Effect of Carbon Fiber Modulus on Mechanical Behavior of Carbon Fibre Composite Rod

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Abstract. Carbon fibre composite rod (CFCR) has been widely used in Aluminum Conductor Composite Core (ACCC) conductor. The mechanical properties of CFCR are related with the safety of electric power supply. The mechanical properties of CFCR are mainly determined by volume fraction of carbon fiber. Therefore, it is necessary to analyze the effect of carbon fiber fraction on the mechanical behavior of CFCR. The relationships between carbon fiber fraction and mechanical properties help to the design of ACCC conductor. This paper presents a finite element model (FEM) to analyze the mechanical properties of carbon fibre composite. The mechanical behaviors of CFCR for different carbon fiber fractions were simulated by using FEM. Based on the simulated results, the effects of carbon fiber fraction on stress and strain of CFCR under pure bending loading were revealed.

Introduction

Aluminum Conductor Composite Core (ACCC) conductors have been widely used as electrical transmission lines [1-3]. For the structure of ACCC conductors, a strong and light composite core is surrounded by strands of annealed Aluminum [4]. Carbon fibre composite rod (CFCR) is chosen to be the composite core because of its high strength and low density [5]. The carbon fibre composite rod is consisted of continuous carbon fibres embedded in a high temperature epoxy [6, 7]. Carbon fibre fraction is directly related with the mechanical properties of CFCR [8]. The poor mechanical properties could lead to the outage of electric power. Therefore, the analysis on mechanical properties of CFCR for different carbon fibre fractions helps to make sure the safety of electric power supply.

Most researchers have conducted the researches of the flexural mechanical properties on carbon fibre composite in the past decades [9-12]. The failure process of CFCR was analyzed in experiments [13]. Mujika et al. further conducted a series of experiments to test flexural, tensile and compressive modulus [14]. For unidirectional carbon fibre composites, the compressive strength was measured by conducting three-point bending tests [15]. Theoretical models were proposed to analyze the normal and shear stress distributions during three-point bending tests [16]. Recently, it is reported that various concentrations of nanotube could improve the mechanical properties of carbon fibre composite [17].

The effect of carbon fibre fraction on the mechanical properties of CFCR has not been conducted in the fantastic pioneer studies. In this work, we used a finite element model to analyze the mechanical properties of CFCR for different carbon fibre fractions. We focus on the stress and strain of CFCR subjected to pure bending loading. Based on the simulated results, the effects of carbon fiber fraction on stress and strain of CFCR under pure bending loading were revealed.

Finite Element Model

The finite element model (FEM) aimed to simulate the mechanical behavior of composite materials, has been developed by means of ABAQUS 6.11. CFCR consists of a T700 carbon fibre composite (CFC). The matrix of CFC is a cycloaliphatic glass fiber composite (GFC). Figure 1 shows the
geometrical modeling of CFCR under pure bending loading. CFCR with a diameter of $D$ is bended under four-point bending loading. The boundaries for simply supported beam were used here. The carbon fibre volume fraction is 50% by choosing half of elements (see in Figure 1). The material properties used in FEM are set as a linear elastic material. Poisson’s ratio for carbon fibre and glass fibre are chosen as 0.2 in FEM. The different mechanical properties of carbon fibre and glass fiber for all of models used here are illustrated in Table 1.

![Figure 1. Geometrical modeling of CFCR under four-point bending loading.](image)

<table>
<thead>
<tr>
<th>No. of model</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>6</th>
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<tbody>
<tr>
<td>Elastic modulus of carbon fiber (GPa)</td>
<td>80</td>
<td>130</td>
<td>180</td>
<td>230</td>
<td>280</td>
<td>330</td>
<td>380</td>
</tr>
<tr>
<td>Elastic modulus of glass fiber (GPa)</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
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Model was meshed by elements defined by 4 nodes with 2 degrees of freedom in tetrahedral bodies. The bilinear plane stress quadrilateral element of CPS4R was employed in these simulations. The model consisted of approximately 1000 elements and 1111 nodes. When the calculations have been accomplished, the stress and strain are obtained by means of output databases. Based on the calculated stresses, the effect of carbon fibre modulus on the mechanical properties of CFCR can be analyzed.

**Simulated Results**

Figure 2 shows the stress distribution of CFCR. The stress in carbon fiber is different from that in glass fibre. The Mises stress in carbon fiber is larger than that in glass fibre. The farther away from neutral surface, the Mises stress is both larger in carbon fiber and glass fibre. As shown in Figure 2, the maximum stress appears in the outside zone of CFCR.

![Figure 2. Stress distribution of CFCR under four-point bending loading.](image)
In order to reveal the mechanism of elastic deformation in CFCR, the FEM simulation is carried out at different elastic modulus of carbon fibre. Figure 3 illustrates the stress-modulus curves for different fibres. The Mises stress in carbon fibre is larger than that in glass fibre. With the increasing carbon fiber modulus, the Mises stress in carbon fibre increases but the Mises stress in glass fibre decreases. The strain-modulus curves for different fibres are shown in Figure 4. The variation of strain with carbon fibre modulus is different from the variation of stress. Strain decreases with the increasing carbon fibre modulus for both carbon fiber and glass fiber. The strain in carbon fiber is less than that in glass fiber.

Figure 3. Relationship between stress and carbon fibre modulus in carbon fiber and glass fiber.

Figure 4. Relationship between strain and carbon fibre modulus in in carbon fiber and glass fiber.

Summary
A 2D finite element model (FEM) is employed to research the effect of carbon fibre modulus on the mechanical properties of carbon fibre composite rod (CFCR). According to the simulated results, the Mises stress in carbon fibre is larger than that in glass fibre but the strain is carbon fiber is less than that in glass fibre. The stress in carbon fiber increases with the increasing elastic modulus of carbon fibre. The stress in glass fiber decreases with the increasing elastic modulus of carbon fibre. The variation of strain with carbon fibre modulus is different from the variation of stress. Strain decreases with the increasing carbon fibre modulus for both carbon fiber and glass fiber.
Acknowledgement
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References

Reference to a book:

Reference to a chapter in an edited book:

