Flow-induced Orientation of Cellulose Nanofiber Suspension in Planar Channels with an Abrupt Contraction

Taisuke Sato 1*, Shuya Namatame 2, Takatsune Narumi 3, and Akiomi Ushida 3
1 Center for Transdisciplinary Research, Institute for Research Promotion, Niigata University, 8050 Ikarashi 2-no-cho, Ikarashi, Nishi-ku, Niigata-shi, Niigata, Japan
2 Graduate School of Science and Technology, Niigata University, 8050-2 Ikarashi, Nishi-ku, Niigata-shi, Japan
3 Institute of Science and Technology (Faculty of Engineering), Niigata University, 8050-2 Ikarashi, Nishi-ku, Niigata-shi, Japan
E-mail: Taisuke@eng.niigata-u.ac.jp

Introduction. In recent years, cellulose nanofiber (CNF) is one of the materials expected to be applied in various fields. When nanofibers are molded by dispersing them in plastic melts, the properties of final product are affected by the fiber orientation induced by material flow during the molding process. This is because the orientation state of the fibers in flowing is substantially fixed as it is after cooling and solidification of the molded items. Therefore, in this study, we aimed to investigate the flow-induced orientation of fibers when the fluid in which the nanofibers extracted from the pulp is suspended in water flows in a planar channel with an abrupt contraction.

Test Fluid. The nanofibers used in this study are those extracted from natural pulp and are called cellulose nanofibers. In this experiment, we used nanofibers suspended in water as a concentration of 0.5 wt.%, which was supplied by DKS Co. Ltd.

Test Channels. Figure 1 presents a schematic diagram of the test channel. Four planar abrupt contraction channels with different contraction ratio of 2-1, 4-1, 8-1 and 16-1 were examined. In the test channel dimensions, $2H_1 = 2$ mm, 4 mm, 8 mm and 16 mm, $2H_2 = 1$ mm and $2H_3 = 1$ mm. The origin of the Cartesian coordinate system is located at the contraction in the center with respect to both the width and height directions. The $x$ axis corresponds to the flow direction and the $y$ and $z$ axes are perpendicular to it.

Flow-induced Birefringence. We used the FIB system developed in our previous study(1) to analyze the flow-induced orientation of fibers on the centerline of the test channels ($y = 0$). Details of the optical system were reported previously(1).

Experimental Setup. In this study, the typical shear rate $\dot{\gamma}_{op}$ is defined as

$$\dot{\gamma}_{op} = \frac{U}{H_3} \quad (1)$$

Where $U$ is the mean velocity in the upstream. All of the experiments were performed at room temperature ($20 \pm 1 ^\circ C$).

Results and Discussion. Figure 2 shows the distribution of the birefringence along the centerline ($y = 0$) at the typical shear rate of 25 s$^{-1}$. The birefringence is normalised as $\Delta n / \Delta n_u$, where $\Delta n_u$ is the value of the birefringence at the upstream position ($x/H_1 = -20$). As the birefringence is correlated with the degree of fiber orientation, a high birefringence indicates a highly oriented fiber state. In the upstream region, a dramatic increase in the birefringence occurs in the vicinity of the contraction. Although the result of the orientation angle of fibers is not shown here, we confirmed that the value is indicated 0° in the upstream region. This result indicates that the fibers were highly orientated in the flow direction. It is considered that this fiber orientation was induced by the elongational flow generated in the vicinity of the abrupt contraction. After the abrupt contraction, the birefringence decreases and reaches a constant value. It was found that the distance at which the birefringence reaches a constant value is not affected by the contraction ratio.

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(1) Sato, T., Narumi, T., Yasuda, K., Ushida, A. and Kayaba, R., *Nihon Reoroji Gakkaishi*, 44, (2016), 109-116.