IN-SITU DAMAGE MONITORING OF TEXTILE COMPOSITES USING X-RAY COMPUTED TOMOGRAPHY

W.-J. Na[1], H.-C. Ahn[1], K.-M. Park[1], H.-M. Kang[2], W.-R. Yu[1*]

[1] *Department of Materials Science and Engineering, Seoul National University, 599 Gwanangno, Gwanak-gu, Seoul 151-742, Republic of Korea*
[2] *Central Advanced Research & Engineering Institute, Hyundai Motor Group, Uiwang-Si, Republic of Korea*

**woongryu@snu.ac.kr*

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Abstract

The damage sensing of composites is an important issue to ensure their reliable applications. The damage density and/or the visual inspection of the internal structure have characterized micro-damage in composites. Recently, micro X-ray computed tomography has been considered as a useful technique for nondestructive imaging. In this study, the internal damage state was observed under tensile loading using in-situ micro CT and specially designed loading stage. The damage state and mechanism were analyzed and compared with those determined by piezoresistive signals obtained from dispersed CNT network.

1 Introduction

Due to their high productivity and good mechanical properties, textile composites have been used in various fields such as military, civil engineering, and aerospace industries [1]. The reliability of the mechanical performance is most important factor to facilitate textile composites to be extensively used in the transportation vehicles such as automotive. The reliability of textile composites is strongly dependent on the occurrence of the internal damages. The evolution of the damages in textile composites is then explained by the initiation of the transverse micro-cracks, their multiplication and accumulation, and micro-delamination and debonding [2]. Keen evaluation of these damage modes is essential to ensure the reliable usage of textile composites.

The damage behavior of textile composites has been characterized by various techniques including acoustic emission, full-field strain measurement, postmortem observation using microscopy, optical coherence tomography, X-ray computed tomography (CT), etc. Among these techniques, in-situ methods are preferred to investigate damages more precisely without any changes in the microstructure during the sample preparation. Recently, in-situ observation of damages in a textile composite was carried out using X-ray CT [3].

In this study, the damage behavior of woven composites is investigated using in-situ micro X-ray CT. Since the maximum load in available X-ray CT machine is limited, notched specimens are prepared and tested to observe the microstructure of the composite until the fracture occurs. The woven composites are then tested in other tensile machine, recording their piezoresistive behavior during the tensile testing. The internal structure obtained from X-ray CT is analyzed and compared with the piezoresistive behavior of the woven composites, demonstrating that the piezoresistive behavior can be an in-situ measurement method of the internal damage.

2 Materials and testing method

2.1 Fabrication of composite specimen

Plain weave preforms made of ultra high molecular weight polyethylene (UHMWPE) fibers were used as the reinforcement. The preforms were laminated with a stacking sequence of (22/85/-85/-22). The stacking sequence was chosen to imitate the winding angles of general composite pressure vessels. Epoxy (Epofix, Struers) resin was used as the matrix. The basic material properties of the fiber and the matrix and weave information are shown in Table 1. Vacuum-assisted resin transfer molding (VARTM) process was used in room temperature to fabricate composite specimens.

Reinforcement		**Matrix**	
Elastic modulus	111 GPa	Elastic modulus	3.8 GPa
Tensile strength	3 GPa	Tensile strength	83 MPa
Denier	1580		
Pattern	Plain weave	**Structure**	Four layer laminated
Unit-cell size (mm)	2.66×2.66		

Table 1. Material properties of constituents and condition of fabric

2.2 In-situ observation with tensile test

The tensile specimens with two notches were designed as shown in Figure 1. The round-shaped notches were introduced at the central part of the specimen to concentrate the stress [4]. The tensile behavior of the composites was tested twice, i.e., each in universal tensile test (UTM) and micro-CT. The stress-strain curve from UTM was firstly analyzed to characterize the tensile behavior of the composites. The piezoelectric behavior of the composite was measured during UTM testing. On the other hand, the tensile behavior of the composites was also tested in micro X-ray CT machine (Skyscan 1172, Belgium), and their stress-strain curve was obtained using a tensile loading stage in Fig. 1 (b). Beside the stress and stain curve, the internal structure of the composites was observed and recorded in the test. X-ray CT was operated at 40 kV and 200 μA .

