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1—1 Reconstruction of Fiber Orientation Distribution by Observing Interference Fringe Patterns and Elliptical Marks

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Abstract

Measurement of the fiber orientation is one of the most important inspection items to examine the shape and strength of the products[1]. The 3D fiber orientation has been measured by analyzing the elliptical marks of the cross section of the fiber from the photograph of the FRP. In these methods, it is not possible to obtain the azimuth and depression angle of the 3D fiber orientation parameters[2]. We propose the method measuring 3D fiber orientation from the elliptical marks and the interference fringe patterns by observing the cut section of the FRP with scanning acoustic microscopy (SAM). This proposed method makes it possible to measure the 3D fiber orientation distribution. We show the effectiveness of this method by reconstructing fibers in the FRP.

1 Introduction

Fiber orientation distribution in FRP affects the shapes and mechanical property of the products. Therefore, in the case of the product design, not only to estimate the fiber orientation distribution in FRP by the simulation, but also to examine the orientation distribution of the producted moldings is necessary. Some methods of measuring of the 3D fiber orientation by analyzing the elliptical marks of the cross section of the fiber from the image of FRP through scanning electric microscopy (SEM) were proposed. In this method, that we cannot calculate the azimuth angle of the parameters of the 3D fiber orientation as we measure the fiber orientation only by analyzing the shape of the cross section.
In this paper, we observe the cut section of FRP through SAM, and examine the method for the 3D fiber orientation by analyzing the elliptical marks and the interference fringe patterns of the fiber.

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2 Observation of the Cross Section through SEM and SAM

2.1 Orientation of the Molding Cross Section through SEM

The shapes of the fiber in FRP are generally cylindric. When the molding of FRP is perpendicularly cut off to the mold flow and the cut section of the molding is observed through SEM, we confirm the elliptical marks of the cut section of the fiber, shown in Fig. 1.

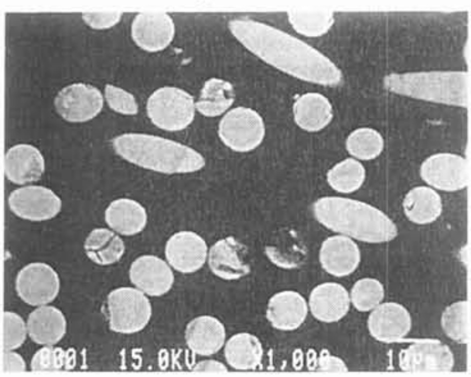


Fig. 1 The observed example of cross section image through SEM

We can calculate the depression angle α from the relation between the major axis **a** and the minor axis **b** of the elliptical mark, shown in Fig. 2. However, we cannot calculate the depression angle β only by observing elliptical mark of fiber, shown in Fig. 3.

2.2 Observation of the Molding Cross Section through SAM

We try to observe the cut section of the molding of FRP through SAM. SAM enables us to examine the material condition of the inside non-destructively[3]. The example of the image observed through SAM is shown in Fig.4. We can confirm the elliptical mark and the interference fringe patterns of each fiber. The interference fringe patterns appear in the direction of the gradient.

In this paper, we measure the 3D fiber orientations in the moldings of FRP by analyzing the elliptical marks and the interference fringe patterns of the fiber.

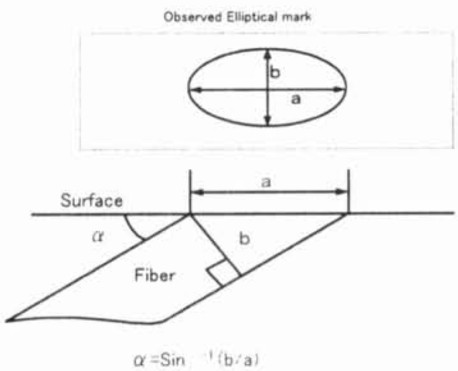


Fig.2 The relationship between depression angle (α) and elliptical mark

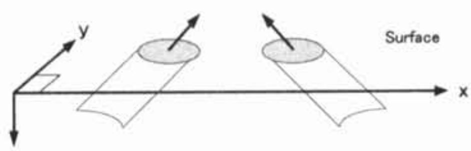


Fig.3 The ambiguity of fiber orientation in measuring elliptical mark

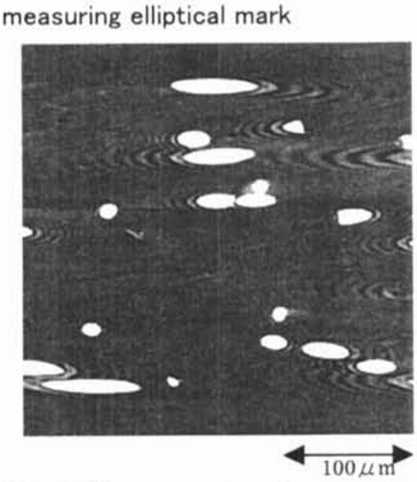


Fig. 4 The example of cross section image observed through SAM

3 Measurement of the 3D Fiber Orientation by the Elliptical Marks and Interference Fringe Patterns

3.1 Parameters of the 3D Fiber Orientation in the Molding of FRP

The 3D fiber orientation in molding of FRP consists of four parameters of intersection point coordinate with the surface (x0,y0), the azimuth angle α and the depression angle β, shown in Fig.5($0 \leqq \alpha \leqq 90$, $0 \leqq \beta < 360$). Therefore, the 3D fiber orientation can be calculated by obtaining four parameters from the elliptical marks and the interference fringe patterns of the fiber observed through SAM.

