of sisal fiber yarns reinforced composites was investigated. Three different levels of twist of sisal fiber yarns reinforced composites were prepared through compressive moulding. It was shown that with the increase of fiber twist level, the mechanical properties of its reinforcing composites were dropped gradually. A theoretical model was proposed to predict the tensile strength of sisal fiber twisting yarns reinforced composites and showed good agreement with the experimental results.

Keywords: *natural fiber, sisal yarns, twist, mechanical properties*

1. Introduction

The growing environmental awareness and new rules and regulations are forcing the industries to seek more ecologically friendly materials for their products. The use of natural fibers for the reinforcement of composites has lately received increasing attention, both by academia and by industry [1]. Due to its high specific strength and modulus [2], natural fibers are promising reinforcements for fiber reinforced composite materials.

However, the length of natural fibers is limited due to their naturally growing characteristics. Natural fibers are always short and discontinuous. The relatively poor mechanical properties of short natural fiber reinforced composite, which cannot fully utilize the strength and stiffness of the fibers, are not suitable for most structural components [5]. In order to obtain the excellent mechanical properties of natural fibers as much as possible, the production of continuous natural fibers is necessary. However, natural fiber cannot be in continuous form without being twisted [Fig.1][4]. With regard to the influence of fiber twist to natural fiber yarns, Goutianos and Peijs [3] reported that with the increase of twisting level, the tensile strength of dry roving yarns increased gradually. When the strength reached a maximum point, it would decrease with further increasing twist. However, the strength of impregnated yarns would drop gradually with the increase of the level of fiber twist.

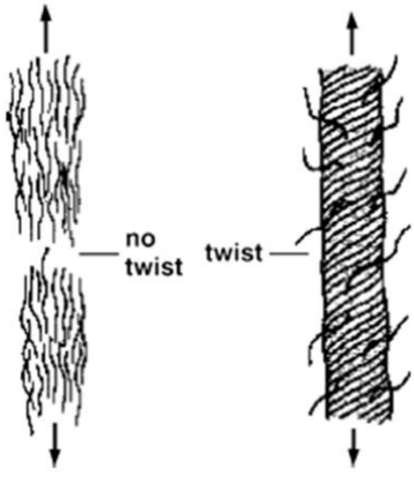

Fig.1 Twisted and non-twisted yarns

Therefore, it is necessary to understand the effect of fiber twist on the mechanical properties of natural fiber reinforced composites, so that the predictive model of its mechanical properties could be established. In this paper, the influence of fiber twist on the sisal fiber yarns reinforced composites was investigated. Tensile and flexural tests were applied to compare the mechanical properties of non-twist sisal fiber yarns with those of different levels of twisted yarns reinforced composite. The effect of fiber twist on the reinforcing fibers and the interface between fiber and matrix was revealed. Based on the above, a theoretical model was proposed to predict the mechanical properties of twisted natural fiber reinforced composites.

2. Experiment

2.1 Materials

Sisal fibers (Guangxi Province, China) and Phenolic resin (Shandong Province, China) were used to make sisal fiber yarns reinforced composites.

2.2 Composites fabrication

In order to investigate the effect of fiber twist on the mechanical properties of sisal fiber yarns reinforced composites, non-twist and two different levels of twist sisal fiber yarns were prepared. Sisal fibers were first cut to 300mm long, and combined each bunch of fiber together to make the sisal fiber yarns. The yarns were then manually twisted to different levels of twist (30 turns/m and 50 turns/m respectively). The twisted sisal fiber yarns were made into unidirectional sheet and then impregnated with the resin. The composites were then made by hot press. The fiber volume fractions of the three types of composites were all similar which were around 66%. The fabrication process flow of the unidirectional sisal fiber yarns reinforced composites is depicted in Fig.2.

