Mechanical properties analysis of CFRP tie bar based on ANSYS

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Abstract. Carbon fiber reinforced plastics (CFRP) have high strength-to-weight ratios, high stiffness-to-weight ratios and high reliability, which leads to the wide application of CFRP in various fields. In this paper, CFRP tie bar was formed by resin transfer molding (RTM), and finite element analysis (FEA) was performed to analyze the mechanical properties of CFRP tie bar based on ANSYS. Simulation results showed that the strength of tie bar with 0^{o} fiber orientation was greater than that of 45^{o}, and the failure mode of tie bar with 0^{o} fiber orientation was different from that of 45^{o}. The following experimental results were used to verify the simulation.

Introduction

Owing to high strength-to-weight ratios, high stiffness-to-weight ratios, high reliability and good designability, composite materials attract considerable attention, and the application of composites is increasing rapidly in the structures of aerospace, marine, and automobile engineering[1-5].

Tie bar is the ordinary component for machine, and the optimization of tie bar will lead to the better performance for whole system. Some researchers have devoted their efforts on the optimization of tie bar. Soohyun Nam et al. developed a light weight carbon composite tie bar to replace the conventional steel tie bar, the new composite tie bar achieved high elastic strain and provides a consistent compaction pressure to the stack over long operation time.[6] Shashidar Reddy et al. studied a combination of crack-stop hole and carbon fiber reinforced plastics (CFRP) overlays under static loads using finite element analysis (FEA) to evaluate its potential as a viable repair technique.[7]

CFRP is the typical anisotropic material, the properties are not only depend on the properties of the raw materials, but also the orientation of reinforcement. The structure of reinforcement is the major issue of design for composite structure. In this paper, finite element analysis (FEA) software ANSYS was used to analyze the mechanical properties of tie bar, and found out the failure mode of structure with different fiber orientation, the results can provide scientific basis for the optimization of composite structure.

FEA based on ANSYS

ANSYS is the powerful software for finite element analysis, which provides some special elements for analysis of composite materials, namely shell99, shell91, shell181, solid46, solid191 and so on. According to the dimension of composite tie bar, shell91 element is suitable for the FEA. Shell91 element is shown in Fig. 1, which has 8 nodes and 6 freedoms (the displacement of X, Y and Z, and the rotation of X, Y and Z).

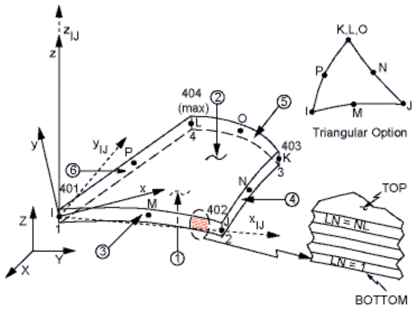


Fig. 1. Shell91 element

The failure of composite materials is different from that of the traditional material. Composite lamina has two modes of failure, namely first ply failure (FPF) and last ply failure (LPF). Obviously, FPF is the situation when the first layer fails, and LPF is the situation when the last layer fails. During the loading of composite materials, the layer in composites fails according to property of material and fiber orientation. If the layers are made form the same materials, the failure of layers is only depended on fiber orientation. For the reason of safety, the strength of FPF is usually used as the final strength of composite lamina. In failure judgment, ANSYS provide three criteria for the validation of layer: maximum stress, maximum strain and Tsai-Wu strength.

Tsai-Wu failure criteria take into account the difference in strengths due to positive and negative stresses. For a particular case of unidirectionally reinforced lamina in a plane stress state, the Tsai-Wu criterion is formulated as follows:

$$f = F_1 s_1 + F_2 s_2 + F_{11} s_1^2 + F_{22} s_2^2 + F_{66} s_6^2 + 2F_{12} s_1 s_2 = 1 \tag{1}$$

Where F_i and F_{ij} (i,j=1,2,6) are strength tensors of the Tsai-Wu second and fourth rank, respectively. F_i and F_{ij} are determined by tensile, compressive and shear tests. On the basis of Eq. (1), the parameters F_i and F_{ij} can be found:

$$\begin{cases} F_{11} = \dfrac{1}{X_t X_c}, F_{22} = \dfrac{1}{Y_t Y_c}, F_{66} = \dfrac{1}{S^2} \\ F_1 = \dfrac{1}{X_t} - \dfrac{1}{X_c}, F_2 = \dfrac{1}{Y_t} - \dfrac{1}{Y_c}, F_{12} = -\dfrac{1}{2}\sqrt{F_{11}F_{22}} \end{cases} \tag{2}$$

Where X_t, X_c are uniaxial and compressive failure stresses along the 1-axis, Y_t, Y_c are uniaxial and compressive failure stresses along the 2-axis, S is failure stress in pure shear.