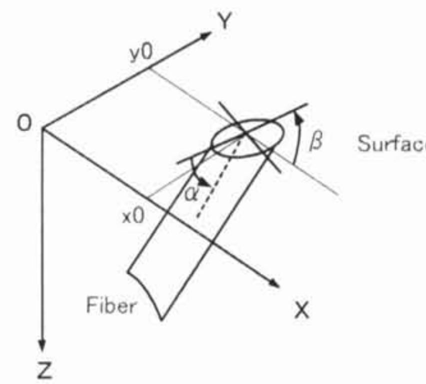


Fig. 5 The 3D fiber orientation parameters for a fiber in the FRP

3.2 Filtering and Binarizing of the SAM Image

Size of the image observed through SAM is 400 × 400 pixels, and 256 levels.

In present method, we need the edge information of the elliptical marks and the interference fringe patterns. We use the Sobel operator[4] to detect the edge of the elliptical marks and the interference fringe patterns. Then, we make the binary image with the threshold value set by the histogram from the edge image. The noise with polishing injury or impurity is included in the binary image. Then small edge is removed as the noise. The elliptical marks and the interference fringe patterns are detected from the binary image with the noise rejection.

3.3 Detection the Elliptical Marks From the Binary Image

The elliptical mark consisting of the five parameters of the center coordinate (x0,y0), the major axis **a**, the minor axis **b** and the gradient β is shown by equation (1), shown in Fig.6.

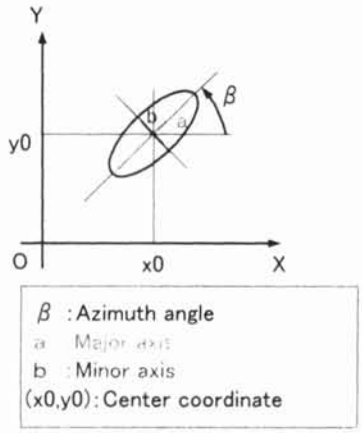


Fig. 6 The ellipse parameters

$$X=a/2\cos\theta\cos\beta - b/2\sin\theta\sin\beta + x0$$
$$Y=a/2\cos\theta\sin\beta + b/2\sin\theta\cos\beta + y0 \quad (1)$$
$$(0 \leqq \beta < 180,\ 0 \leqq \theta < 360)$$

We use Hough transformation method for detecting the elliptical marks from the binary image. Hough transformation method is one of the image processing techniques in which we can detect the shapes of the edge parameters on the image. The merit of Hough transformation method is that we can detect the shapes even in the image with the noise[5]. We calculate the depression angle α from the elliptical parameters of the major axis **a** and the minor axis **b** by equation (2). We make the parameter list of each elliptical mark of the fiber which consists of x0, y0, a, b, α and β.

$$\alpha=\sin^{-1}(b/a) \quad (2)$$

3.4 Direction of the Azimuth Angle of the Elliptical Mark from the Interference Fringe Patterns.

The depression angle α can be calculated form the major axis **a** and minor axis **b**, but whether the azimuth angle β is d or d+π cannot be decided shown in Fig.7.

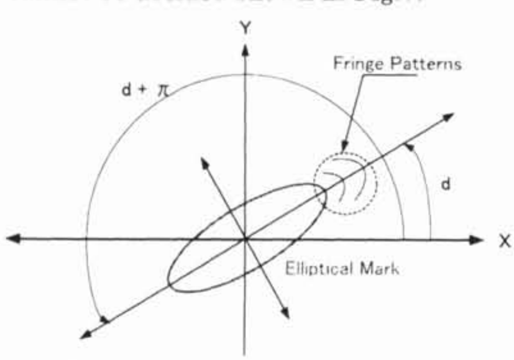


Fig. 7 The relationship between the interference fringe patterns and direction of fiber

In this paper, we decide the azimuth angle β by the interference fringe patterns observed through SAM. The interference fringe patterns appear at the azimuth angle β, d or d+π. We trace along the major axis from the center to the outside of the ellipse, and whether the interference fringe patterns exist outside of the circumference is examined. As the interference fringe patterns exist in the direction of d in Fig.7, we decide the azimuth angle β is d. Then, the parameters of the 3D fiber orientation are calculated from elliptical marks and the interference fringe patterns.

4 Measurement Experiment of the 3D Fiber Orientation by SAM Image

4.1 Measurement in the Cylindric Material

We applied the proposed method to the 3D fiber orientation measurement of the cylindric molding. This sample cannot be observed through SAM for the cylindric non-destructively. Therefore, we cut off the sample and we observed the cut section through the microscope. The observed image is shown in Fig.8. We can confirm the difference between the fiber orientation of the skin layer and the core layer.