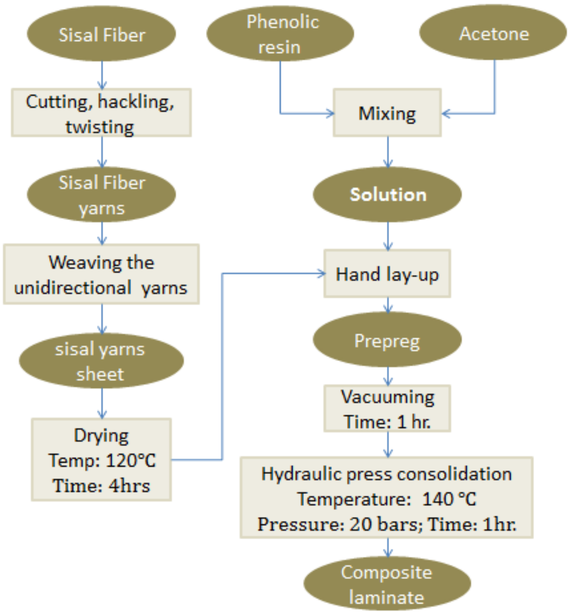

Fig.2 The fabrication process flow of the unidirectional sisal fiber yarns reinforced composites

3. Result and Discussion

3.1 Mechanical properties

The effects of different levels of fiber twist on the flexural modulus and strength are shown in Fig.3 and Fig.4, respectively. The results showed that the higher the level of the fiber yarns twist, the lower the flexural properties of natural fiber reinforced composites. The reduction of the flexural properties could be very high, almost 30% decline of the flexural modulus from non-twist sisal fiber yarns to 30 turns/m twisted sisal fiber yarns. With the increase of the twist level, the tensile properties also dropped as shown in Fig.5 and Fig.6, which are similar to the flexural results.

There were three main reasons which might lead to the decrease of the mechanical properties. Firstly, with the increase of the level of

