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Test Method

Influence of specimen size and inner defects on high strain rates compressive behaviors of plain woven composites

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ABSTRACT

This paper reports the influence of specimen size and inner defects on high strain rates compressive behaviors of plain woven composites. The compressive behaviors of plain woven composites along out-of-plane direction were investigated from experimental and numerical approaches. In experimental, the compressive stiffness and strength decreased as the size of plain woven composite specimens increased. In finite element analysis (FEA) model, a new microstructure model with random defect distribution was established to find the influence of inner defects and specimen size effect on the compressive behaviors under high strain rates. From the numerical results, the compressive strength, modulus and fracture strain decreased obviously with the increase of volume fraction and size of defects. We found that the good agreement existed between the testing and the FEA results. The defects size and distribution were the main factors to weaken the compressive stiffness and strength.

1. Introduction

Size effect has been admitted existing in many materials, such as metals [1,2], concretes [3–5], and fiber reinforced composites [6–9]. This is because more and larger defects are thought to be inclined to exist in bigger specimens. Researches on size effect on composites were mainly reported with experimental method in the last century. Weibull statistic distribution theory model [10] was often used to match the experimental results by many researchers. However, the Weibull statistic distribution theory model could not always match all the results well. Nevertheless, for plain woven composites, the structure is more complex than that of laminates and unidirectional lamina. It is necessary to know the fracture mechanism and size effect of plain woven composites during the dynamic compressive process.

Many researchers have investigated the mechanical properties of plain woven composites with different methods. Römelt and Cunningham [11] established a binary model to predict the tensile properties of plain woven composites. The result was in agreement with the experimental in the elastic state. Bednarcyk et al. [12] used the multi-scale method to calculate the elastic constants of plain woven composites. Zhang et al. [13] used the full size microstructural model to simulate the compressive properties of plain woven composites along in-plane and out-of-plane direction under different strain rates. However, they ignored the defect effect in the plain woven composites. Defects are considered the most important factor of size effect on materials. It should be ascribed to the random damage of carbon fiber filaments during the manufacturing process of plain woven composites. Hence, it is imperative to study the defect effect on the mechanical properties of plain woven composites.

In this work, we investigated the size and the defect effect on the compressive behaviors of plain woven composites. In the experiments, the specimens with three sizes were prepared and tested under high strain rates. The compressive behaviors were also analyzed through finite element model with inner defects distributions. Defects were introduced into the microstructure model with Mont Carlo method. Then the effects of volume fraction and size of defect were investigated. From the comparisons between the experimental and FEM results, the mechanisms of the influence of specimen size and inner defects distribution on the compressive behaviors were revealed.

2. Experimental tests

2.1. Material preparations

The plain woven carbon fiber fabric supplied by Sigmatex Inc. (Shanghai, China) was used as the reinforcement material. The number of plies of fabric was 16. JC02A epoxy resin supplied by Changshu Jiafa Inc. (China) was used as the matrix material. The curing temperature parameters of epoxy resin were as follows: 90°C/2 h, 110°C/1 h and

