Mechanical Deformation Mechanism of Fiber Reinforced Composites T-joints

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Abstract. In this paper, we focus on the need for ideal theory analytical solution of mechanical deformation mechanism for T-joints. Through removing unnecessary constraints, stress equivalence system of T-joints can be established by force method. Solution equations of unknown nodal forces and the total vertical displacement can also be obtained, and this result can be used to evaluate strength of FRC T-joints.

1. Introduction

Fiber reinforced composite materials (FRC) have advantages of strength and modulus for the super ratio, and should be widely used in modern aerospace structures. As a kind of typical structural unit, T-joints is made up of three pieces of laminated plates and filler. Photograph of fiber reinforced composites T-joints is shown in Fig.1. This structure has assembly advantage over other connection of engineering. T-joints can save a lot of mechanical connection, further reduce the weight and improve the fatigue life of structure.

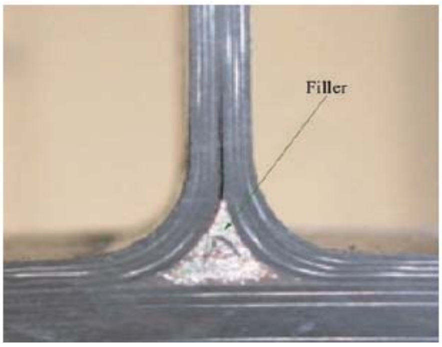

Figure 1. Photograph of fiber reinforced composites T-joints

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On the other hand, the industry is slow to accept this joint structure, because the main reason for hindering the joint structure to get more extensive application is lack of information on the reliability and understanding of its mechanical deformation mechanism [1-3]. Composite joint development is a complex and comprehensive strong technical problem which is considered bearing capacity as the main index of the design requirements, the varieties and properties of structure, fatigue life, experimental and testing, manufacturing process and a series of problems. Some researchers [4-7] analyze finite element method of T-joints structure strength. Because of the complexity of the problem, it is difficult to get ideal theory analytical solution.

2. Deformation theory model of T-joints

T-joints is composed of three co-curing laminated plates in this paper, with film bonding interface and solidification. Arc transitional area is in the Root of joint, and the joints interior is full of filler commonly used foam or one-way belt. Padding around is connected with the laminated plates by film. T-joints measures 200 x 50 x 120mms. The sub-layer number of layer 1, 2, laminated plates is 13 layer, Angle of the layer and the order is (-45/0/45/0/-45/0/0/0/45/0/-45/0/45) with thickness of 1.5 mm. layer 3 laminated plates is 32 layer, and angle of the layer and the order is (45/0/-45/0/0/45/0/-45/0/0/45/0/-45/0/45/-45)with thickness of 4 mm.

Considering the structure symmetry, half of the T-joints is taken to analyze. The length of the AB is l_1, and the height is h_1. The length of the BC is l_2, and the height is h_2. BD Is the circular arc with radius R, The stiffness of AB, BC, BD is EI_1, EI_2, EI_3. Pull force F act on area of D, First, the constraint reaction everywhere can be calculated, then bending moments can also be obtained.

The strength and stiffness value of filler material are often far less than the fiber reinforced composite material, so influence on deformation and damage of T-joints by filler can be ignored. The stress drawing of T-joints is shown in Fig.2.

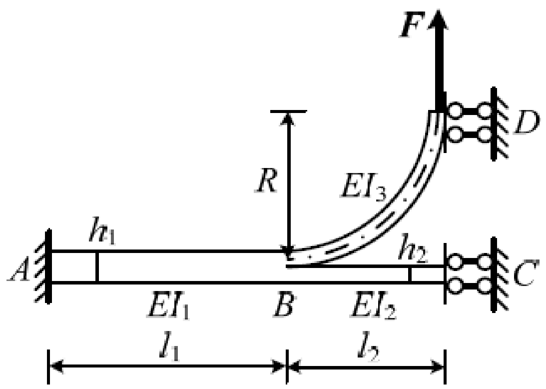

Figure 2. Stress drawing of T-joints

Assuming the width unit of component is 1, section inertia of each part can be obtained as follows.

$$I_1 = \frac{h_1^3}{12}, \quad I_2 = \frac{h_2^3}{12}, \quad I_3 = \frac{(h_1 - h_2)^3}{12} \tag{1}$$

3. Mechanical deformation mechanism

Support reaction of the fourth statically indeterminate structures can be solved by force method, and stress equivalence system of T-joints can be obtained through removing unnecessary constraints of C, D. Combined equations have to be solved in the analysis of the super static determined structure, And unknown nodal forces can be replaced by X_1, X_2, X_3, X_4. The stress equivalence system of T-joints is shown in Fig.3.