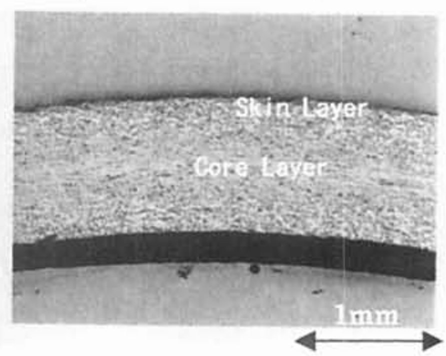
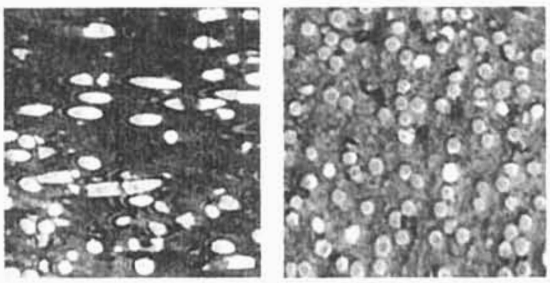


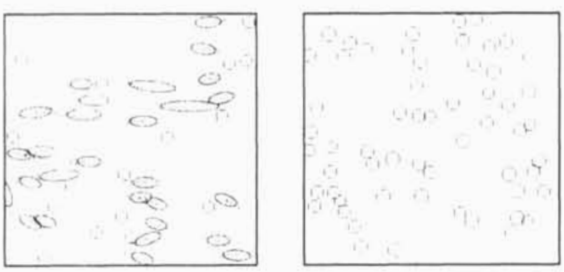
Fig. 8 The sample used for the measurement experiment

We observed the core layer and the skin layer of this sample through SAM. The image of the observed core layer is shown in Fig.9(a) and the image of the skin layer is shown in Fig.9(b). In the core layer, the fibers are orientated horizontally to the surface and in the skin layer, all fibers are orientated vertically to the surface. The result of the detection of the elliptical marks and the decision of the azimuth angle by the fringe patterns are shown in Fig.10. In the skin layer, only circle has been confirmed. This result shows that all fibers are orientated vertically to the surface. In the core layer, we can confirm that the ellipse and circle exist. The azimuth angle β of the ellipse is orientated horizontally right and left.



(a) Core layer (b) Skin layer

Fig. 9 The image observed through SAM



(a) Core layer (b) Skin layer

Fig. 10 Measured circle and ellipse patterns

4.2 3D Fiber Orientation Distribution

Fig.11 shows the distributive relation between the azimuth angle and the depression angle. In the core layer, about 30% fibers are orientated horizontally to the surface. The azimuth angle βs horizontally are concentrated in 0 or 180 degrees. A point shows a fiber, the position of the radius shows the depression angle and the position of the circumference shows the azimuth angle. Fig.11 shows the points are concentrated around the center.

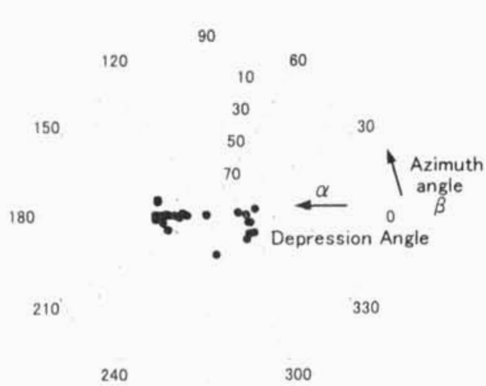


Fig. 11 3D fiber orientation distribution in the core layer

4.3 Visualization of the 3D Fiber Orientation

The calculated parameters of each fiber were converted to CAD data and the position of each fiber was displayed by using the 3D CG software. The result is shown in Fig.12. In this method, the 3D fiber orientation distribution can be visualized. In this method, the fiber orientation distribution can be visualized from various angles. This method is effective for the analysis of the fiber orientation distribution.

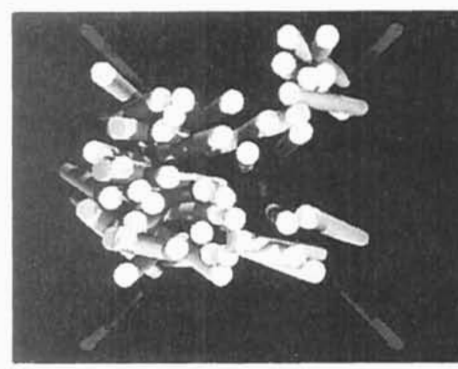


Fig. 12 The image reconstructed from the measured fiber orientation

5 Conclusion

We proposed a measurement method of the 3D fiber orientation by observing the cut section of the molding through SAM.
The following results were obtained:

(1) This proposed method has the feature that we can measure the azimuth angle without ambiguity in measuring the 3D fiber orientation.
(2) We applied this proposed method to the 3D fiber orientation measurement of the cylindric molding. In the core layer, the fibers were orientated horizontally to the surface and in the skin layer, all fibers were orientated vertically to the surface.

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