공초점 레이저 주사 현미경을 이용한 단섬유 복합재료 내의 섬유 배열

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Fiber Orientation in Short Fiber Composites with a Confocal Laser Scanning Microscope

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INTRODUCTION

Fiber orientation in short fiber composites highly depends on the detail of process conditions and affects mechanical and thermal properties of the final product such as stiffness, thermal expansion, and strength. Therefore, it is important to measure the actual fiber orientation in the real composites and to apply the measured fiber orientation to characterization of the localized properties of materials and verification of the numerically predicted fiber orientation.

In determining the orientation states in the composites, the most popular method has been the calculation of directional angles of fibers from measurement of the geometrical parameters of fiber images on the only one surface of part [1,2]. Although it is a very economical and fast method, all the angles cannot be determined completely. However, by using the CLSM [3], more than two planes below the surface can be focused so that we can remove the ambiguity in determining the angles.

THEORY

Since the CLSM is capable of optical sectioning, images of more than two planes within the sample can be obtained. Assuming that each image of a fiber that intercepts two parallel planes is identical, the directional angles (θ, ϕ) can be determined by using center coordinates of the two images as shown in *Fig.1*.

To compactly describe orientation states in the composites, orientation tensor is employed [1, 4]. The tensors are formed as follows.

$$a_{ij} = \frac{\sum (p_i p_j) F_n}{\sum F_n} \tag{1}$$

Simplified optics of the CLSM [5] is shown schematically in *Fig. 2*.

EXPERIMENTAL

The tensile specimens of polystyrene reinforced with 3 vol% (4.5 wt%) carbon fibers were injection-molded. The injection pressure was 8 Mpa, holding pressure was 7.5 Mpa, barrel temperature was 200°C, mold temperature was 60°C; and filling time was 1.6 sec, holding time was 5 sec, and cooling time was 25 sec.

Each sample, prepared from the specimen, was polished by using metallographic method. Dimensions of the specimen, sampling positions and observed locations are described in *Fig. 3*. Two cross-sections separated by 10μm at one point were acquired by using the CLSM, Bio-Rad Radian 2000MP (NA 0.75, objective ×40, eyepiece ×10, transmission mode). The actual size of observed domain was 187 μm × 187 μm.

The details about numerical methods are summarized in Table 1 [6].

RESULTS AND DISCUSSION

Figure 4 shows that the predicted diagonal components of orientation tensors along the points 'a' through position 1 to 5 defined in *Fig. 3*. The predicted components of tensor are in good agreement with the measured ones. It can be also found that the signs of the off-diagonal components are changing along the flow direction. In *Fig. 5*, while the degree of alignment of fibers in the flow direction is slightly varying in the measured results, the predicted orientation is maintained along the points 'd' through position1 to 5 defined in *Fig. 3*. In general, the predicted orientation states correspond to the measured ones, but show some disagreement at the gate and the end of cavity. It is believed that the discrepancy is resulted from the effect of fountain flow that we did not consider in the numerical analysis, and also the initial condition may affect the predicted orientation state especially near the gate.

CONCLUSIONS

The use of CLSM makes it possible to remove the ambiguity in determining the off-diagonal components of tensors. By measuring the proper sign of the components, the accurate orientation states can be obtained in even complex geometry. The measured orientation states can be utilized to verify the numerical codes. Once the codes are verified, it is believed that numerical prediction can be used for the optimum design of the mold and the final product

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Table 1. Methods and conditions employed for numerical analysis.

