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Mechanical behavior of carbon fibre composite rod subjected to pure bending loading

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Abstract. Carbon fibre composite rod (CFCR) has been widely used in Aluminum Conductor Composite Core (ACCC) conductor. CFCR is usually under flexural loading during the operation of electric power. Therefore, the flexural properties of CFCR are related with the safety of electric power supply. The failure of CFCR could lead to the outage of electric power. Therefore, it is of importance to analyze the mechanical behavior of CFCR under flexural loading. The material of CFCR is transverse isotropy, which is different from isotropy material. The available finite element models (FEMs) are based on isotropy material. It is unreasonable to use these FEMs to predict the mechanical behavior of CFCR. This paper presents a new FEM to analyze the mechanical properties of transverse isotropy materials. Using the proposed FEM, the mechanical behaviors of CFCR under flexural loading are obtained.

1. 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]. CFCR is usually under flexural loading during the operation of electric power [8]. The failure of CFCR could lead to the outage of electric power. Therefore, the flexural mechanical properties of CFCR should be good enough to make sure the safety of electric power supply.

The flexural mechanical properties of carbon fibre composite have been extensively researched in the past decades [9-12]. The failure process of CFCR was analyzed by using acoustic emissions and subsequent Scanning Electron Microscope (SEM) [13]. Mujika et al. proposed an experimental procedure for determining flexural, tensile and compressive modulus [14]. The compressive strength of unidirectional composites was obtained by three-point bending tests [15]. Analytical expressions were derived to obtain the normal and shear stress distributions in a three-point bending test [16]. Recently, it is found that various concentrations of nanotube help to suppress the failure of carbon fibre composite [17].

The fantastic pioneer studies have concentrated on the analysis of failure process of CFCR based on experimental technique. However, the finite element model (FEM) based on transverse isotropy material has not been put forward to analyze the mechanical behavior of CFCR under pure bending loading. In this work, we propose a new FEM for transverse isotropy CFCR to predict the flexural mechanical properties of CFCR. We focus on the stress distribution and the stress evolution of CFCR subjected to pure bending loading.

2. Finite element model

Figure 1 shows the geometrical modeling of CFCR under flexural loading. CFCR with a diameter of D is bended on the surface of wheel. The geometry sizes for all of the models used here are illustrated in Table 1. A 3D FEM can be set up (Figure 2) accounting for the geometry size in Table1.

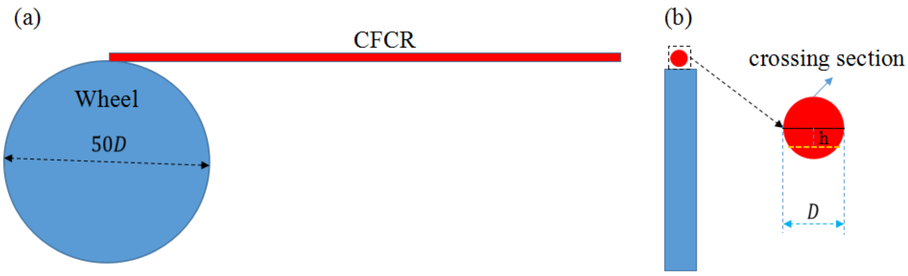

Figure 1. Geometrical modelling of CFCR: (a) Front view; (b) Side view.

Figure 2. 3D finite element model.

Table 1. Geometry sizes for all of the models.

Parameter	D (mm)	50D (mm)
Value	10	500

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 CFC is 55%. For aligned fibres, fibres and matrix are subjected to the same uniform strain in the fibre direction [18]. Based on the available results [19-21], the differences between tensile and compressive property should be considered during flexural loading. The material properties used in FEM are set as a linear elastic material. The tensile and compressive parameters for FEM model are shown in Table 2.

Table 2. Tensile and compressive parameters for FEM model.

Loading type	Modulus (GPa)	Poisson ratio
Tension	150	0.3
Compression	50	0.3

Model was meshed by elements defined by 8 nodes with 3 degrees of freedom in tetrahedral bodies. The linear hexahedral element of C3D8R was employed in these simulations. The model consisted of approximately 7137 elements and 10897 nodes. The center of the wheel in Figure 1 was hinged and one side of CFCR was fixed on the circumference of the wheel. Therefore, CFCR can be twined on the circumference of the wheel when the wheel rotates. When the calculations have been accomplished, the stresses are obtained by means of output databases. Based on the calculated stresses, the mechanical properties of CFCR can be analyzed.

