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Structure and compressive strength of carbon fibers

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Introduction

Carbon fibers (CF's) are known as typical high strength fibers, whereas their drawback is the relatively low compressive strength. In order to increase the compressive strength, it is desired to elucidate compressive fracture mechanisms. In the present study, an attempt has been undertaken to analyze the compressive fracture mechanisms of CF's through time-resolved small-angle X-ray scattering (SAXS) measurements using synchrotron radiation during compressive fracture process. As a first step of the study, a theoretical model of the axial compressive fracture of CF's has been proposed as shown below.

Results and discussion

The major structural component of CF's is the carbon layer stacks oriented preferentially in parallel to the fiber axis. Although the carbon layer stacks show extremely large in-plane strength, they are easily broken in shear. Therefore, the shear fracture of misaligned carbon layer stacks can be a cause of compressive fracture of CF's. This fracture model, however, can not explain the lower strength in compression than in tension. Alternatively, the present authors propose that the compressive fracture of CF's is triggered by the buckling of carbon layers. The buckling of carbon layers tends to take place in the unsupported region adjacent to voids. Based on this model, the compressive strength of CF's, σ, is derived as

$$\sigma = \frac{\pi^2 E d_{002}{}^2}{3 L_p{}^2} \qquad (1)$$

where E is the Young modulus of carbon layer, d_{002} the interlayer spacing of carbon layer stacks and L_p the void length parallel to the fiber axis.

Polyacrylonitrile-based carbon fibers derived with different production conditions were used for the experiments. The voids in these fibers produced equatorial streaks in SAXS patterns as shown in Fig. 1. The sizes of voids determined with SAXS are shown in Fig. 1 as a function of carbon layer stacking height determined with wide-angle X-ray diffraction (WAXD). The axial compressive strength of single filament was measured using a specially designed compression test apparatus with a gage length of 10 µm and a compression speed of 3 µm/min. The results are shown in Fig. 1 together with the compressive strength calculated from Eq.(1). Although there is some deviation between the measured and calculated compressive strengths, it is within an acceptable range by considering the simplification of the structure. It is noted that the maximum of the compressive strength at the carbon layer stacking height of about 1.7 nm is reproduced by Eq.(1). This equation suggests that reduction of the void length parallel to the fiber axis is crucial for increasing the compressive strength of CF's since the interlayer spacing can not be decreased below that of graphite.

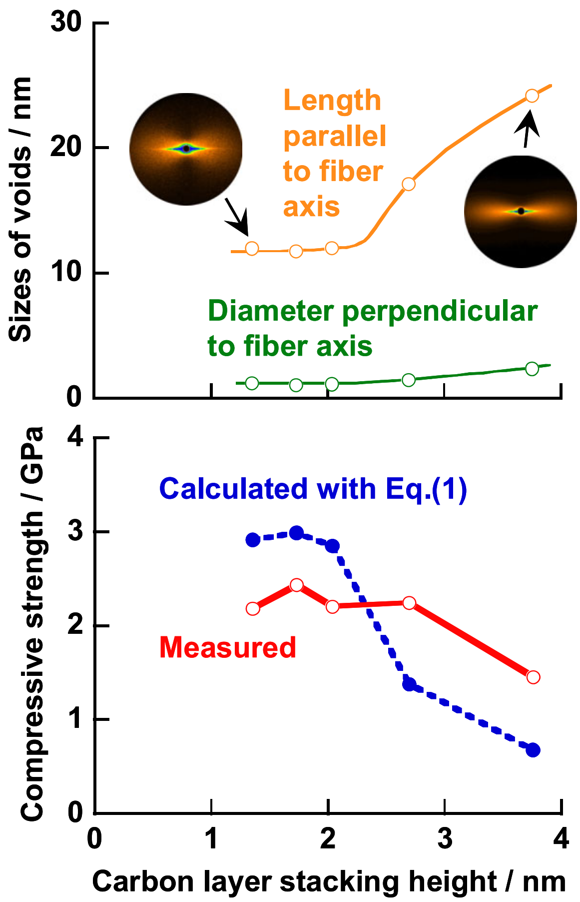

Figure 1 Sizes of voids determined with SAXS, axial compressive strength measured on single filaments and that calculated with Eq.(1) versus carbon layer stacking height determined with WAXD for CF's. Insets are SAXS patterns of CF's where fiber axis is in top-and-bottom direction.

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