BL-15A2/2020G516

Strain-Induced Crystallization Near Crack Tip of Natural Rubber

Tomohiro YASUI[1], Ruito TANAKA[1], Hideaki TAKAGI[2], Nobutaka SHIMIZU[2], Noriyuki IGARASHI[2], Katsuhiko TSUNODA[3], and Shinichi SAKURAI[1 *]

[1]Department of Biobased Materials Science, Graduate School of Kyoto Institute of Technology, Matsugasaki, Sakyo-ku, Kyoto 606-8585, Japan
[2] High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
[3] Bridgestone, 3-1-1 Ogawa Higashi-cho, Kodaira, Tokyo 187-8531, Japan

1 Introduction

Natural rubber (NR) is soft but has the property that it is not broken when momentary stress is applied. Strain-induced crystallization (SIC) is considered to play an important role for the NR's toughening. The studies on the relationship between the prevention of the crack propagation and SIC under uniaxial elongation for the cross-linked natural rubber has been done. In the current study, we used cross-linked NR with 50 phr carbon black inclusion. To elucidate the relationship between SIC and suppression of crack propagation during equibiaxial elongation, we detected SIC at the crack tip by wide-angle X-ray diffraction (WAXD) measurements.

2 Experiment

We prepared a sheet of cross-linked natural rubber with 1.4 phr of sulfur and 50 phr of carbon black (34.3 mm x 34.3 mm, thickness was 0.22 mm). A 13-mm long notch was made at the center of the NR sheet with a utility knife. For the equibiaxial elongation experiments, the cross-head speed was 0.2 mm/s. Under such a very slow elongation, stress relaxation can be almost completed. The rubber sheet was elongated up to 3.0 times, since the crack propagation was prevented. WAXD measurements were performed by changing the irradiation position of X-ray by 0.1 mm until no crystal peaks were seen from the crack tip. The wavelength of X-ray was 0.1 nm and the beam size was 30 μm (H) x 37 μm (V), using the synchrotron radiation as an X-ray source at the beamline BL-15A2 of Photon Factory at KEK (High-Energy Accelerator Research Organization) in Tsukuba, Japan.

3 Results and Discussion

Near the crack tip, WAXD showed a crystalline peak. The WAXS pattern with crystal reflections observed here were similar to those observed when the specimen was uniaxially elongated. WAXD mapping revealed the presence of crystals only near the crack tip (Fig. 1). It was considered that the presence of crystals prevented crack propagation because SIC did not develop far from of the crack tip. It was also found that the orientation direction of the c-axis of the crystals is equal to the tangential direction of the crack (Fig. 2). These results indicate that crack propagation in the equibiaxially elongated specimen is suppressed by crystals generated by SIC, and that the strain field is the same as in the uniaxially elongated specimen.

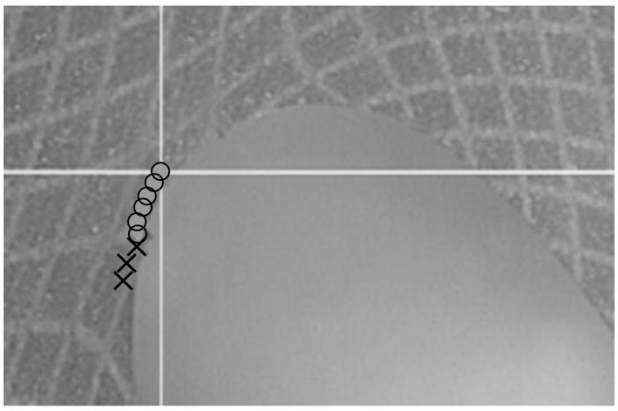

Fig. 1: Appearance of the notched specimen biaxially elongated with 3.0 × 3.0 times. ○ Crystallization was detected. × Crystallization was not detected.

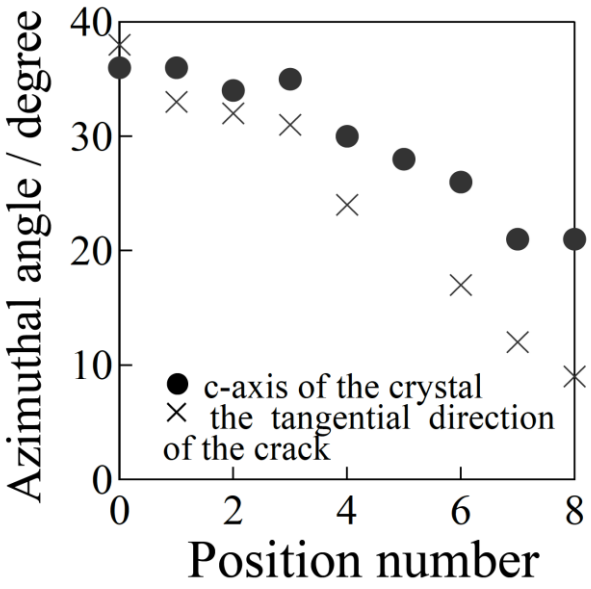

Fig. 2: Relationship between the orientation direction of the c-axis and the tangential direction of the crack.

* shin@kit.ac.jp