3. Simulated results

Based on the proposed FEM, the numerical simulation of CFCR subjected to pure bending loading was conducted. Figure 3 shows the calculated results from finite element model. There is a stress distribution in the materials under pure bending loading; however, the materials outside the loading zone are free of stress. The cross-section of CFCR is inset in Figure 3b. The Mises stress in outer surface is larger than that in internal surface. The maximum stress appears in the outside zone of CFCR, where the Mises stress is ~2.66GPa.

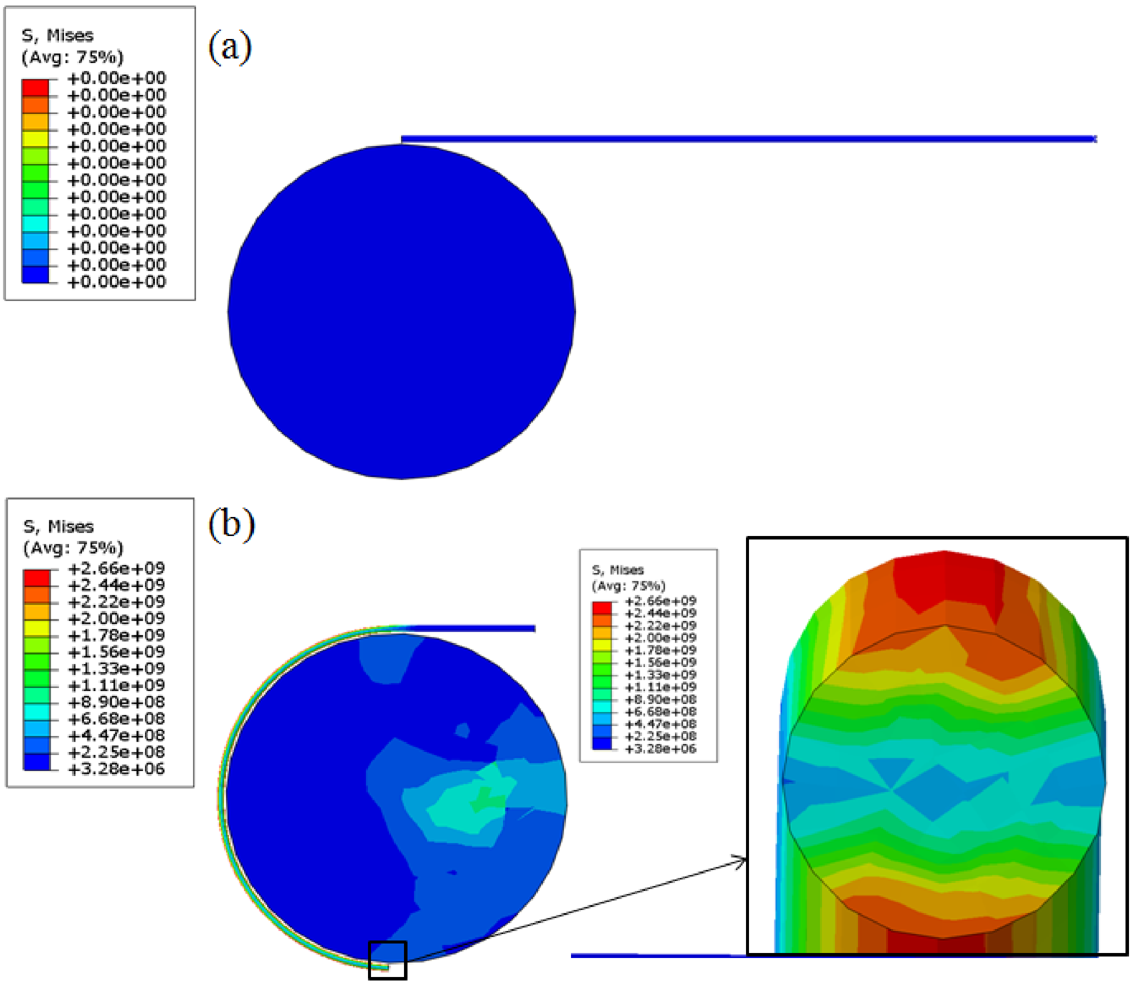

Figure 3. Calculated results from finite element model: (a) before deformation; (b) after deformation.

