Fracture failure analysis of Fiber Reinforced Composites T-joints

Wei Su1,3,*, De-zhi Kong1, Ren-huai Liu1,2,3, Shi-qing Huang2,3
1Science and Technology on Reliability Physics and Application Technology of Electronic Component Laboratory, China Electronic Product Reliability and Environmental Testing Research Institute, Guangzhou, China
2Department of Mechanics and Civil Engineering, Jinan University, Guangzhou, China
3MOE Key Lab of Disaster Forecast and Control in Engineering, Jinan University, Guangzhou, China

*Corresponding author e-mail: suwei5@126.com

Abstract. This paper discusses staple FRP T-joints on the project based on the classical beam theory of Euler-Bernoulli and a theoretical model of energy release rate is set up to discuss fracture propagation of composite T-joints. The paper is further analysis on fracture failure affected by composite panel depth and joints chamfer dimension parameters and so on. The conclusion benefit for extensive use of projects is also summarized.

1. Introduction
In recent years, Fiber reinforced composite materials (FRC) T-joints get more and more extensive application in the actual projects. The strength is affected severely because stress concentration is around the structure cracks. As a kind of typical structural unit, T-joint is made up of three pieces of laminated plates and filler. Fiber reinforced composites T-joints is shown in Fig.1. T-joints can save a lot of mechanical connection, further reduce the weight and improve the fatigue life of structure.

Figure 1. Fiber reinforced composites T-joints
Composite joint development is a complex and comprehensive strong technical problem which is considered bearing capacity as the main index of the design requirements [1-4], the varieties and properties of structure, fatigue life, experimental and testing, manufacturing process and a series of problems. Pradhan [5] uses the method of finite-element to research the influencing factors of strength in mixed joints composites. Kayapo and Dzenis [6] set up the crack of nonlinear finite element model of single lap joint. Strain energy release rate is preferred parameters of fracture mechanics method, and in this paper FRP T-joints on the project based on the classical beam theory of Euler-Bernoulli and a theoretical model of energy release rate is set up to discuss fracture propagation of composite T-joints.

The theoretical model of energy release rate for T-joints
According to the theory of brittle fracture of Griffith, T-type cracks need to absorb energy, at the same time release part when they propagate and form new surface. If the energy absorption rate is greater than the strain energy release rate, crack will be stable, otherwise unstable. 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 $BC$ is $h_2$, and the height is $h_4$. $BD$ 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, and 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. Simplified free-body diagram of T-joints is shown in Fig.2.

![Figure 2. Simplified free-body diagram of T-joints](image)

On the basis of calculation results, the total vertical displacement of $C$ can be expressed by equation (1).

$$
\Delta_c = FL_1\left\{-6h_1(h_1-h_3)l_1^3l_2(l_1+2l_2)(3\pi-8)-l_1[3h_1h_2l_1(l_1+2l_2)+(h_1^2h_2l_1-h_1^2l_2)]
(4h_1+3l_2)(\pi^2-8)R+24h_1^2l_1(l_1+2l_2)(\pi-3)R^2\right\} / Eh_1^3(h_1-h_2)l_2(\pi^2-8)R
$$

Elastic strain energy in linear elastic system can be expressed as follows:

$$
U = \frac{1}{2}F\Delta_c
$$
According to the theory of brittle fracture of Griffith, when the external load is constant, can be expressed as follows:

\[
G = \frac{1}{\pi} \frac{\partial U}{\partial R} = \frac{F}{2\pi} \frac{\partial \Delta_c}{\partial R}
\]  

(3)

Then putting equation (1) substituting into equation (3), the equation (4) can be obtained as follows:

\[
G = \frac{6F^2 l_1(l_1 + 2l_2)[(h_1 - h_2)^3 l_1^2 (3\pi - 8) + 4h_1^3 (\pi - 3)R^2]}{2\pi Eh_1^5 (h_1 - h_2)(\pi^2 - 8)R^2}
\]  

(4)

**Numerical experiments**

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. Set \(F=20kN, E=135GPa, \pi=3.14, R=10mm, l_1=90mm, l_2=10mm, h_1=5.5mm, h_2=4mm,\) the thickness of the skin \(h_2\) and the flange \(h_1- h_2,\) chamfering radius \(R,\) the length of the flange \(l_1+ l_2\) can be gained. This paper discusses the relationship between the change flange and skin thickness and energy release rate in the case of constant force \(F,\) also discusses the relationship between the change flange length and the chamfering radius and energy release rate. The Relational graph of \(G\) and \(h_2\) when \(h_1=5, 6, 7, 8mm\) can be shown in Fig.3

![Figure 3. Relational graph of \(G\) and \(h_2\) when \(h_1=5, 6, 7, 8\) mm](image)

Also, given the height of the flange and the skin, we also can analyze the influence of the flange length and the change of the chamfering radius on energy release rate, as shown in Fig.4 and Fig.5.
Conclusion
The result of research shows that based on the classical beam theory of Euler-Bernoulli, fracture failure is affected by composite pane depth and joints chamfer dimension parameters and so on. From Fig.3, energy release rate $G$ increases with the sum of the flange thickness and the thickness of skin. As shown in Fig.4 and Fig.5, energy release rate $G$ increases with the length of the flange. The conclusion provides a valuable reference to further study the T-joints mechanical performance under complex conditions.

Acknowledgments
This work was financially supported by Key Lab Fund (JAB1728150) and the Distinguished Young Scientist Program of Guangdong Province (2015A030306002), National Natural Science Foundation of China (51505089), National Science Foundation of Guangdong Province (2016A030313672) and Pearl River S&T Nova Program of Guangzhou (2014J220086), Science and Technology Research Project of Guangdong (2015B090912002, 2015B090901048).

References
[1] Pradhan S C,Y Lam K.A finite element approach, International Journal Adhesion and Adhesives[J]. TayTE.Determination of fracture parameters of laminated thermoplastic
composite materials, 2000, 20: 395-401.

[2] Kayupov S, Dzensis. In-plane biaxial crushing of honeycombs- Part II: analysis[J]. 1999, 36(29): 4397-4423.

[3] Xie D, Chung J, M Waas A, al et. Failure analysis of adhesively bonded structures: from coupon level data to structure level predictions and verification[J]. INTERNATIONAL J ournal of fracture, 2005, 134: 231-250.

[4] Wong C M S, L Matt hews F. A finite element analysis of single and two hole bolted joint s in fibre reinforced plastic[J]. J ournal of Composite Materials 1981, 15: 481 - 491.

[5] Lie S T, G Yu, Z Zhao. Analysis of mechanically fastened composite joint s by boundary element methods[J]. Composites Part B, 2000, 31: 693 - 705.

[6] Tsujimoto Y, D. Wilson. Elasto plastic failure analysis of composite bolted joints[J]. J ournal of Composite Materials, 1986, 20: 236 - 252.