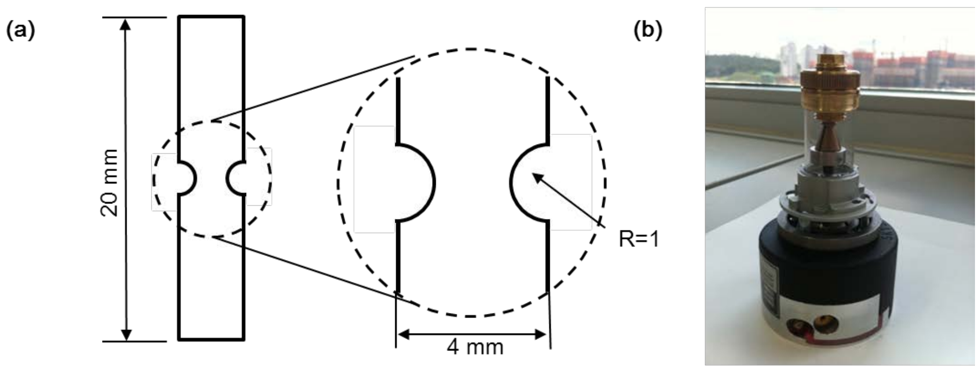

Figure 1. The shape of specimen and loading process (a) schematic presentation of designed specimen (b) in-situ tensile loading stage in CT

3 Result and discussions

3.1 Mechanical behavior of woven textile composite

Figure 2 shows a typical stress-strain curve of the woven composites. Note that overall stress-strain behavior is nonlinear. The stress and strain curve can be divided into several sections by characteristic strains at which the slope of the stress-strain curve was changed (see the auxiliary (vertical) lines). The stress increased linearly in the first stage, followed by the slope decreases in the stage 2. The slope was then increased slightly again in the stage 3, implying that there was a strengthening mechanisms in the woven composite, which was probably due to yarn compaction and rotation. Fig. 2 (b) shows the stress and strain curve obtained from micro X-ray CT machine via the tensile loading stage. The nonlinear behavior was also observed, however the slope of early stage was different from that obtained from UTM testing. Since this was due to a slight slippage of the specimen, it was ignored in further analysis.

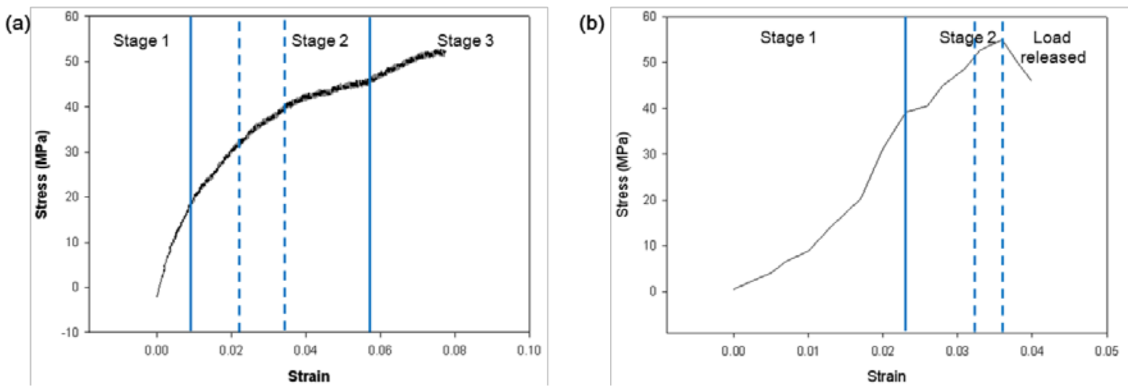

Figure 2. The stress-strain curve of woven textile composites measured (a) from UTM and (b) micro X-ray CT.

3.2 Damage behavior observed with micro-CT

The micro CT images obtained during the tensile testing were reconstructed in order that the yarn, the epoxy matrix and the cracks could be distinguished by grayscale. The internal structure of the woven composites was visualized in Figure 3. Since there was no external force before the test started (Fig. 3 (a)), the specimens were clearly full of yarn and matrix. Some voids and micro-cracks formed during the VARTM can be observed. As the tensile load increased from the elastic to the plastic deformation, debonding can be observed as shown in Figs. 3 (c) and (d). To clearly observe the internal damages, 3D images were reconstructed in Fig. 4. At the reference and elastic state, there are some voids around yarns. The yarn-matrix debonding is observed at the lower part of round notch. As the load increases, the transverse cracks and debonding are clearly observed. Detailed analysis on this in-situ observation will be presented at the Conference.