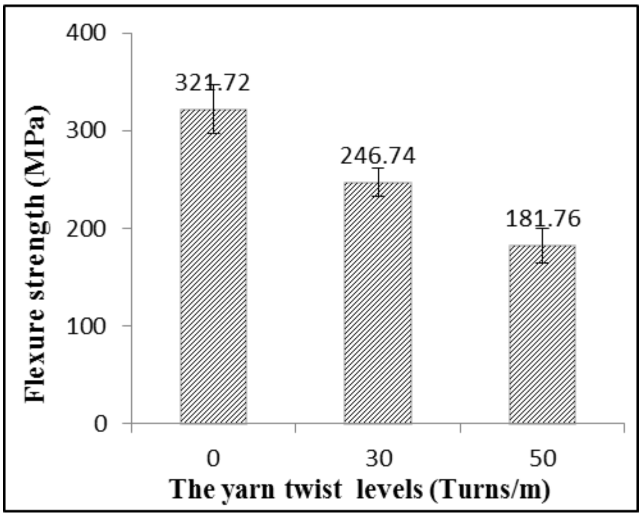

Fig.3 Flexure strength of obtained composites

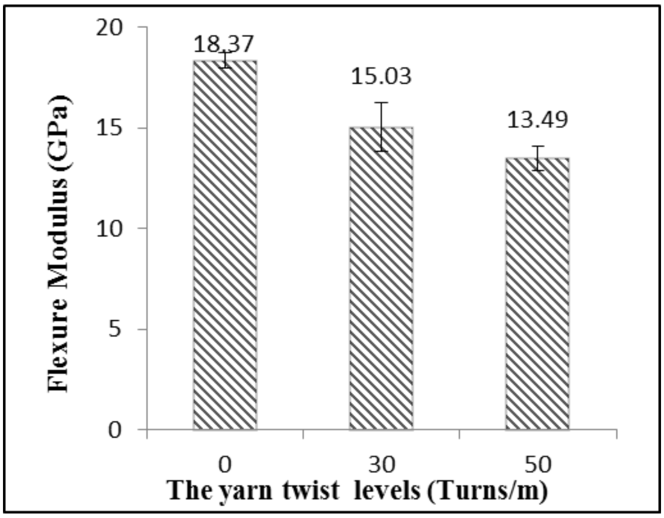

Fig.4 Flexure modulus of obtained composites

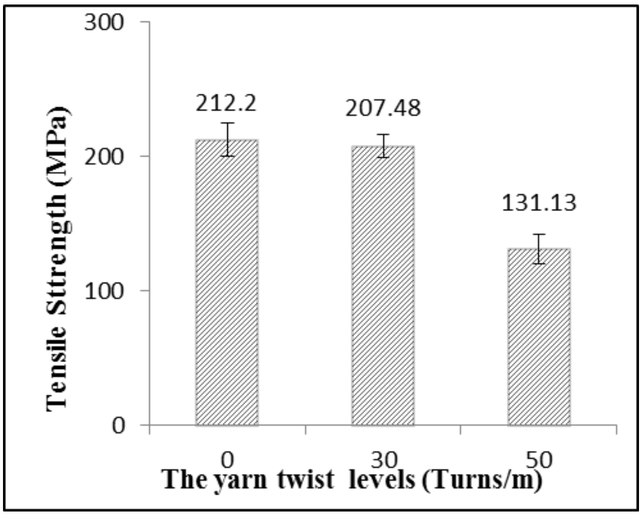

Fig.5 Tensile strength of obtained composites

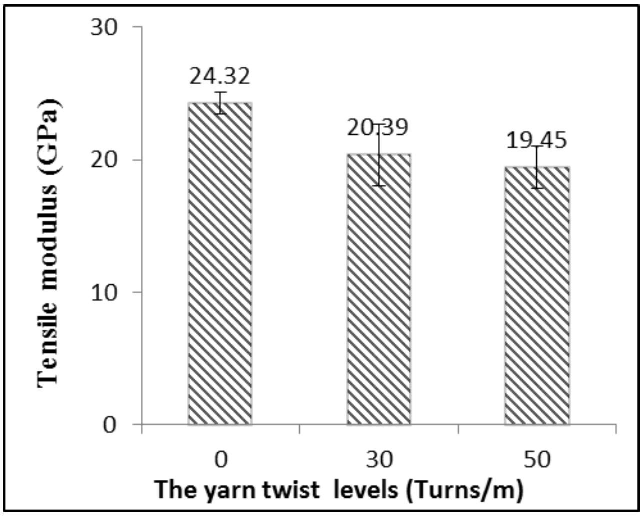

Fig.6 Tensile modulus of obtained composites

fiber twist, the angle between fiber orientation and the direction of applied load increased as illustrated in Fig.10[7]. The relationship is shown in Table 1. Therefore, the loading capacity of the composites decreased. Moreover, in the operation of twist insertion during the ring spinning, the yarns were prestressed on each component fiber. The prestress also increased with the rise of the twisting angle, which would also lower the loading capacity of the reinforcing fibers in the composites. When the twisted yarns were impregnated with polymeric resin such as phenolic resin, the permeability of the yarns decreased and impregnation of the yarns became more difficult, due to the high level of the twist (see Fig.7). Consequently, the interfacial property between sisal fiber and phenolic resin would be impaired dramatically. The fracture mode of no twist and 50 turns/m twisted sisal fiber yarns reinforced composites were shown in Fig.8 and Fig.9 respectively. It can be clearly observed that all the non-twist yarns reinforced composites showed fiber breakage fracture. While for the 50 turns/m twisted yarn reinforced composite, interfacial debonding is the major fracture mode, which was caused by the poor permeability between fibers and matrix.

Twist level(turns/m)	Periphery twist angle(°)	Mean twist angle(°)
0	0	0
30	18.96	13.18
50	39.87	27.91

Table 1 The relationship of twisting angles with fiber twist level

Fig 7 High level of sisal fiber yarn twist

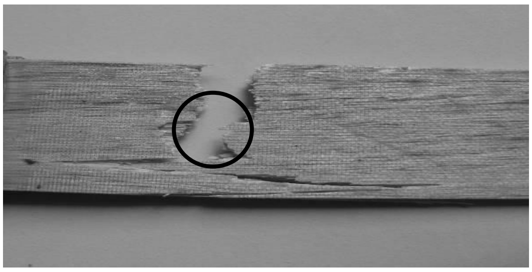

Fig 8 The fracture mode of non-twist yarns reinforced composite

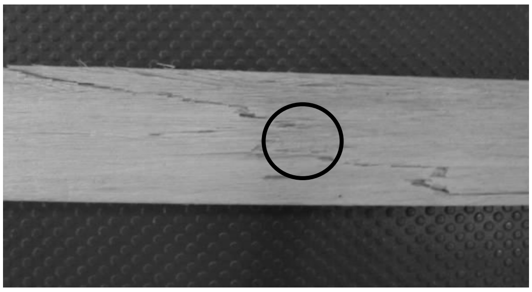

Fig.9 The fracture mode of 50 turns/m twist yarns reinforced composite

3.2 Prediction model

In the progress of twist insertion during ring spinning, the initial filament of parallel fibers was converted into a helical yarn structure by simultaneously twisting all fibers around the yarn axis. Therefore, the radial location of a given fiber in the cross section of the yarn determined its twisting angle. More specifically, the fibers had larger twisting angles at the periphery than in the interior of the yarn [6]. So the mean fiber twisting angle of the yarn was meaningful for the prediction model. The methods to estimate the mean twisting angle were depicted in Fig. 10, and were given by Eq. (3) and Eq. (4) [7].

