Simulation Study on Tensile Strength of Carbon Fiber Twisted Sewing Thread

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Abstract. The twist of the suture is an important parameter that affects the suture effect. If the suture is not twisted, the suture is easy to wear and fluff during the sewing process, resulting in thread breakage. At the same time, that will affect the suture effect and the strength of the suture itself. The article uses experiments and simulations to compare the mechanical properties of carbon fiber twisted threads. Refer to GB /T 3362—“Test Method for Tensile Properties of Carbon Fiber Multifilament” to test the tensile strength of T700-12K carbon fiber tow. And in ABAQUS, the three-dimensional Hashin damage criterion is used for 20 twists/m, 50 twists/m, and 80 twists/m subjected to finite element prediction. The results show that the carbon fiber sewing thread with 80 twists/m has higher tensile strength than the carbon fiber sewing thread with 20 twists/m and 50 twists/m.

1. Introduction

At present, a great deal of research has been done on the finite element simulation of mechanical properties of stitched fabric reinforced composites. K. T. Tan[1] et al. used coupled continuous shell element and bonding element to predict the compression strength of stitched fabric reinforced composite materials after impact by finite element method, and this method has a good prediction effect. A. Margossian[2] et al. used the finite element software PAM--Form to simulate the local stitching process of fabric, and found that the finite element model can be used to determine the influence of joint on forming behavior, and optimize the stitching process. Li Chen[3] et al. established a three-dimensional finite element analysis model of the sutured one-way plate, taking into account the in-plane and out-plane bending of the fibers caused by suturing, and the results showed that the model could well predict the tensile and compression properties of the sutured one-way plate. Guo Y, Jiang[4] et al. through the open-end bending test (ENF) method, the effect of the type II interlaminar fracture toughness of the stitched composite material and the suture density on the type II interlaminar fracture toughness of the stitched composite material was studied. It was found that the suture thread changed the failure mode of the composite material. Based on the above research, the finite element model of carbon fiber sewing thread with different twist was established in this paper, and the finite element prediction of the tensile strength of carbon fiber sewing thread with different twist was carried out to provide reference for the research of carbon fiber sewing technology.

2. Experimental Part

2.1. Main Raw Materials and Equipment

T700-12K carbon fiber (Shanghai Lishuo Composite Material Co., Ltd.); UTM5205X,200kN microcomputer controlled electronic universal testing machine (Shenzhen Sansi Zongheng Technology
2.2. Experimental Program and Results

UTM5205X, 200kN microcomputer controlled electronic universal testing machine was used to test the tensile properties of carbon fiber tow, including tensile strength, elastic modulus and other indicators. Refer to GB/T 3362—2017 "Test Method for Tensile Properties of Carbon Fiber Multifilament" was tested. In this paper, there are 5 samples preparation is shown in Figure 1. The experimental conditions were set as follows: constant elongation (CRE) at room temperature, 150 mm interval between upper and lower clamps, and 10 mm/min stretching speed\(^{[3]}\).

![Test samples](image1.png)

**Figure 1.** Test samples

Tensile experiment data is shown in Table 1.

| Test samples | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 |
|--------------|--------|--------|--------|--------|--------|
| Load         | 668N   | 645N   | 610N   | 755N   | 667N   |

3. Finite Element 3D Model Construction

3.1. Twist of Carbon Fiber Sewing Thread

Special system twist \(T_s\):

\[
T_s = \frac{\text{The sum of the sample twists}}{\text{The clamping length of the sample (mm) } \times \text{Number of test}} \times 100 (\text{twist/10cm})
\]  

(1)

Metric count twist \(T_m\):

\[
T_m = \frac{\text{The sum of the sample twists}}{\text{The clamping length of the sample (mm) } \times \text{Number of test}} \times 1000 (\text{twist/m})
\]  

(2)

3.2. The Geometry of Twisted Sewing Thread

In this paper, the metric number of actual twist is used. References show that because the resin has a poor infiltration effect on the sewing thread with the twist higher than 100 twists/m, it is easy to produce the defect of the stitching laminate. Therefore, only the mechanical properties of the sewing thread with 20, 50 and 80 twist/m are studied. The geometrical models of 20 twists/m, 50 twists/m and 80 twists/m carbon fiber sewing thread were established in ABAQUS, with the length of 200mm and the diameter of 1mm. This is shown in Figure 2.

![The geometry of twisted sewing thread](image2.png)

**Figure 2.** The geometry of twisted sewing thread

3.3. Material Parameters

In this paper, the material parameters of twisted carbon fiber sewing thread are shown in Table 2.
Table 2. Material parameters

|    | E_1  | E_2  | E_3  | \(\nu_{12}\) | \(\nu_{13}\) | \(\nu_{23}\) | G_{12} | G_{13} | G_{23} |
|----|------|------|------|-------------|-------------|-------------|--------|--------|--------|
|    | 230000 | 14000 | 14000 | 0.324       | 0.324       | 0.45       | 9000   | 9000   | 5000   |

4. Damage Criterion of Twist Sewing Thread

For the initial damage of composite materials, most of the existing research work adopts the failure criterion of single-layer composite materials, and the most representative ones are Hashin criterion and Tsai-Wu criterion. In this paper, the Hashin criterion is used as the damage criterion of the fiber bundle. The resin-rich matrix is generally considered to be an isotropic material. Considering the complex stress state of the resin-rich matrix region, the Mises strength failure criterion is used as the material failure criterion.

