Safety Analysis of Carbon Fiber Composite Subjected to Different Levels of Bending Moment

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Abstract. Carbon fiber composite rods can be widely employed in engineering due to their high ratio of the strength and density. Carbon fiber composite rods can be only used in the suitable conditions. In particular, under the bending deformation, the failure of carbon fiber composite rods can lead to the engineering accident if the applying bending moment is beyond a certain value. In this paper, a finite element model (FEM) for carbon fiber composite rod was put forward to simulate the mechanical responses of carbon fiber composite rod subjected to bending moment loading. A series of simulations under different levels of bending moments were conducted. Based on the calculated results, the limit bending moment was obtained by comparing the mechanical responses and the failure strength.

1. Introduction
Carbon fiber composite rods can be produced by continuous carbon fibers embedded into the high temperature epoxy [1]. Because of the special components, carbon fiber composite rods possess high strength and low density [2]. The strength can be higher than 1 GPa, but the density is near to one quarter of that of steels. Unlike the isotropic properties in steels, carbon fiber composite rods can be easily broken under the bending moment loading [3]. In order to promote the application of carbon fiber composite rod, most researchers concentrate on the flexural behavior of carbon fiber composite rod. By means of microscope, the failure process of carbon fiber composite rod was investigated in experiments [4]. During three-point bending tests, the compressive strength was calculated based on the collective applying loads [5]. The shear strength was further measured by analyzing the shear stress distribution in three-point bending tests [6]. Recently, the fracture toughness, the impact damage, fatigue life and wear property of carbon fiber composite rod have been investigated in experiments [7-10]. These experimental results can guide the researchers to establish the theoretical and numerical models [11]. Quan et al. proposed the theoretical model for the mode-I and mode-II fracture response of carbon fiber composites [12]. Mori et al. simulated the tensile behavior of carbon fiber composite material [13]. Because of the safety of carbon fiber composite rod under bending moment loading, here, we simulated the bending behavior of carbon fiber composite rod by finite element method.

2. Finite Element Model
To study the mechanical properties of carbon fiber composite plates under bending moment, this paper used ABAQUS 6.14.4 for plane finite element simulation. For the size of model, we set the length of the model to 0.8 m and the diameter to 0.02 m, with total composed of T700 carbon fiber and 4211 resin. The physical properties of the two materials are shown in Table 1. In order to analyze the model with finite element method, we used a 100 by 10 grid to divide the model, while fill half of the elements by carbon fiber, and fill rest elements by resin (Figure 1).
In this paper, the boundary condition of simply supported on both sides is adopted. The load along the y axis is respectively applied at the upper end of the model 0.2 m from the left and right end points. After the model is established by the above methods, the mechanical response of the model under different loads can be studied. The simulation values of different material layers with different bending moments are shown in Table 2.

Table 1. Physical properties of materials.

| Material       | Density(kg/m³) | Young's modulus(GPa) | Poisson's ratio |
|----------------|----------------|----------------------|-----------------|
| Carbon fiber   | 1700           | 230                  | 0.3             |
| resin          | 1000           | 4.5                  | 0.3             |

![Figure 1. Finite element model under four-point loading](image)

Table 2. A series of simulations under different levels of bending moment.

| number | Bending moment (KN·m) | Maximum stress in carbon fiber(MPa) | Maximum stress in resin(MPa) |
|--------|------------------------|------------------------------------|------------------------------|
| 1      | 20                     | 393.211                            | 9.53247                      |
| 2      | 40                     | 778.889                            | 19.0649                      |
| 3      | 60                     | 1168.33                            | 28.5974                      |
| 4      | 70                     | 1376.24                            | 33.3636                      |
| 5      | 72                     | 1402                               | 34.3169                      |
| 6      | 74                     | 1454.88                            | 35.2701                      |
| 7      | 76                     | 1494.2                             | 36.2234                      |
| 8      | 78                     | 1518.83                            | 37.1766                      |
| 9      | 80                     | 1572.84                            | 38.1299                      |
| 10     | 100                    | 1947.22                            | 47.6623                      |
| 11     | 120                    | 2336.67                            | 57.1948                      |
| 12     | 140                    | 2726.11                            | 66.7273                      |
| 13     | 160                    | 3145.69                            | 76.2597                      |
| 14     | 180                    | 3505                               | 85.7922                      |
| 15     | 200                    | 3894.45                            | 95.3247                      |
| 16     | 220                    | 4283.89                            | 104.857                      |
| 17     | 240                    | 4673.34                            | 114.39                       |
| 18     | 258                    | 5023.84                            | 122.969                      |
| 19     | 260                    | 5062.78                            | 123.922                      |
| 20     | 262                    | 5101.72                            | 124.875                      |
| 21     | 264                    | 5140.67                            | 125.829                      |
| 22     | 280                    | 5452.22                            | 133.455                      |
| 23     | 300                    | 5898.17                            | 142.987                      |
3. Mechanical Response

Figure 2 shows the deformation and stress distribution of the model when 140 kN was loaded at each of the two points on the upper side. According to the deformation diagram, three features can be summarized. Firstly, the maximum stress in carbon fiber is significantly greater than the maximum stress in resin, which is mainly affected by the difference in Young's modulus of the two materials. Secondly, in the y-axis direction, the maximum stress of the entire model is generally distributed in the lowermost layer and the uppermost layer. This is because the upper and lower layers are the farthest from the neutral layer. Thirdly, in the x-axis direction, the maximum stress of the model is distributed at the midpoint of the model, because the bending moment received at the midpoint is the largest.

![Figure 2. Mises stress distribution after finite element simulation](image)

Based on the calculated data in Table 2, the relationship between maximum stress and bending moment was obtained by using the logarithmic function. Figure 3 shows that the maximum stress in the carbon fiber and resin increases with the increasing bending moment. As shown in Fig. 3, the limit bending moment for carbon fiber layer is 260 kN·m; however, the limit bending moment for resin layer is only 75 kN·m. Because the allowable stress of the resin is much smaller than that of the carbon fiber, the load that the composite material can withstand mainly depends on resin layer. Changing the output of abaqus6.14.4 to strain, we can obtain the variation of maximum strain with the increasing bending moment (Fig. 4). The maximum strain in carbon fiber or resin layer increases with the increasing bending moment. As for the maximum strain, the limit bending moment in carbon fiber is 180 kN·m, but the limit bending moment in resin layer is 100 kN·m. From the perspective of maximum deformation, the limit loading of the carbon fiber composite rod is once again determined by the resin layer. Comparing the limit bending moments in Fig. 3 and Fig. 4, the final limit bending moment is the smallest limit bending moment, i.e., 75 kN·m.
4. Concluding Remarks
In this paper, a carbon fiber composite material model was established by the finite element method. Using the proposed model, the trend of stress and strain of the composite rod with load was studied. In general, under the same load, the stress and strain of carbon fiber are always greater than those of resin layer. In addition, because the failure of any material in the composite material will cause the overall failure, the overall bearing capacity of the composite material is mainly limited by the resin. For the carbon fiber composite rod with the diameter of 0.2 m, the limit bending moment is 75 kN·m based on the simulated results.

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6. Reference
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