Materials Science

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Orientation change of carbon nanotubes in a twisted yarn during stretching

Masatoshi SHIOYA*[1], Yoshiki SUGIMOTO[1], Shinichi SAKURAI[2], Katsuhiro YAMAMOTO[3]
[1]Tokyo Institute of Technology, 2-12-1-S8-34 Ookayama, Meguro-ku, Tokyo 152-8552, Japan
[2]Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan
[3]Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466-8555, Japan

Introduction

It has been reported recently that high strength yarns can be derived by twisting carbon nanotubes (CNT's). It is worthwhile to investigate the mechanism with which load applied to the yarn is effectively transferred to the component CNT's. The present study aims at investigating changes in the orientation of CNT's in a twisted yarn during stretching in order to develop a structure model of the yarn for the model analysis of the stress transfer.

Experimental

A twisted yarn of CNT's produced by Suzhou Institute Nanotech and Nano-bionics of Chinese Academy of Science, China were used for the experiments. According to the catalog data, this yarn has the tensile strength of 350 MPa, the tensile modulus of 13 GPa, the diameter of 8 to 12 μm and the inclination angle of CNT's from the yarn axis on the surface of 10°. Eight filaments were aligned in parallel, bonded to a cardboard at a gage length of 10 mm and gripped with a tensile loading machine. The yarns were stretched stepwise with the increment of the gage length of 20 μm. At each step of stretching, small-angle X-ray scattering (SAXS) was measured for 120 s. The SAXS patterns were detected using an image intensifier and a CCD camera.

Results and discussion

Typical SAXS pattern of the twisted yarn of CNT's and the distribution of the total SAXS intensity at a given value of s are shown in Figure 1 where s is the magnitude of scattering vector. The intensity distribution has a peak. The measured intensity distribution almost coincided with that calculated based on a hollow tube with the inner and the outer diameter of 7 and 14 nm. The difference between the inner and the outer diameter of the CNT's almost coincided with the thickness of the wall, 3.8 nm, determined from the width of the 002 diffraction peak in the wide-angle X-ray diffraction profile.

The degree of orientation of CNT's around the yarn axis can be represented by the orientation parameter defined as 1 - ($\Delta\varphi$/180°) where $\Delta\varphi$ is the full-width at half-maximum of the azimuthal SAXS intensity distribution. The orientation parameter was determined from the variation of the width of the azimuthal SAXS intensity distribution with s. The changes of the orientation parameter during stretching the twisted yarn are compared with the stress-strain curve cited from the catalogue in Figure 2. The orientation parameter initially increases almost linearly with the strain similarly to the stress. At a strain beyond about 0.01, the increases in both the orientation parameter and the stress become slow. It is suggested that slip of the CNT's takes place in the twisted yarn at a large strain.

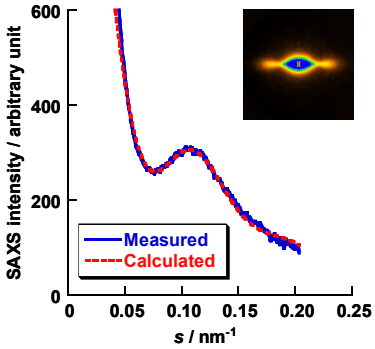

Figure 1 SAXS pattern (inset) and distribution of total SAXS intensity at a given s for twisted yarn of CNT's. Yarn axis is in top and bottom direction of the pattern.

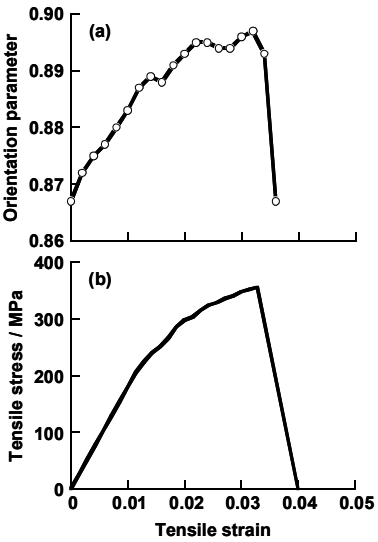

Figure 2 (a) Measured orientation parameter and (b) tensile stress cited from catalogue vs. tensile strain for twisted yarn of CNT's.

* shioya.m.aa@m.titech.ac.jp