Pressure/Temperature	Hybrid FEM/FDM
Melt front advancement	Control volume method
Injection pressure	8 MPa
Holding pressure	7.5 MPa
Filling time	1.6 sec
Inlet temperature	200°C
Wall temperature	60°C
C_I	0.01
Inlet fiber orientation	Random state

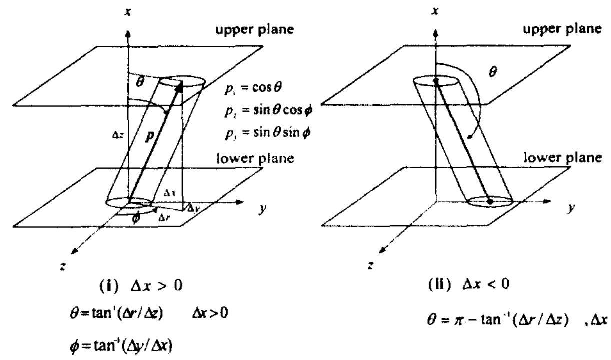


Fig. 1 The coordinate system employed to define directional angles.

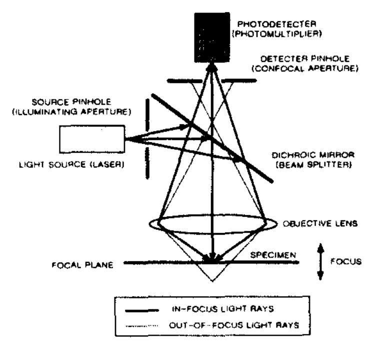


Fig. 2 Simplified optics of a confocal laser scanning microscopy.

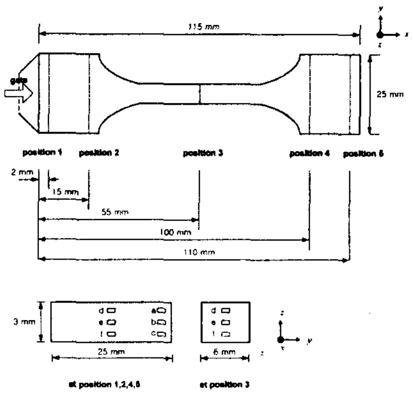
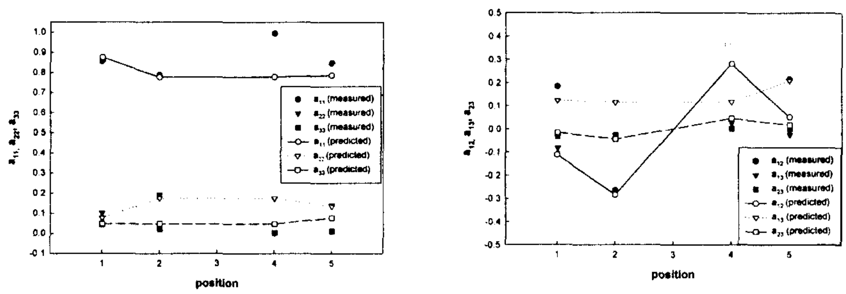
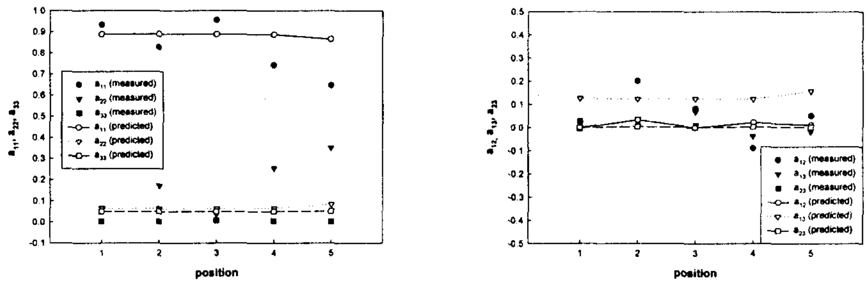


Fig.3 Dimensions of the specimen, sampling positions and observed locations.



(a) (b)

Fig. 4 Measured and predicted orientation tensors along the location '**a**'; (a) diagonal terms (b) off-diagonal terms.



(a) (b)

Fig. 5 Measured and predicted orientation tensors along the location '**d**'; (a) diagonal terms (b) off-diagonal terms.