Owing to all sisal fibers were simultaneously twisted around the yarn axis, the length (L) in the yarn direction of a single twist was same for all fibers.

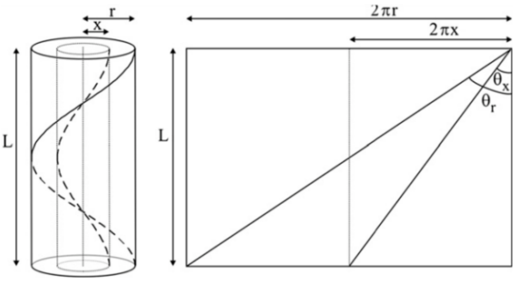

Fig.3 Model of the twisted fiber structure in a ring spun yarn

Thus, the twisting angle (θ_x) of each fiber can be calculated through the given radial location (x) between 0 and the yarn radius (r) as Eq. (1).

$$\tan\theta_x = \frac{2\pi x}{L} \Longrightarrow \theta_x = \tan^{-1}\frac{2\pi x}{L} \qquad (1)$$

Considering the proportional contribution of θ_x, the mean fiber twisting angle (θ_{mean}) could be obtained by Eq. (2) [7].

$$\theta_{mean} = \tan^{-1}\frac{2\pi r}{L} - \frac{L}{2\pi r} + \frac{L^2}{4\pi^2 r^2}\tan^{-1}\frac{2\pi r}{L} \quad \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

And then substitute Eq. (1) into Eq. (2) to eliminate L and r.

$$\theta_{mean} = \theta_r + \frac{\theta_r}{(\tan\theta_r)^2} - \frac{1}{\tan\theta_r} \qquad (3)$$

It was demonstrated that (θ_{mean}) is a function of the fiber twisting angle at the yarn surface (θ_r) only. Thus, the loading capabilities of sisal fiber yarns P_y could be expressed by Eq. (4)

$$P_y = N * \sigma_f * A_f * \cos\theta_{mean} \tag{4}$$

And the fracture strength of yarns (σ_{fy}) is given in Eq. (6)

$$\sigma_{fy} = \frac{P_y}{A_y} = \frac{N * \sigma_f * A_f * \cos\theta_{mean}}{A_y} \tag{5}$$

The axial tensile strength was expressed as σ_f and the cross sectional area of sisal fibers and sisal yarns was indicated by A_f and A_y, respectively. The rule of mixture was applied to calculate the ultimate stress of the composite.

$$\sigma_1 = V_f\sigma_f + V_m\sigma_m = \frac{V_f * N * \sigma_f * A_f * \cos\theta_{mean}}{A_y} + V_m\sigma_m \qquad \cdots\cdots\cdots\cdots\cdots\cdots \tag{6}$$

where σ_m was the tensile strength of phenolic resin and V_m was its volume fraction. Meanwhile the fiber volume fraction was V_f . The comparison of theoretical and experimental strength of different level of twist yarns reinforced composite was shown in Table 2. The experimental strength of 30 turns/m yarns reinforced composites was similar to the theoretical strength. As for the 50 turns/m yarns reinforced composites, the theoretical strength was higher than the experimental strength. The poor permeability between fibers and matrix and unstable mechanical properties of sisal fibers could lead to the deviation between experiment and theoretical calculation.

Twist level (turns/m)	Theoretical Strength (MPa)	Experimental Strength (MPa)
0	/	212.2
30	206.61	207.48
50	177.51	131.13

Table 2 Comparison of theoretical and experimental strength of different level of twist yarns reinforced composite

4. Conclusion

The high twisting level of sisal fiber yarns impaired the mechanical properties of its reinforced composites. The changes of orientation angles between reinforcing fibers and the applied load, the prestress introduced by the manufacturing of the natural fabrics and the poor impregnation cause by the twisting all contributed to the decline of the mechanical properties. A theoretical model was proposed to predict the mechanical properties of natural fiber reinforced composites, which showed quite good agreement with the experimental results.

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