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Application News

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Industrial X-ray Inspection System

Observations of Glass-Fiber-Reinforced Plastics Using an X-Ray CT System

Introduction

Fiber-reinforced plastics (FRP) are composite materials consisting of glass fibers or other fibers mixed into plastic to add strength. Materials in which glass fibers are used are referred to as glass-fiber-reinforced plastics (GFRP) .

GFRP are widely utilized in motorcycles, automobiles, and other products in transportation machinery-related fields, and for housing equipment and machines. Injection molding is one of the methods used to manufacture parts utilizing GFRP. With injection molding, the orientation of the internal fibers changes depending on the flow of the resin. There is a relationship between this fiber orientation and the mechanical properties of the material, as well as the occurrence of warping and other molding defects. Accordingly, observing the orientation of the internal fibers becomes very important. Conventionally, to observe the fiber orientation, the sample was generally cut and then observed or photographed. With this method however, evaluation takes time and effort, and it is difficult to accurately assess the 3-dimensional structure.

This article introduces CT images of GFRP samples taken using an X-ray CT system, as well as analytical results of the CT data using the fiber orientation analysis software.

Observations of Glass-Fiber-Reinforced Plastics (GFRP)

Figs. 3 and 4 show the results of images of a GFRP sample (Fig. 2) taken using the inspeXio SMX-100CT Micro Focus X-Ray CT System (Fig. 1). The GFRP sample was created by excising the slender portion of a dumbbell-shaped test piece.

Fig. 3 shows a fluoroscopic image of the excised sample fragment as a whole (a), as well as a magnified fluoroscopic image of the central part (b). In the image of the sample as a whole, the glass fibers can be observed, but only indistinctly. However, when this is further magnified, it becomes possible one by one to distinguish the individual glass fibers mixed into the plastic. In the fluoroscopic image however, the fibers unfortunately all appear to overlap in the thickness direction, and so the orientation of the fibers cannot be accurately observed. The CT image results for this GFRP samples are shown below.