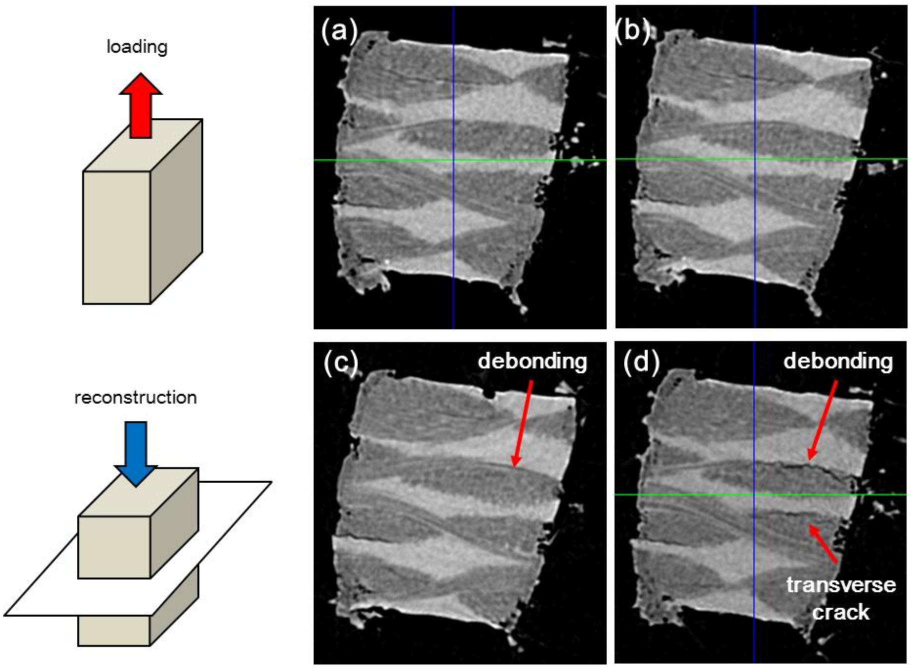

Figure 3. The cross section of woven composite in each state of damage region. (a) no deformation (b) elastic deformation (c) damage initiation (d) and damage accumulation .

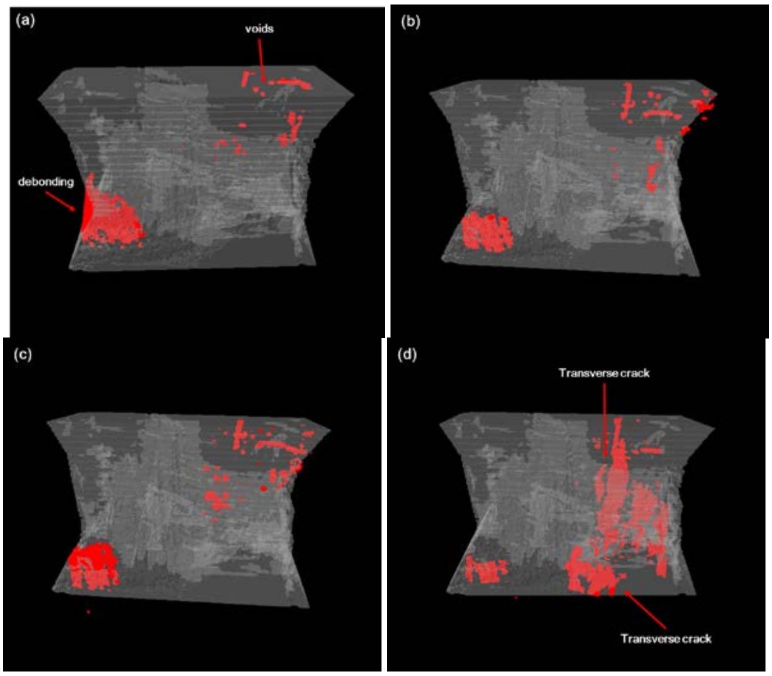

Figure 4. The 3D X-ray CT images of woven composite. (a) reference state (b) elastic region (c) damage initiation region and (d) damage accumulation region

3.3 Piezoresistive behavior of woven composite

The piezoresistive behavior of the woven composites was shown in Figure 5. As in the stress-strain curve, the slope of the resistance changes varied as the deformation increased, implying that the resistance change was highly related to the internal damages. This relationship is under investigation along with the in-situ observation results.

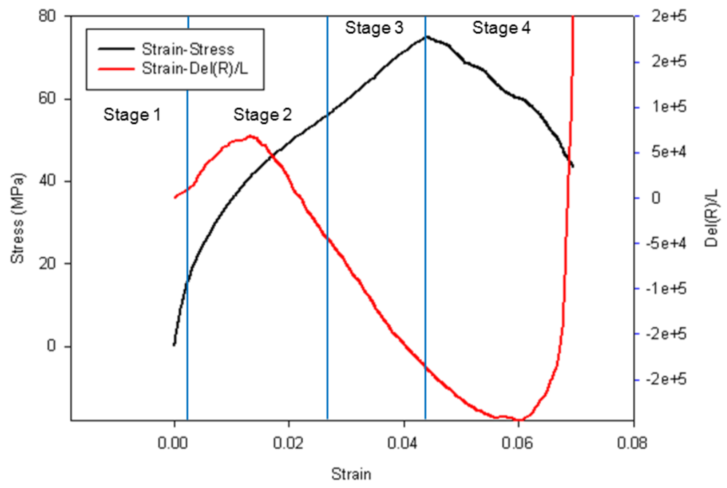

Figure 5. The piezoresistive behavior of woven composite.

4 Summary

The damage behavior of woven composites was investigated using in-situ X-ray CT and specially designed loading stage. The piezoresistance behavior of the woven composites was also measured from other tensile testing using UTM. By investigating the damage mode in X-ray CT image and correlating them with the piezoresistive behavior, it will be demonstrated at the Conference that that the piezoresistive behavior using CNT network inside woven composites can be an effective in-situ measurement method of the internal damage.

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