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Changes in Long Period of Polyamide 6 Filament by Heating

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1 Introduction

Recently, actuators made with twisted polymer filaments which contract and recover in response to the temperature change attract great attention for their extraordinary large actuation stroke and silent operation [1]. It has been considered that their extraordinary large stroke is related to the negative thermal expansion coefficient in the filament axis direction, to which the entropic elasticity may play an important role. However, details of the mechanisms of the actuation have not been completely clarified yet. The present experiments aim at collecting basic data required for considering the mechanisms of the actuation of the polymer filament actuators. The changes in the long period of the polyamide 6 filament during heating and cooling cycles have been investigated.

2 Experimental

A polyamide 6 filament (BERRY LINE Nylon, Tackleberry Co., LTD.) with the glass transition temperature at about 47 °C, the melting temperature at about 220 °C, and the diameter of 370 μm was used for the experiments. The nylon filament was heat treated at 180 °C for 1 hr by holding it at a constant length since similar heat treatment is applied to produce the polymer filament actuators. The SAXS measurements were performed at BL-6A in Photon Factory using the X-ray with the wavelength of 0.15 nm at the sample-to-detector distance of 1.4 m. The nylon filament was heated and cooled at a fixed length using a heating apparatus (Instec, HCS302) during the SAXS was detected with PILATUS3 1M.

3 Results and Discussion

Fig. 1 shows the SAXS pattern of the nylon filament at 180 °C. The filament axis is in parallel to the up-and-down direction of this figure. The layer-line scattering is caused by the long-period structure of nylon 6 which consists of the alternative repetition of the crystallites and the amorphous regions in parallel to the filament axis.

Fig. 2 shows the SAXS intensity distributions along the line in the meridional direction and passing through the center of the incident beam, which were measured during the heating process of the 2nd heating and cooling cycle. It can be found that the scattering peaks shift to the lower scattering angles with increasing temperature. This indicates that the long period increases with increasing temperature. It can be also found that the scattering intensity increases with increasing temperature above the glass transition temperature. This indicates that the electron density difference between the crystallites and the amorphous regions increases due to the expansion of the free volume in the amorphous regions.

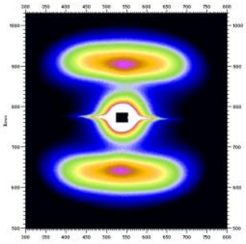

Fig. 1: SAXS pattern of nylon filament obtained at 180 °C.

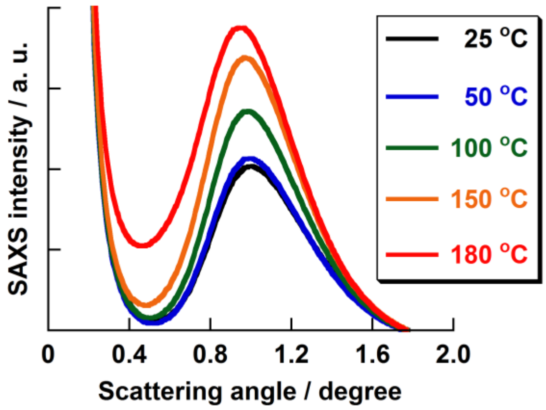

Fig. 2: SAXS intensity distributions of nylon filament obtained at temperatures shown in the figure.

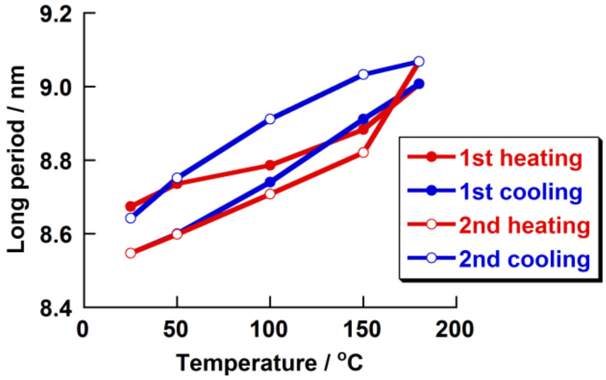

Fig. 3: Long period vs. temperature during 1st and 2nd heating and cooling cycles shown in the figure for nylon filament.

Fig. 3 shows the changes in the long period during heating and cooling cycles. It can be found that long-period increases during heating. It has been reported that oriented nylon 6 shows negative thermal expansion at temperatures above about 100 ^{o}C. [2] This difference may arise due to the difference in the extent of orientation between the specimens used in this study and the literature. Further experiments are needed for understanding the results shown in Fig. 3.

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References
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