Fig. 1 Overview of the inspeXio SMX-100CT Micro Focus X-Ray CT System

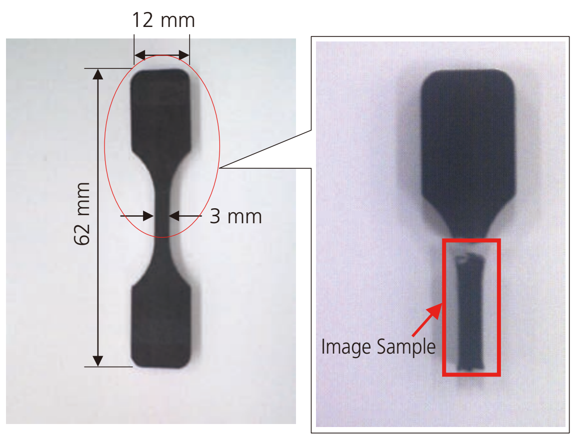


Fig. 2 Overview of a GFRP Sample

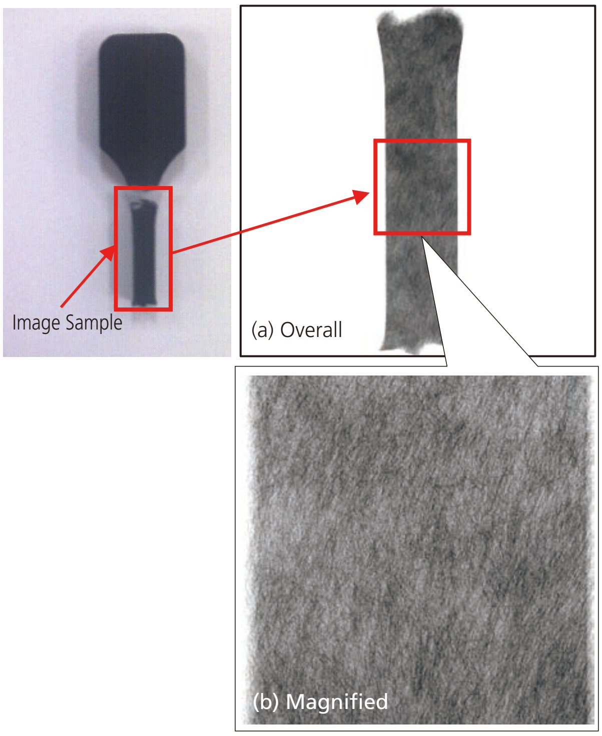


Fig. 3 Fluoroscopic Image of a GFRP Sample

Fig. 4 shows the MPR (Multi Planar Reconstruction) image. In an MPR display, multiple CT images are stacked up in a virtual space, so as to line up four images: a CT image (1); mutually orthogonal longitudinal images (2) and (3); and an arbitrary cross sectional image orthogonal to the longitudinal cross sectional images (4).
From Fig. 4 images (1) to (4), it is possible to observe the orientation of the fibers in the 3 directional cross sections intersecting at right angles.
Fig. 5 shows consecutive longitudinal cross sections of the GFRP sample, from near the surface to the center. It can be confirmed that the orientation near the surface and at the central part has changed.
Fig. 6 shows a 3-dimensional display of this CT imaging data. Converting to a 3-dimensional display makes it possible to observe the glass fibers volumetrically.

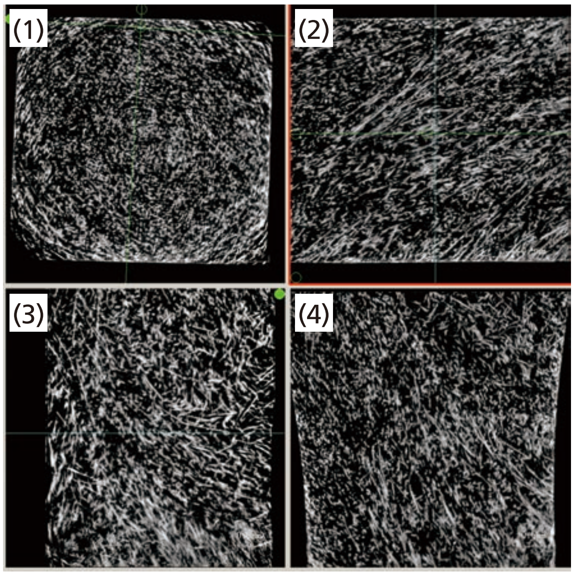


Fig. 4 MPR Images of GFRP

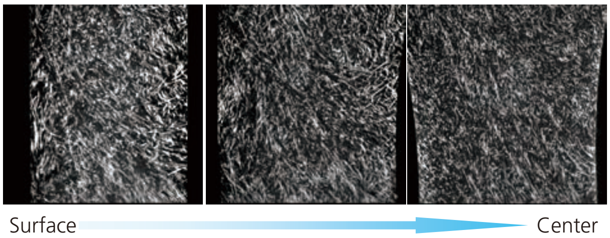


Fig. 5 CT Images of GFRP

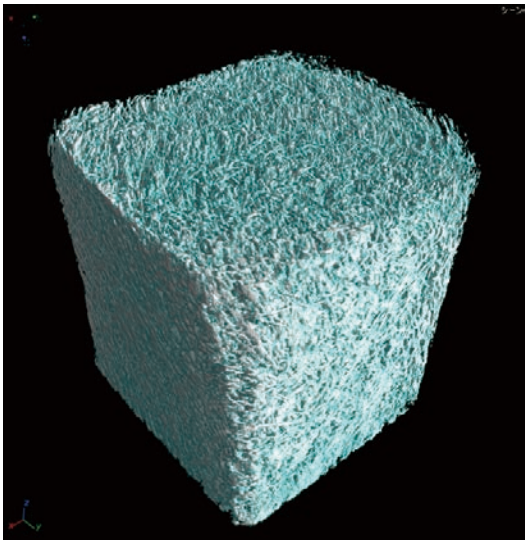


Fig. 6 3D Image of GFRP

Next, Figs. 7 and 8 show the results of magnifying the image of the central part of the GFRP sample. It is possible to check individual fibers that would have been impossible to check in a low-magnification image.