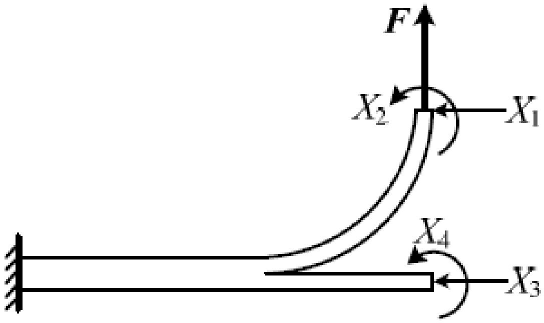

Figure 3. The stress equivalence system of T-joints

Solution equations of unknown nodal forces can be expressed as follows:.

$$\begin{aligned}
\delta_{11}X_1 + \delta_{12}X_2 + \delta_{13}X_3 + \delta_{14}X_4 + \Delta_{1P} &= 0 \\
\delta_{21}X_1 + \delta_{22}X_2 + \delta_{23}X_3 + \delta_{24}X_4 + \Delta_{2P} &= 0 \\
\delta_{31}X_1 + \delta_{32}X_2 + \delta_{33}X_3 + \delta_{34}X_4 + \Delta_{3P} &= 0 \\
\delta_{41}X_1 + \delta_{42}X_2 + \delta_{43}X_3 + \delta_{44}X_4 + \Delta_{4P} &= 0
\end{aligned} \tag{2}$$

In the equation, each coefficient and free items can be obtained by each mechanical subsystem. The coefficient substituted into the force method equation can solve the unknown reactions as follows:

$$\begin{aligned}
X_1 &= \frac{2F[-I_3 l_1^2(\pi-2) + I_1(\pi-4)R^2]}{I_1(\pi^2-8)R^2} \\
X_2 &= -\frac{F[I_3 l_1^2(\pi-4) + I_1(\pi^2-2\pi-4)R^2]}{I_1(\pi^2-8)R} \\
X_3 &= \frac{F\{2I_3 l_1^2 l_2(8-3\pi) + R[(-I_2 l_1^2(\pi^2-8) + 8I_1 l_2(\pi-3)R]\}}{(h_1-h_2)I_1 l_2(\pi^2-8)R} \\
X_4 &= -\frac{FI_2 l_1^2}{2I_1 l_2}
\end{aligned} \tag{3}$$

Vertical displacement under the action of X_1, X_2, X_3, X_4, F can be expressed as follows:.

$$\begin{aligned}
\Delta_{X_1} &= \frac{1}{EI_1}[\int_0^{l_1} X_1 \times R(l_2+x)dx] \\
\Delta_{X_2} &= \frac{1}{EI_1}[\int_0^{l_1} X_2 \times (l_2+x)dx] \\
\Delta_{X_3} &= \frac{1}{EI_1}[\int_0^{l_1} -(l_2+x)\times X_3 \times \frac{h_1-h_2}{2}dx] \\
\Delta_{X_4} &= \frac{1}{EI_2}[\int_0^{l_2} X_4 \times xdx] + \frac{1}{EI_1}[\int_0^{l_1} X_4 \times (l_2+x)dx] \\
\Delta_F &= \frac{1}{EI_1}[\int_0^{l_1} F\times(R+x)\times(l_2+x)dx]
\end{aligned} \tag{4}$$

The total vertical displacement of C can be expressed by $\Delta_C = \Delta_{X_1} + \Delta_{X_2} + \Delta_{X_3} + \Delta_{X_4} + \Delta_F$, then putting equation (4) substituting into equation (3), the equation (5) can be obtained as follows:

$$\begin{aligned}\Delta_C = Fl_1\{-6h_1(h_1-h_2)^3 l_1^2 l_2(l_1+2l_2)(3\pi-8) - l_1[3h_1h_2^3l_1(l_1+2l_2)+(h_1^3h_2l_2-h_1^4l_2)\\ (4l_1+3l_2)](\pi^2-8)R + 24h_1^4l_2(l_1+2l_2)(\pi-3)R^2\} / Eh_1^6(h_1-h_2)l_2(\pi^2-8)R\end{aligned} \quad (5)$$

4. Conclusion

The result of research shows that T-joints support reaction of statically indeterminate structures can be solved by force method and stress equivalence system of T-joints can be obtained through removing unnecessary constraints. Solution equations of unknown nodal forces and the total vertical displacement can be obtained. Ideal theory analytical solution of mechanical deformation for T-joints is established at last and this result can be used to strength evaluation of FRC T- joints.

Acknowledgments

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