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Investigation of the Strain Field at Microscale Using Digital Image Correlation for Unidirectional CFRP under Transverse Loading

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1. Introduction

Identification of strain or stress distribution using a numerical method requires assumptions such as boundary condition, representative volume element size and fiber shape morphology. The verification of the microstructural behavior of the composite material using the DIC technique is a method of directly confirming the actual physical phenomena. Several researchers have conducted studies to identify strain distributions in the microscale region using the DIC technique [1-3].

In this paper, strain distributions between fibers are observed using ultra-high resolution SEM images and compared with finite element analysis results. Also, the displacement of the carbon fiber detected by image processing is used to investigate the size of the representative volume element and the periodic boundary condition applied to the numerical analysis.

2. Microscale Tensile Test

Fig. 1 shows the in-situ test equipment to observe the amount of micro displacement generated by increasing the load. The deformation of the specimen is observed in real time by driving the micro tensile test machine in the SEM chamber. The photographed images provide information on the strain field using the DIC technique.

Fig.1 Microscale tensile test machine in SEM

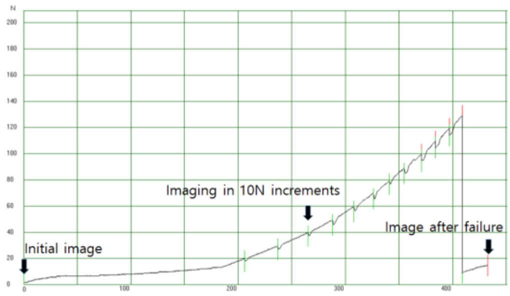

Fig.2 Displacement-load curve

The tensile test is performed by increasing the load in 10N increments, and images of the composite microstructure are taken at each step as shown in Fig. 2.

3. Microscale Strain Distribution

SEM images with a high magnification of 12000 times and a large number of pixels of 14milion are used to obtain a more accurate microscale strain distribution. Fig. 3 shows a example of observing strain using DIC. It shows the transverse strain in the loading direction when a load of 16MPa, which is slightly lower than the load of about 20MPa generating debonding of carbon fiber and matrix. It can be seen that the matrix having lower elastic modulus than elastic modulus of fiber is compressed.

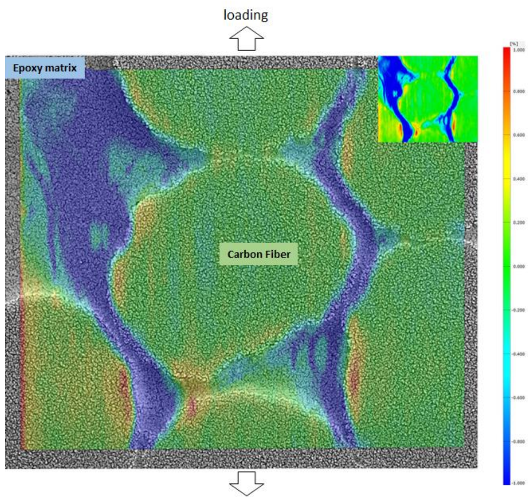

Fig.3 Transverse strain by DIC and SEM image

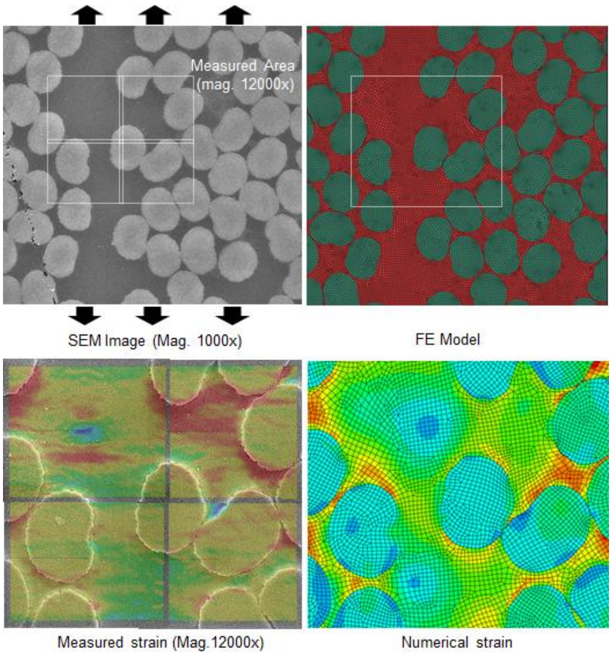

Fig.4 Experimental and numerical strain field

Fig. 4 compares the observed strain with the strain derived using the finite element analysis. The numerical model reflects the actual fiber geometry generated through image processing. The test results and the numerical results are similar, but the details are different. The reason for this difference is that the surface of the specimen is locally deformed easily by the electron beam and the allowable strain of the material is very small, so that the error of strain field may increase when the DIC technique is applied.

4. Microscale Fiber Center Displacement

Fig. 5 shows the microstructure of the two specimens. One sample has a resin rich zone and the other sample has a uniform fiber arrangement. The x-strain is defined as the value obtained by dividing the x-direction displacement of the fiber center by the distance from the origin. The x-displacement has a constant deviation irrespective of the x coordinate. Due to the constant deviation of the x-displacement, the x-strain decreases inversely with increasing x-coordinate as shown in Fig. 5 and Table 1. In the case of periodic boundary condition, the strain corresponds to a constant value in the direction of load. But, in practice, the boundary condition is a strain variation of about 10% of overall strain for a random RVE of about 20D size. Since the deviation of the strain is more influenced by the smaller RVE, it is necessary to select the RVE as large as possible and to apply statistical approach if using small RVE to obtain the correct stress distribution.

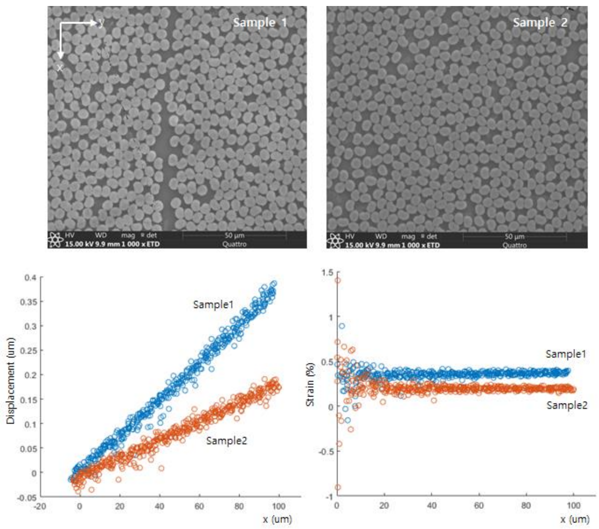

Fig.5 Fiber displacement and strain in loading direction x

Table 1 Strain and displacement of the fiber center of sample 1 (fiber diameter D=5um)

Fiber Location(X)	Displacement (um)		Strain (%)	
	Mean	Max.-Min.	Mean	Max.-Min.
20~25um	0.083	0.050	0.34	0.14
45~50um	0.176	0.037	0.36	0.10
70~75um	0.274	0.038	0.37	0.07
95~100um	0.367	0.037	0.37	0.04

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