The geometric dimensions of CFRP tie bar is shown in Fig.2, and the FEA model is shown in Fig.3.

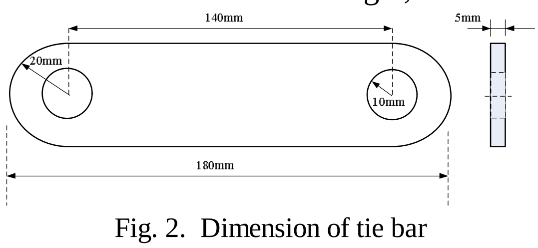


Fig. 2. Dimension of tie bar

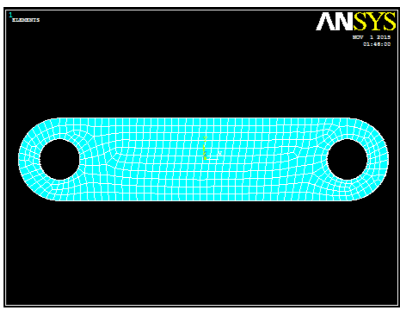
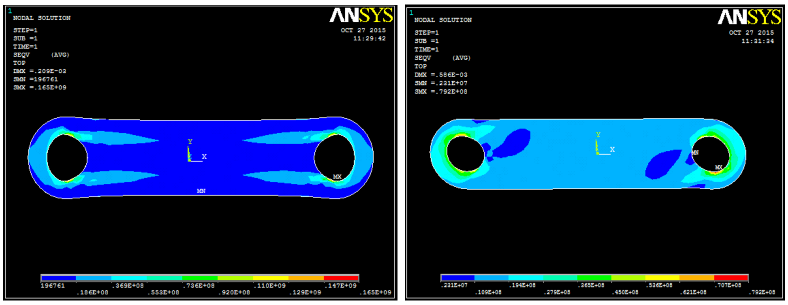


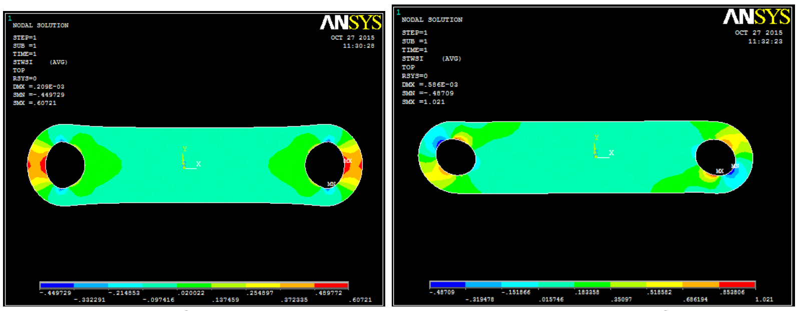
Fig. 3. Mesh of FEA model

Tensile force of 4kN is loaded on the line of bearing hole, and simulation results are shown in Fig.4 and Fig.5. Fig.4 is the distribution of von Mises stress, and Fig.5 is the distribution of Tsai-Wu strength index. The Tsai-Wu strength index is the failure criteria for composite materials, and the composite fails when the index is equal or greater than 1.For the case of 0^o fiber orientation, the results show that the max stress is 1.65e8Pa and the max Tsai-Wu strength index is 0.607, so the composites is safe with the loading of 4kN. The max stress is in the upper and the under part of the bear hole, but the max Tsai-Wu strength index occurs in the left and right part of the hole. The max stress and the max Tsai-Wu strength index are not in the same place, it means that the max stress will not necessarily lead to fail. According to Eq.(1), Tsai-Wu strength index is not only depend on s_1、 s_2 and s_6 , but also the function of composites strength (X 、 Y 、 S)。 On the other hand, von Mises stress is only related with s_1、 s_2 and s_6, thus, the max von Mises tress and the max Tsai-Wu strength index will not necessarily occur in the same place. For the situation of 45^o, the max Tsai-Wu strength index is 1.021, which means that the tie bar is not safe under the loading of 4kN. The max stress occurs in the -45^o orientation of the hole, and the max Tsai-Wu strength index is in the 45^o orientation. Due to the shear strength is greater than the tensile and pressure strength of Y and Z, so the tie bar of 0^o fiber orientation fails with shear of X-axial and tie bar of 45^o fails with the tensile of Y, and the strength of tie bar with 0^o fiber orientation is greater than that of 45^o orientation.