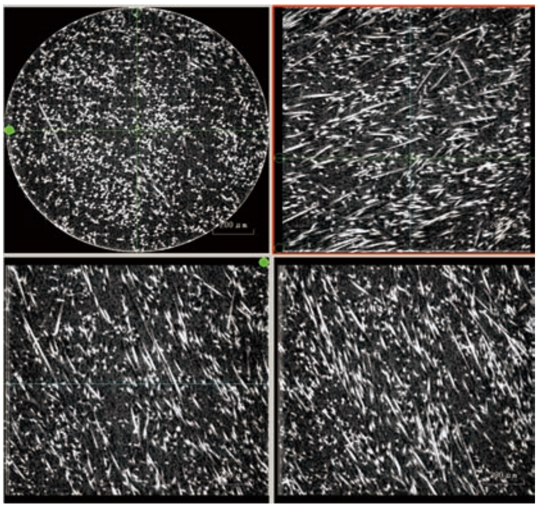


Fig. 7 MPR Images of GFRP (magnified)

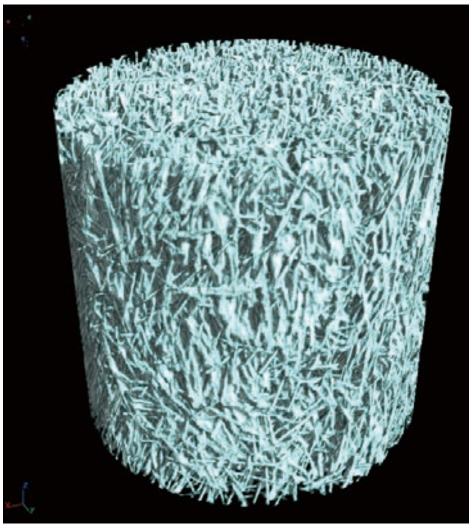
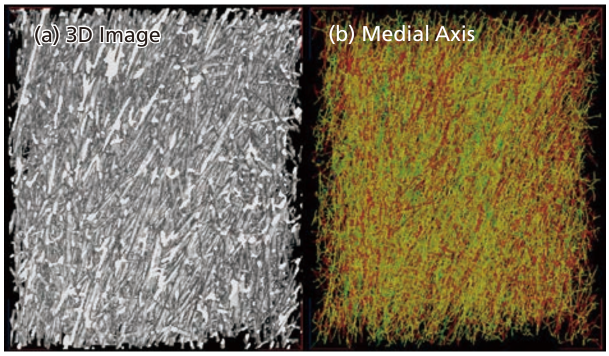


Fig. 8 3D Image of GFRP (magnified)

It is possible to intuitively investigate how the fibers are oriented directionally, by performing CT imaging and observing the results 2-dimensionally in an arbitrary cross section, as well as creating a 3-dimensional display. However, some sort of numerical indices are required in order to compare the results with other samples, and to evaluate the state and distribution of the fibers 3-dimensionally.
Accordingly, we next introduce a method of analyzing and evaluating the orientation of the fibers 3-dimensionally from the CT data.

