In Situ Observation of Multiple Failure Modes in Carbon-Epoxy Laminated Composites Using 3D Micro-Computed Tomography

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1 INTRODUCTION

Experiments are still the major means for characterizing damage and failure behavior of composite structures. Digital image correlation (DIC) technique is now widely applied for current testing protocols since the visualization of real time displacement (or strain) fields from DIC provides much information and sometimes new insights about the mechanical behavior of composite structures. However, it is still an issue to characterize the complex interaction of multiple failure modes such as matrix microcracking, in-plane fiber splitting and delamination [1], since DIC data is only available from an exterior surface where a speckle pattern is applied. In order to have better understanding of the interactions between various surface as well as subsurface failure modes, it is required to implement an imaging technique that shows the interior structure of composite materials where individual failure modes are initiated. X-ray computed tomography provides nondestructively actual three-dimensional (3D) information of the damaged microstructure [2]. In this presentation, the progressive damage and failure as a crack grows under mechanical loading is quantified with fully three-dimensional characterization.

2 MATERIALS AND METHOD

2.1 Test materials and Setup

Composite panels of $[90_2/0_2]_S$ configurations were first manufactured by laying up prepregs to achieve the total thickness of 1.13 mm. Specimens with a single edge notched specimens are made of $[90_2/0_2]_S$ panel. The specimen dimension is represented on Figure 1.

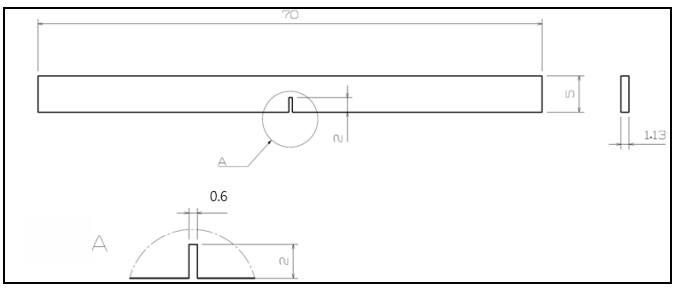

Figure 1: Single edge notched specimen dimension for $[90_2/0_2]_S$

2.2 Experimentation

In situ test was carried out at the 6c beamline at the Pohang Accelerator Laboratory (PAL) in Korea. The experiments were performed with *in situ* X-ray scanning in nine loading sequences, corresponding to various percentage of ultimate tensile strength, shown in Figure 2. 3D tomography images of carbon-reinforced laminated composites undergoing mechanical loading were obtained from sets of X-ray projection images (radiographs) recorded as the test instrument was rotated stepwise through an angular range of 180°. For investigating the failure progress, the X-ray scans with first sequence of loading were pre-loaded state. The specimens were re-loaded to next sequence and re-scanned in

gradual increment to 77% of ultimate tensile failure stress.

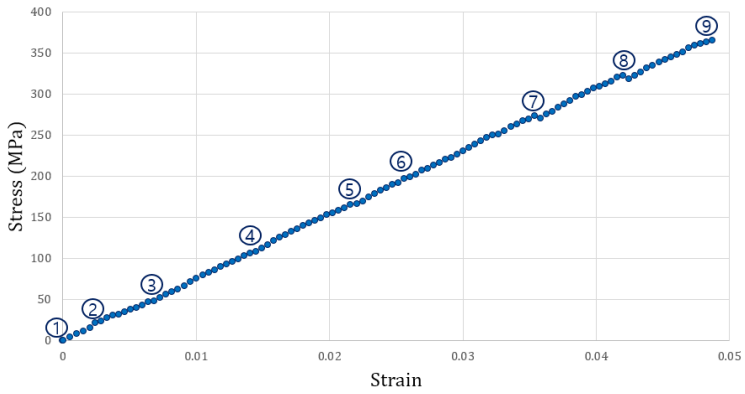

Figure 2: $[90_2/0_2]_S$ Stress-strain curve during *in situ* tensile test, points indicate loading sequence

3 RESULT AND CONCLUSION

CT reconstruction allows the volume of a given sample to be visualized as a three-dimensional grey-scale map [3] in which the grey-scale value correlates to the local material X-ray adsorption coefficient, depending on atomic numbers. Two dimensional (2D) tomographic slices are generated from X-ray projection images using a commercial reconstruction algorithm, Octopus v8. Data are processed using image processing tools and visualized using AMIRA 6.2 (FEI, Inc.). The solid materials (matrix and fiber) and vacancies (cracks, voids and air) have a different gray-scale intensity representation. By segmenting the appropriate grey-scale values, cracks on the specimen can be defined. As the applied load increases, the multiple damage progression can be analyzed in three-dimensional tomography, as shown in Figure 3. The fiber direction splitting on the 0° plies and delamination on the interface of 0° ply and 90° ply are investigated. In addition, the transverse matrix cracks on 90° ply are observed. More detailed analysis based on the experimental observation will be presented at the conference.

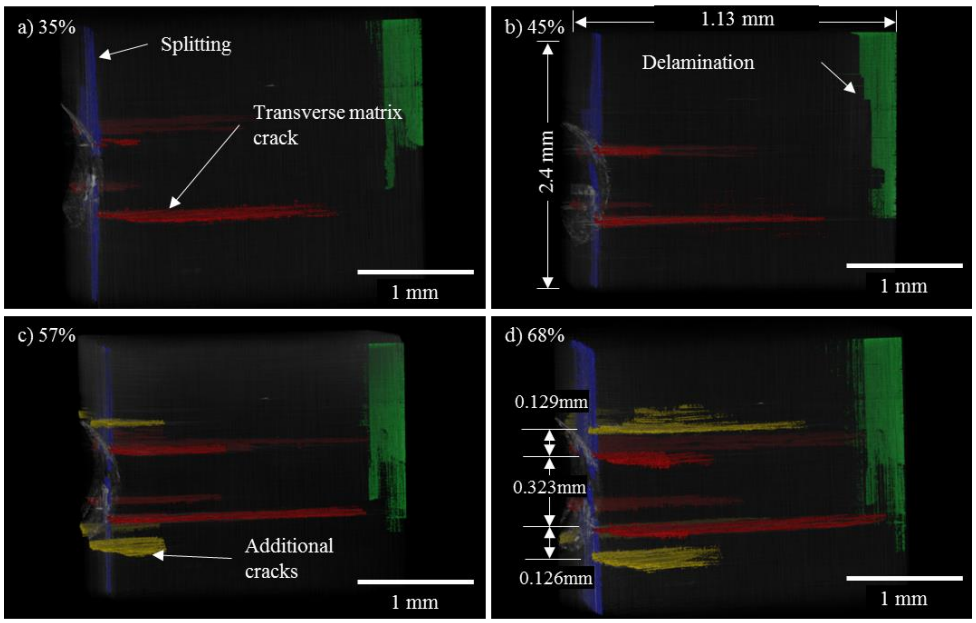

Figure 3: Fully 3D computed tomography result of in situ tensile test with $[90_2/0_2]_S$ specimen

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