According to the numerical results, the evolutions of stress and strain are further illustrated in Figure 4 and Figure 5 respectively. The stress increases with the increasing time and reaches a stable value of 2.66 GPa (Figure 4). After the rapid increase of strain at the beginning of deformation, the stable strain of 0.017 is achieved (Figure 5). Both stress and strain increase greatly when CFCR is bended onto the surface of wheel. If CFCR is completely bended onto the surface of wheel, a stable status of deformation is obtained. The stable status of deformation results in the homogeneous stress distribution along CFCR which is completely bended onto the surface of wheel (Figure 3b).

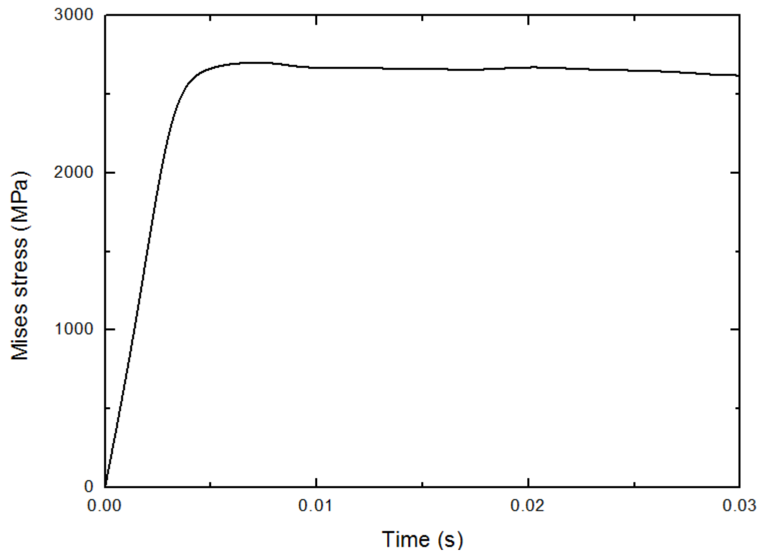

Figure 4. Evolution of Mises stress with the increasing time.

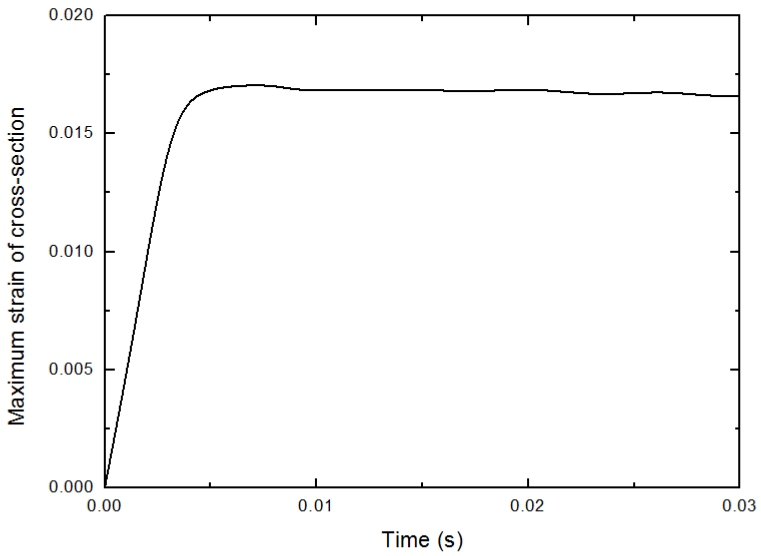

Figure 5. Evolution of strain with the increasing time.

4. Conclusions

Based on the theory of transverse isotropy materials, a 3D finite element model (FEM) is proposed to research the flexural behavior of carbon fibre composite rod (CFCR). The details on the 3D FEM have been described. The mechanical properties of CFCR under pure bending loading are further investigated by using the proposed FEM. The Mises stress in outer surface is larger than that in internal surface. The maximum stress of ~2.66 GPa appears in the outside zone of CFCR. Both stress and strain increase greatly with the increasing time and reach the stable values. The stable status of deformation results in the homogeneous stress distribution along CFCR if CFRCR is completely bended onto the surface of wheel.

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