The specific form of Hashin failure criterion is as follows:

**Axial tension-shear damage of fiber bundle (M1) \(\sigma_{xy} \geq 0\)**

\[
\left(\frac{\sigma_x}{X_T}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2 \geq 1
\]

(3)

**Axial compression shear damage of fiber bundles (M2) \(\sigma_{xy} < 0\)**

\[
\left(\frac{\sigma_y}{X_C}\right)^2 \geq 1
\]

(4)

**Transverse tension and shear damage of fiber bundles (M3) \(\sigma_{xy} + \sigma_z \geq 0\)**

\[
\left(\frac{\sigma_x + \sigma_y}{Y_T}\right)^2 + \left(\frac{\sigma_z}{S_{23}}\right)^2 + \left(\frac{1}{S_{12}}\right)(\sigma_{23} - \sigma_{22}\sigma_{33}) + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2 \geq 1
\]

(5)

**Transverse compression and shear damage of fiber bundles (M4) \(\sigma_{xy} + \sigma_z < 0\)**

\[
\left(\frac{\sigma_x + \sigma_y}{2S_{12}}\right)^2 + \left(\frac{\sigma_z + \sigma_y}{Y_C}\right)^2 + \left(\frac{\tau_{12}^2 + \tau_{23}^2 + \tau_{31}^2}{2S_{12}}\right) + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2 \geq 1
\]

(6)

where, \(X_T\) and \(X_C\) are the axial tension-compression strength of the fiber bundle respectively; \(Y_T\) and \(Y_C\) are respectively the transverse tension-compression strength of the fiber bundle; \(S_{12}, S_{13}\) and \(S_{23}\) are shear strengths.

von Mises stress the concrete form of strength criterion is:

\[
(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{12}^2 + \tau_{23}^2 + \tau_{31}^2) = 2\sigma_m^2
\]

(7)

where, \(\sigma_m\) is the matrix rupture strength.

In this paper, the user-defined material subroutine UMAT of ABAQUS is used to judge the integral point of component material element by damage criterion. After the damage occurs, the corresponding material properties are degraded according to the corresponding failure mode of damage criterion.

5. ABAQUS Simulation Forecast

ABAQUS is a finite element software dedicated to engineering simulation, which can solve a series of simple or relatively complex linear and nonlinear engineering problems. In ABAQUS, the carbon fiber twisted sewing thread is meshed with a hexahedral three-dimensional eight-node reduced integral unit.
(C3D8R). At the same time, proper mesh refinement is carried out in areas with greater stress, as shown in Figure 3.

![Mesh model of twisted carbon fiber sewing thread](image)

Figure 3. Mesh model of twisted carbon fiber sewing thread

When performing tensile simulation analysis in ABAQUS, two carbon fiber tows in the sewing thread are set for surface interaction. At the same time, a reference point RP is established on the surface of the carbon fiber tow, and the reference point RP and the cross section of the carbon fiber sewing thread tow are set as a coupling constraint, that is, the two tows in the carbon fiber sewing thread will not detach during the loading process. In order to simulate the tensile experiment more accurately, one end of the carbon fiber sewing thread section is fully constrained, that is, U1=U2=U3=UR1=UR2=UR3 =0, and the other end of the section applies a surface displacement through the reference point RP, using ABAQUS's superior non-linear calculation ability is calculated by the explicit solver module ABAQUS/Explicit.

### 6. Forecast Result

As shown in Figure 4, after analysis and calculation by ABAQUS, the visualization module shows the stress distribution cloud diagram of the carbon fiber sewing thread model after tensile deformation. As shown in Table 3, the maximum stress of 20 twists/m carbon fiber sewing thread is 654.6MPa, and the maximum stress of 50 twists/m carbon fiber sewing thread is 875.6MPa, and the maximum stress of the 80 twists/m carbon fiber sewing thread is 1163MPa. This shows that as the twist increases, the stress borne by the carbon fiber sewing thread also increases, which can improve the interlayer mechanical properties of the carbon fiber composite.

![Stress cloud diagram of sewing threads with different twists](image)

Figure 4. Stress cloud diagram of sewing threads with different twists

| twists  | 20 twists/m | 50 twists/m | 80 twists/m |
|---------|-------------|-------------|-------------|
| S       | 645.6MPa    | 875.6MPa    | 1163MPa     |

Table 3. Tensile stress of different twists

The prediction result selects the load comparison curve of the reference point RP of the sewing thread. As shown in Table 4, it is found through comparison that as the twist of the carbon fiber sewing thread
increases, the greater the ultimate damage load that the sewing thread can withstand. The maximum load of 20 twists/m carbon fiber sewing thread is 445N, the maximum load of 50 twists/m carbon fiber sewing thread is 596N, and the maximum load of 80 twists/m carbon fiber sewing thread is 790N.

Table 4. Loads with different twists

| twists   | 20 twists/m | 20 twists/m | 80 twists/m |
|----------|-------------|-------------|-------------|
| load     | 445N        | 596N        | 790N        |

7. Conclusion
In this paper, the tensile failure of carbon fiber sewing threads with 20 twists/m, 50 twists/m, and 80 twists/m are respectively predicted by the finite element method. It is concluded that as the sewing thread is twisted, the stress of the sewing thread will increase. The tensile stress that can withstand increases accordingly, which improves the interlayer mechanical properties of carbon fiber composite materials and provides a reference for the sewing technology of carbon fiber composite materials. At the same time, the wear of the sewing thread should be considered in the carbon fiber sewing process, and further analysis will be carried out in future research.

Acknowledgments
The authors acknowledge the financial supports from National Natural Science Foundation of China (No.51975470).

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