(a) 0^o (b) 45^o

Fig. 4. Distributions of von Mises stress



(a) 0^o (b) 45^o

Fig. 5. Distributions of Tsai-Wu strength index

Experiment

Carbon fibers (T300) and epoxy resin (E51) were used in the forming of tie bar, and the orientation of fiber is $[0^o]_{14}$ and $[45^o]_{14}$ respectively, the forming process of CFRP tie bar is shown in Fig.6, and the tensile test was performed to determine the strength of the specimens, the result is shown in Fig.7 and Fig.8.

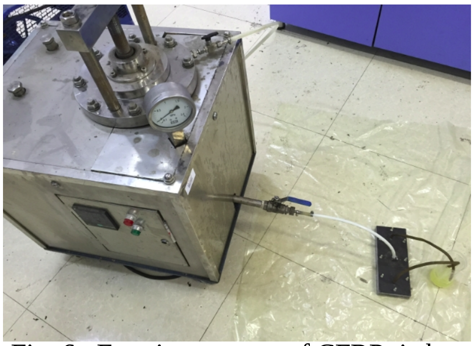
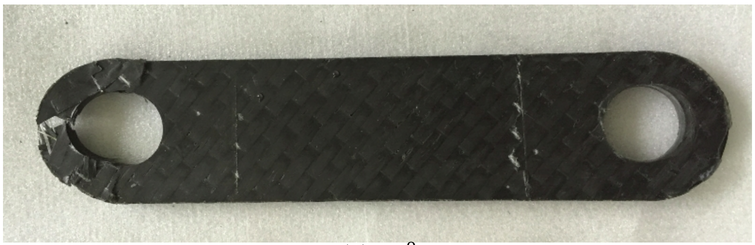
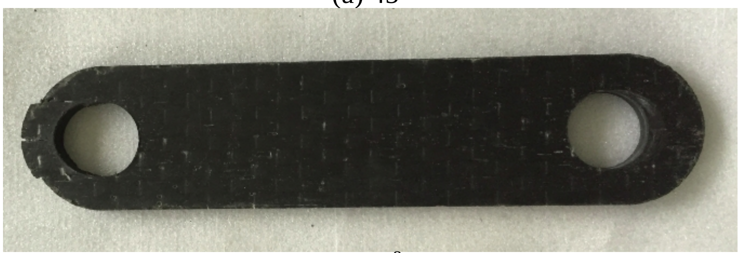


Fig. 6. Forming process of CFRP tie bar

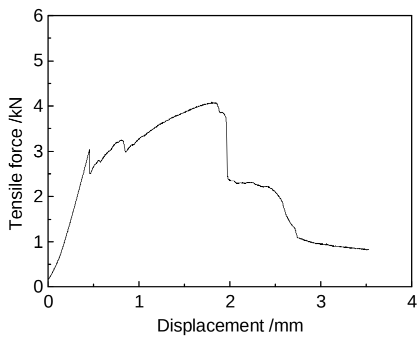


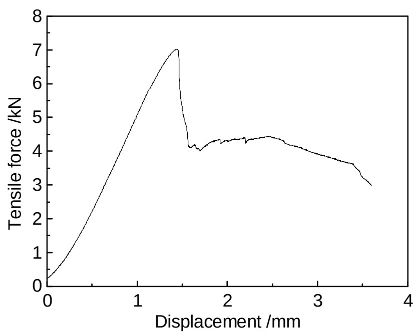
(a) 45°



(b) 0°

Fig. 7. Specimens after tensile test





(a)45°   (b)0°

Fig. 8. Relation between tensile force and displacement

The experimental results shows that the tensile force of 4kN leads the tie bar with 45° fiber orientation to fail and the tensile force of 7kN damages the tie bar of 0°, which is agree with the result of FEA.

Conclusion

In this paper, FEA of composite tie bar is performed based on ANSYS, and the following experimental results are used to verify the simulation. The orientation of reinforce will serious affect the properties of composite laminas, the strength of tie bar with 0° is greater than that of 45° (almost two times of it), thus we can design the composite lamina strength based on ANSYS. And the failing mode of the 0° and 45° are different, the failure of 0° is lead by the shear and the failure of 45° is lead by the tensile of Y axial. Thus, in order to increase the strength of the composite lamina, we can improve the properties of the raw material or optimize the structure of reinforcement.

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