Strain Measurement near Fiber-Matrix Interface of CFRP Cross Section Using DIC-FEM Hybrid Method

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Abstract. This study proposes the use of a DIC-FEM hybrid method for evaluating the strains near the fibre-matrix interface where the strain varies discontinuously. Displacements are measured using digital image correlation from laser microscope images of CFRP cross sections, but detailed measurements are difficult because the spatial resolution is insufficient. Therefore, a DIC-FEM hybrid technique is proposed and the effectiveness of this method is demonstrated by evaluating the strain concentrated in the resin part. Results show that the discontinuous strain distribution and the strain concentration at the fiber-matrix interface can be observed using the proposed method.

Introduction

Although composite materials are lightweight and have excellent strength and durability, they have the problem of delamination and fibre breakage, and since the fibre diameter of CFRP is approximately 7 μm, these fracture behaviours are extremely difficult. Since this is a microscopic phenomenon, it is necessary to understand the fracture behaviours on a microscale. Currently, the development of optical full-field, non-contact displacement analysis methods has made it possible to measure the displacement field of a specimen with high precision. It is expected to be applied in a variety of fields because it does not require an optical system and does not limit the materials it can be used with.

Mahoor et al. [1] stated that random patterns affect the measurement accuracy of digital image correlation (DIC) when it is applied to composite materials at the microscale. Specifically, the accuracy of measurement results using DIC is reduced due to agglomeration of fine particles used as a random pattern that were larger than the fibre diameter, or when nothing is coated on the surface of the material. In addition, research has been conducted on a method for creating optimal random patterns for evaluating deformation in a microscopic field using DIC, and pattern creation by airbrush application using fine particles is considered to be effective. It is necessary to create a random pattern with an optimal size depending on the measurement field of view. However, due to the low resolution of an optical microscope, it is difficult to accurately capture microscale strain distributions at the interface using DIC alone. Therefore, it is thought that using the DIC-FEM hybrid analysis method [2], which combines DIC and FEM, makes it possible to capture the deformation behaviour at the microscale.

In this study, a method to measure strains on a microscale by using the DIC-FEM hybrid analysis method is proposed. An appropriate random pattern for strain measurement near the fibre-resin interface where the displacement changes discontinuously is applied to the specimen, and the displacements near the fibre-resin interface are measured using local DIC. The strain distributions near the fibre-resin interface are evaluated using the proposed method and the effectiveness of it is demonstrated. Results show that the strain concentrations at the matrix part near the fibre-matrix interface can be observed using the proposed method.

Preparation of Microscale Random Pattern

Generally, patterns created by spray paint or polishing on the surface of the specimen to be observed are often used as random patterns. On the other hand, in this study, a random pattern of microparticles is required to observe the fibre-resin interface within an extremely small area. However, microparticles have a high aggregation property and are extremely difficult to disperse over a wide area, so it is necessary to study random patterns on a microscale. In this study, alumina powder with a particle size of 0.5 μm is used in a random pattern to perform microscale DIC. Alumina is chemically stable and has a wide range of particle sizes, making it effective at the scale observed in this study. Furthermore, in order to improve the dispersibility of alumina, highly volatile propanol is used as a solvent and mixed at a solution concentration of 0.5wt%. Iodine solution, which is soluble in propanol and has high dispersibility, is used as a dispersant and applied to the suspension in an amount 1/5 of the amount of alumina powder. In addition, an ultrasonic cleaner uses equipment with a frequency of 40 kHz, sends ultrasonic waves to the beaker with a random pattern suspension in a glass beaker, and stirs it for about 10 minutes. In the stirrer, a rotor is placed in a glass beaker and stirred for about 4 minutes. After dropping this suspension onto the test piece using a Komagome pipette, the surface of the test piece is observed using a laser microscope.

Displacement Measurement

An image obtained with the laser microscope is 1024 × 1024 pixels, the image scale is 0.26 μm/pixel, and the analysis range is 100 × 100 pixels as shown in Fig. 1(a). All images taken using a laser microscope are obtained at a magnification of 100. When performing DIC, image before deformation is acquired at a load of approximately 45 to 50N, and images after deformation are acquired at a load of approximately 70 to 110 N, and the displacements are obtained as shown in Fig. 1(b). The black curves in the contours indicate the positions of the fibres observed under the microscope, and the fibre positions are superimposed on the image.