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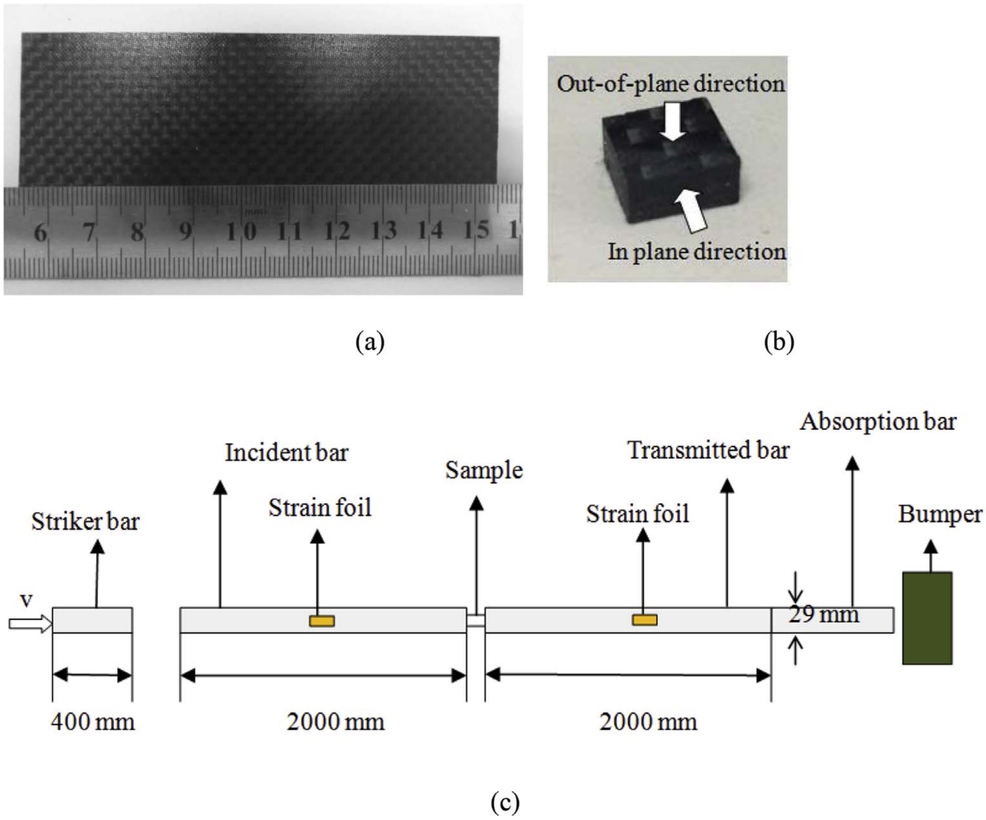

Fig. 1. Plain woven composites and testing apparatus. (a) Plain woven composite. (b) Direction definition in this study. (c) SHPB apparatus test system diagram.

Table 1
Detailed specification of specimens.

Name	Number of the unit cell in each layer	Layers	Length × Width × Height (mm)
2 × 2 × 16	4	16	8 × 8 × 4.8
3 × 3 × 16	9	16	12 × 12 × 4.8
4 × 4 × 16	16	16	16 × 16 × 4.8

130°C/4 h. Fig. 1(a) is the picture of plain woven composite. The volume fraction of carbon fiber was about 36% measured by the burning method. To research the size effect of plain woven composites, the composite plate was cut into three different samples with different sizes. Table 1 shows the specification of different samples.

2.2. Dynamic compression test

The dynamic compression test was conducted by the split Hopkinson pressure bar (SHPB) apparatus along out-of-plane direction (shown in Fig. 1(b)). The schematic of the test system is shown in Fig. 1(c). All specimens were tested under the same strain rate of about 2000 s^{-1}.

3. Numerical model

3.1. Geometric model

3.1.1. Model with no defects

Geometric model of plain woven carbon fiber cloth without defect was established with CATIA software. Fig. 2(a) is the representative unit cell (RUC) of plain woven carbon fabric. The cross-section of fiber tow was assumed to be ellipse. The trace of fiber tow was assumed as sine curve. The microstructure model of 2 × 2 × 16, 3 × 3 × 16 and 4 × 4 × 16 are shown in Fig. 2 (b), (c) and (d), respectively. All of them are arrayed from the RUC in Fig. 2(a).

3.1.2. Model with defects

Carbon fiber filaments are easily damaged during the complex manufacture process of plain woven composites. To introduce defects into the analytical model, following assumptions were assumed:

(1) Defects only existed in the plain woven fabric. Each defect existed as an independent element.
(2) Epoxy resin did not contain any holes or bubbles. There was no void between fiber and resin.
(3) Defects were subjected to uniform distribution. Defects occurred randomly with a given probability, P_d.
(4) The mechanical property of each single defect was weak. Elements of defects were easily deleted in the initial step.
(5) Geometrical model with defects was same to the model without defects.

The details of generating defects are shown in Fig. 3(a). This process is realized with Mesenne Twister (MT) algorithm [14]. The microstructure model of plain woven carbon fiber cloth with defects is shown in Fig. 3(b). The blue elements are defective elements in fiber tows. The red elements represent normal elements in fiber tows.

3.2. Material model

Table 2 lists the mechanical parameters of carbon fiber filaments and epoxy resin. The basic properties of fiber tow were calculated and listed in Table 3. The fiber tow was a transverse isotropic material. The local coordinate system is shown in Fig. 4(a). In numerical calculations of compressive failure of the plain woven composites, the 3-D Hashin