Effect of Carbon Fiber Volume Fraction 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. 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 different carbon fibre fractions could be achieved by choosing different elements (see in Figure 1). The different carbon fibre fractions for all of models used here are illustrated in Table 1.

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

| No. of model | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|--------------|---|---|---|---|---|---|---|
| Fraction (%) | 20 | 25 | 33 | 50 | 66 | 75 | 100 |

CFCR consists of a T700 carbon fibre composite (CFC). The matrix of CFC is a cycloaliphatic high temperature epoxy resin. The volume fraction of carbon fibre in CFCR is shown in Table 1. The material properties used in FEM are set as a linear elastic material. The modulus elasticity and Poisson’s ratio for carbon fibre and epoxy resin are shown in Table 2.

![Table 1. Carbon fibre fractions for FEM simulations.](table)

| Material       | Modulus elasticity | Poisson ratio |
|----------------|--------------------|---------------|
| Carbon fibre   | 230                | 0.2           |
| Epoxy resin    | 4.5                | 0.2           |

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 fraction on the mechanical properties of CFCR can be analyzed.

**Simulated Results**

Based on the proposed FEM, the numerical simulation of CFCR subjected to pure bending loading was conducted. Figure 2 shows the calculated results from FEM. There is a stress distribution in the materials under pure bending loading; however, the stress in carbon fiber is different from that in epoxy resin. The Mises stress in carbon fiber is larger than that in epoxy resin. The farther away from neutral surface, the Mises stress is larger in carbon fiber and epoxy resin. As shown in Figure 2, the maximum stress appears in the outside zone of CFCR, where the Mises stress is \( \sim 4.94 \) MPa.
In order to reveal the mechanism of elastic deformation in CFCR, the FEM simulation is carried out at different volume fraction of carbon fibre. Figure 3 illustrates the stress-time curves for different carbon fibre fraction. With the increasing carbon fiber volume fraction, the Mises stress decreases greatly for low volume fraction of carbon fiber. But the Mises stress is nearly a certain value if the carbon fibre fraction is between 30% and 50%. Mises stress changes from 9.2 MPa to 4.9 MPa if carbon fraction volume fraction goes from 20% to 33%. Then the Mises stress is nearly a certain value around 4.9 MPa when the carbon fraction goes from 33% to 50%. With the increasing carbon fiber volume fraction from 50% to 75% value, the Mises stress decreases gradually, i.e. from 4.9 MPa to 3 MPa.

Figure 4 illustrates the strain-time curves for different carbon fibre volume fraction. It seems that the strain-time curve goes the same tendency as the stress-time curve. For low carbon fiber volume fraction, the strain decreases greatly from 40 με to 21 με when the carbon fraction increases from 20% to 33%. From the 33% to 50% of carbon fibre fraction, the strain seems to stay at stable value around 21 με. As for the carbon volume fraction from 50% to 100%, the strain decreases gradually from 21με to 12.5 με.
Summary

A 2D finite element model (FEM) is employed to research the effect of carbon fibre volume fraction 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 epoxy resin. The maximum of Mises stress decreases with the increasing volume fraction of carbon fibre. The maximum of strain decreases with the increasing volume fraction of carbon fibre. For low carbon fiber volume fraction, the maximum of Mises stress decreases greatly with the increasing volume fraction of carbon fibre. For large carbon fiber volume fraction, the maximum of Mises stress decreases gradually with the increasing volume fraction of carbon fibre. There is a zone of carbon fibre volume fraction, i.e. 33%-50%, where the carbon fibre fraction has no influence on the mechanical properties of CFCR.

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