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A mesoscale ultrasonic attenuation finite element model of composites with random-distributed voids

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ABSTRACT

Interaction between ultrasonic wave and fiber reinforced composites with voids was investigated on the mesoscale by numerical method in this work. DIGIMAT-FE software was used to establish a mesoscale model of void-containing composites, which revealed the real microstructure with randomly distributed voids. Ultrasonic excitation was loaded into the mesoscale model via ABAQUS/Explicit before the finite element analysis (FEA) was carried out. Take T800 carbon fiber/epoxy composite material as an example, the accuracy of the simulated method was verified by comparing the numerical prediction with the analytical and experimental results. Therefore, this simulation method not only can be an effective guidance for manufacturing process but also provide a theoretical basis for reducing void level in order to increase performance of composites.

1. Introduction

Service performance of fiber-reinforced composite is severely influenced by defects introduced from manufacturing process, especially voids [1,2]. Ultrasonic nondestructive testing is considered as the most conventional examination technique for characterizing composite defects and damages on account of its high sensitivity, accuracy and simplicity [3]. Thus, there is a strongly growing need to explore the influence of the voids in composite parts on ultrasonic attenuation during quality evaluation process.

Void size and distribution have significant impacts on the ultrasonic attenuation of composite laminates. A number of studies conducted on the geometry of voids in the composite laminates concluded that the void size and aspect ratio mainly ranged from 0.01 mm to 1 mm and from 1 to 4, respectively [4–6]. The majority of the voids can be considered spherical, except those with large aspect ratio (above 4) [4–6]. In addition, there are different discussions in terms of the void distribution [5,7,8]. However, no well-defined principle has been developed for accurate description.

Due to the periodicity and symmetry of fiber reinforced composites, representative volume element (RVE) of the mesoscale geometric composite structure can be extensively used for the finite element analysis (FEA) in order to study the micro-performance [9–12]. However, numerical model of fiber reinforced composites with the actual volume fraction, shape and spatial distribution of voids within the laminates is rarely reported in literature because traditional modeling approach has a limitation when describing void character.

This investigation managed to take the random features of the voids into consideration by the implementation of DIGIMAT software [13], a nonlinear multi-scale materials and structures modeling platform. The size, spatial distribution and volume fraction of the voids were precisely controlled on mesoscale in this numerical method. Then, in the present work, a mesoscale model of composites with random-distributed voids was successfully built by DIGIMAT-FE. The mesoscale model with void phase effectively reflected the real microstructure and mesoscale properties of the composite material. Five models at each void level (1%, 2% and 3%, respectively) were generated for the randomness and inhomogeneity of void distribution. After applying ultrasonic excitation, the FEA of the mesoscale model was carried out [14]. The ultrasonic attenuations were calculated at different void levels for T800/epoxy composites, and the accuracy of the numerical method was discussed by comparing the simulated prediction with both analytical and experimental results.

2. Experimental procedure

2.1. Preparation of specimens

Square ($300 \times 300\ mm^2$) panels of 5 mm nominal thickness were made of T800/epoxy prepreg (a product of CYTEC Industries) by autoclave processing following the quasi-isotropic stacking sequence. The prepreg was cured at 185 °C for 3 h and all the heating

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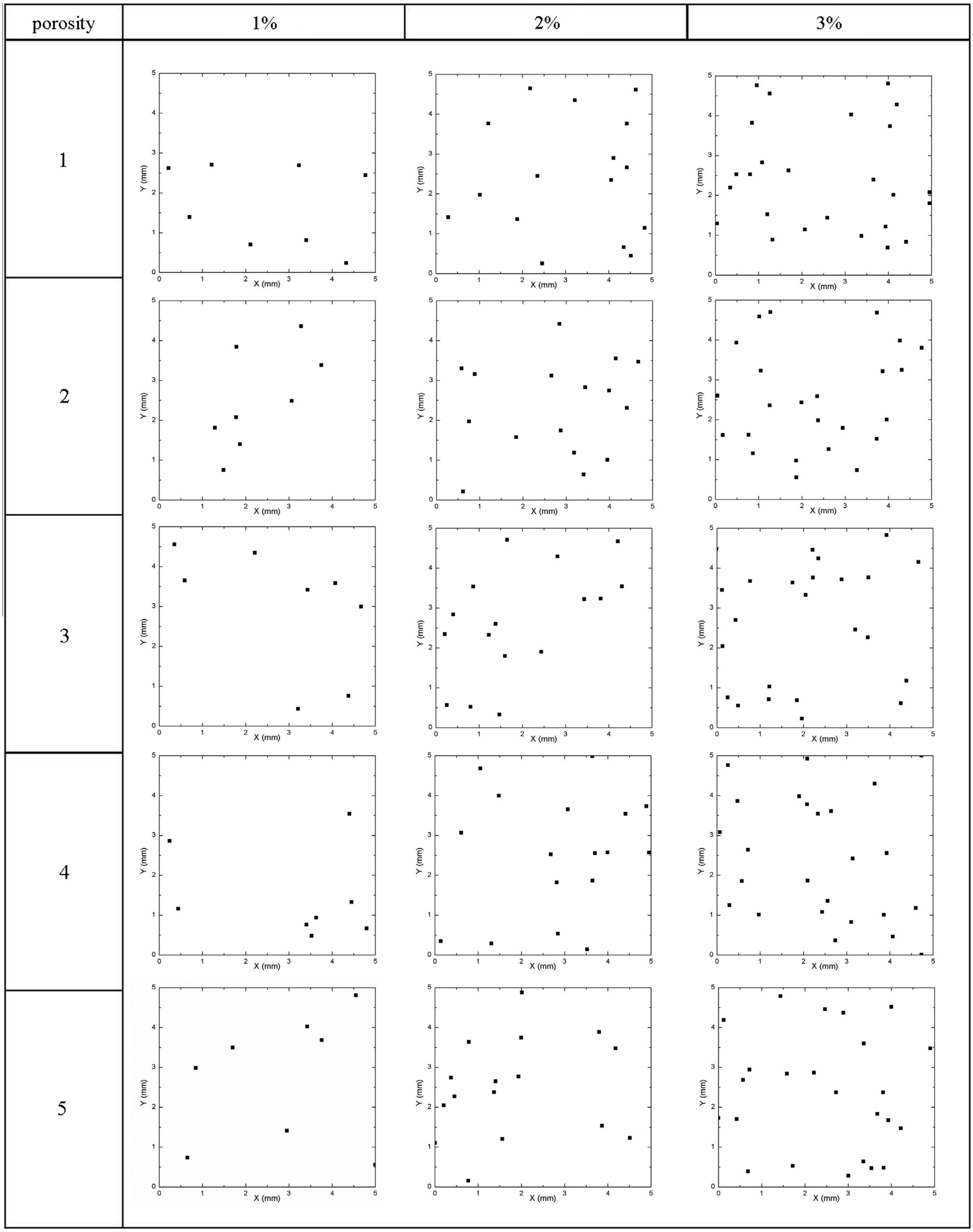

Fig. 1. The void positions of each RVE model at different void levels.

and cooling ramps were carried out at the same rate of 2.5 °C/min. Laminates with intentionally different void levels were produced under an autoclave pressure range of 0.1–0.5 MPa. The pressure inside the vacuum bag was kept 0 MPa throughout the entire cycle.

2.2. C-scan ultrasonic inspection

The ultrasonic attenuation coefficient was measured with ultrasonic echo immersion bottom reflection technique. A glass plane