DIRECT MEASUREMENT ON FRACTURE TOUGHNESS OF CARBON FIBER

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INTRODUCTION

Fracture toughness of carbon fiber is of great interest as well as its strength, because it is essentially important when fracture behavior of composites was investigated. The measurement of fiber fracture toughness is, however, thought to be difficult due to its small diameter. One of the practical ways to estimate fracture toughness is determination of the initial crack size by observing fracture mirror size on a tensile fracture surface of un-notched specimens [1]. Since the mirror size measurement involves a considerable error, estimated fracture toughness is usually scattered significantly. Accuracy of the measured fracture toughness will be significantly improved, if a notch is introduced intentionally by controlling its size and shape. In this study, therefore, a new measurement technique was proposed to estimate fracture toughness of the carbon fiber. At first, applicability of the focused ion beam (FIB) system was examined as a machining tool of notches. The FIB is regarded as a useful machining tool to prepare samples for transmission electron microscope observations. Recent FIB systems have less than 10 nm beam diameter, achieving micro machining by scanning the beam electronically. Various sizes and types of notches were tried to be introduced on the carbon fibers. Tensile tests were carried out on the notched carbon fibers to examine the validity of this technique.

EXPERIMENTAL PROCEDURE

A carbon monofilament was extracted from a bundle, and was attached on an aluminum foil holder. The notch was introduced using the FIB system on a carbon fiber. Ga+ ion beam was extracted from an ion source and accelerated with 30kV accelerating voltage. Various types of notches were introduced by changing a beam diameter and other machining conditions.

Notched carbon fibers were tested in tension following the tensile test method of carbon fiber monofilaments. Fracture surface was observed by SEM to confirm a fracture position and to determine the notch length, a. Fracture toughness (Kc) of the carbon fibers was calculated using the equation in the reference [2]. Effect of anisotropic properties is also examined by finite element analysis.

RESULTS AND DISCUSSION

Notch Machining

Figure 1 shows typical outlooks of notched carbon fibers introduced by the FIB. When the beam diameter of 7 nm was used, a sharp notch was successfully introduced with notch-tip width of less than 50 nm as shown in the figure. On the other hand, 360 nm notch-tip width
was obtained by changing a beam diameter (18 nm). Various kinds of notches were introduced with different notch-width and notch-length.

**Fracture Toughness Tests**

Tensile tests were successfully carried out with linear load-displacement curves up to fracture. After tensile tests, specimens were successfully corrected without secondary damage and fracture surface could be observed as shown in Fig. 2. A flat notch surface was clearly observed as indicated by a circle on the fracture surface. It was also observed that the notch front was straight, indicating machining by the FIB was applicable to the notch introduction. Notch length, a, was measured from the micrograph for every specimen. On the fracture surface, hackle pattern was clearly observed from the notch tip. This means that the fracture of the notched carbon fiber originated from a notch-tip. It was confirmed that fracture toughness tests were successfully carried out with the present technique.

Although $K_c$ obtained by the experiments was somewhat scattered, it showed 1.6 MPa$\sqrt{m}$ on average, when the notch width was less than 0.2 $\mu$m. Since the fracture toughness of the PAN based carbon fibers were reported to be in the rage from 1~2 MPa$\sqrt{m}$ [2], present results is expected to give the reasonable value in this range of notch width.

![Fig. 1: Typical outlook of notched carbon fiber](image1)

![Fig. 2: Fracture surface of notched carbon fiber](image2)

**CONCLUSION**

1. Fracture of notched carbon fibers originated from notch tip with hackle pattern, indicating present technique is applicable for fracture toughness tests of the carbon fiber.

2. Fracture toughness tests should be carried out with small enough notch tip width to which calculated fracture toughness is insensitive. For IM-600 carbon fiber, it was less than 0.2 $\mu$m. With such condition, fracture toughness of IM600 was estimated as 1.6 MPa$\sqrt{m}$ on average.

**REFERENCES**