Sample Analysis of Glass-Fiber-Reinforced Plastics (GFRP)

Up to now, two methods have been used to analyze and evaluate the orientation of fibers. In the direct method, thin samples taken from a molded part are observed under a microscope, the orientation angles of individual fibers are measured, and this data is used to calculate the primary orientation direction and degree of orientation.
In the indirect method, the mechanical properties of small slices excised in various directions from a molded part are measured, and the results are used to estimate the degree of orientation. With the direct method however, cuts must be made in the sample one after the other, which is very labor-intensive. With the indirect method, it is necessary to make assumptions about the orientation direction before cutting the sample into small pieces, and accuracy becomes an issue if such assumptions cannot be made.
In contrast, if the inspeXio SMX-100CT is used, data can be obtained from about 10 minutes of imaging to show in detail how the individual fibers are arranged 3-dimensionally, as shown in Figs. 7 and 8. At this stage, results equivalent to data from microscopic observations in the direct method are entirely at one's disposal.
In observing the fiber orientation, the ExFact Analysis for Fiber (Nihon Visual Science, Inc.) was used. This software performs statistical evaluations/analyses of the shape and distribution of porous samples, particles, fibers, and other samples with complicated 3-dimensional structures, from a variety of perspectives. Firstly, the fibers in the 3-dimensional data in Fig. 9 (a) are subjected to a thinning treatment. Then a variety of statistical parameters are calculated with respect to their shape and distribution (Fig. 9 (b)).



(a) 3D Image   (b) Thinned display at the fiber center line

Fig. 9 Sample GFRP Analysis

The data calculated by ExfactAnalysis for Fiber is as shown below.
- Fiber content :20.06 %
- Number of fibers detected :11,950
- Average fiber diameter :7.97 µm
- Fiber intersections :33,469 points

Here, "fiber intersections" refers to the number of points at which the fibers intersect. The smaller the number of fiber intersections, the more the fibers are oriented in the same direction, indicating that they are neatly arranged.
Next, the 3-dimensional data is divided into a 27 element matrix (3 × 3 × 3), and the average orientation in each cell is evaluated using vectors.

Here, each vector indicates the following:
- Length : Intensity of fiber orientation
- Color : Quantity of fibers
- Orientation : Average fiber orientation

Fig. 10 (b) shows the vectors and observed fibers together, to illustrate that the fiber orientation and the vector orientation are in agreement. Thanks to analysis data from these vectors, not only is it possible to evaluate the orientation in each part of the GFRP sample, but it is also possible to perform a comparative evaluation with results obtained from injection molding simulation software.

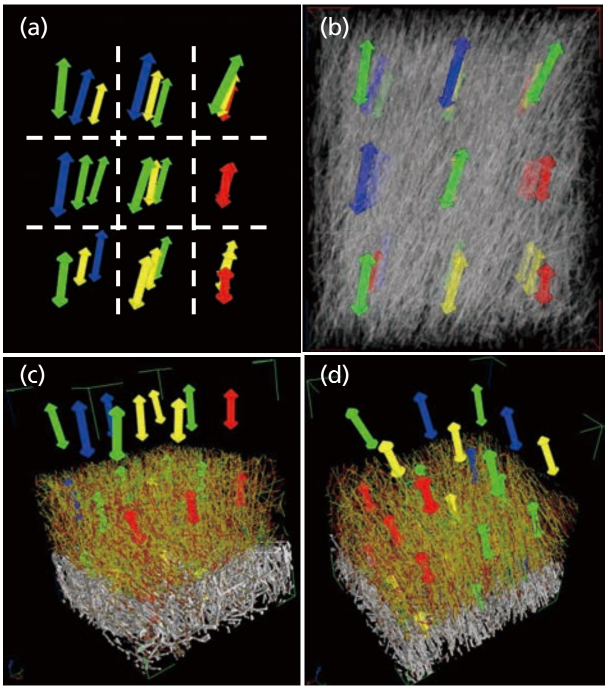


Fig. 10 Sample GFRP Analysis

(a) Visual display of fiber orientation with vectors
(b) Overlay of vectors and 3-dimensional display
(c) 3-dimensional display / thinned display / vector display
(d) 3-dimensional display / thinned display / vector display

Conclusion

In this way, with the inspeXio SMX-100CT, not only is it possible to volumetrically observe the orientation of fibers in a GFRP sample, but it is also possible to utilize analysis software to quantify and evaluate the fiber orientation.

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