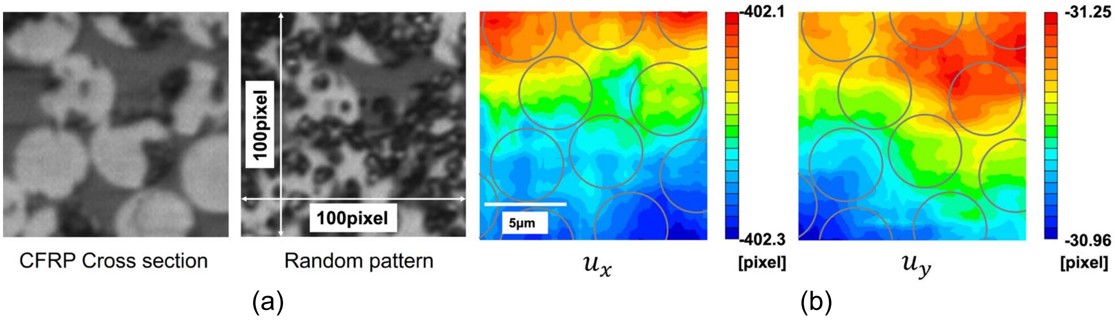

Fig. 1 (a) Microscopic image images of CFRP cross section and (b) displacement distributions obtained using digital image correlation

Results

Figure 2(a) shows the displacement distribution obtained from the displacement measurement results obtained by DIC in Fig. 1(b) by the hybrid method, and Fig. 2(b) shows the strain distributions. In Fig. 2(a), it is observed that the displacement distributions similar to the experimental displacement distribution are obtained by the hybrid method. From the strain distributions, the strain concentration at several locations in the resin part is observed. Furthermore, a discontinuous strain distribution is observed at the interface between the fibre part and the resin part, which have different elastic moduli.

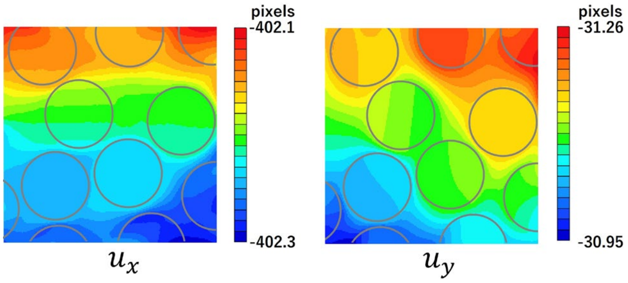

Fig. 2 Displacement distributions obtained using DIC-FEM hybrid method

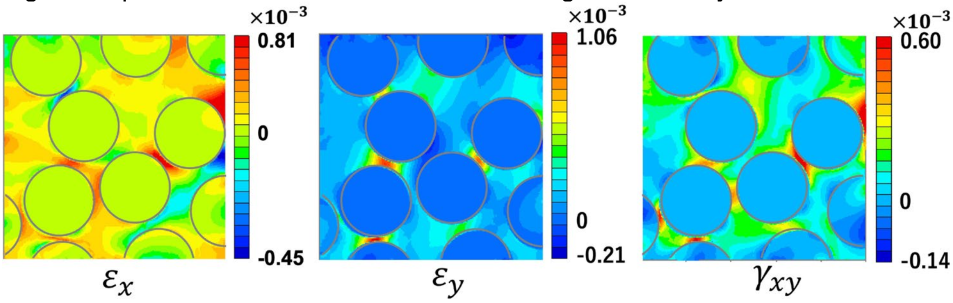

Fig. 3 Strain distributions obtained using DIC-FEM hybrid method

Conclusions

In this study, a DIC-FEM hybrid method for evaluating strains near fibre-matrix interface of CFRP cross section is proposed. For this purpose, a fine random pattern is created and applied on a specimen surface, and it is observed using a laser microscope. Displacement distributions are obtained using digital image correlation. Then, the proposed hybrid method is used to obtain strains. The effectiveness of this method is demonstrated by evaluating the strain concentrated in the resin part. Results show that the discontinuous strain at the fibre-matrix interface can be observed using the proposed method.

References

[1] Canal, L.P., Gonzalez, C., and Molina-Aldareguia, JM., Application of Digital Image Correlation at The Microscale in Fiber-Reinforced Composite, Composites: Part A, Vol. 43, (2012), pp. 1630-1638.

[2] Yoneyama, S. and Arikawa, S., Identification of Boundary Condition from Measured Displacements for Linear Elastic Deformation Fields, Procedia IUTAM, Vol 4, (2012), pp. 215-226.