OBSERVATION OF FLOW BIREFRENGENCE IN DYNAMIC SQUEEZE FLOW

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ABSTRACT

In this study, it is visualized the flow birefringence of an aqueous surfactant solution, which forms wormlike micelles and has strong viscoelastic properties, in a dynamically oscillating two-dimensional squeezed flow over the entire flow field. Strong flow birefringence was observed in the direction of elongation and a phase difference between the birefringence and the strain was confirmed. This result indicates that viscoelastic properties in extensional flow can evaluate from the birefringence measured by image immediately after cessation of the squeeze motion.

INTRODUCTIN AND PURPOSE

In aqueous surfactant solutions, surfactant molecules aggregate above a concentration called critical micelle concentration to form micelles. Micelles are known to take various shapes depending on a surfactant concentration and a salt concentration. The surfactant solution forming wormlike micelles exhibit strong viscoelasticity, and their rheological properties have long been the subject of research. Wormlike micelles change their macrostructure under strong shear deformation. This is called the shear-induced structure (SIS), and it leads to the occurrence of opaque, shear thickening, and inhomogeneous flow in rheometric flow have been reported[1)]. However, those relationship is not fully understood.

On the other hand, there have been efforts to investigate elongation-induced structures (EIS). The Capillary Breakup Elongational Rheometer (CaBER, Thermo Scientific HAAKE) and stagnation point flow are used for those study. Studies using stagnation point flow have reported that EIS occur at a lower strain rate and strain than SIS[2,3)]. In study using CaBER, micelle structures and EIS were reported based on the relationship between the shape change of filaments and the ratio of relaxation times between shear and elongational flow[4)]. These reports suggest that important findings about macrostructure of micelles can be obtained from elongational flow, where micelle are stretched and occurred orientation in only one direction.

In this study, we propose a method to visualize micelle motion in dynamically fluctuating squeeze flow. The flow birefringence of the entire squeeze flow field is observed, and the rheological properties of a surfactant solution in the elongational flow are clarified from the relationship between the birefringence and the squeeze motion.

EXPERIMENTAL APPALATUS AND SAMPLE FLUID

Fig. 1 shows the experimental apparatus used for the flow birefringence observation. From the direction of observation, circular polarizer, squeeze flow cell, circular polarizer, and the light source are arranged in this order. A video camera capable of shooting at 120 fps was used to capture images from the start of flow to relaxation. **Fig. 2** shows a schematic diagram of the squeeze channel and drive system. The squeeze channel consists of a reservoir (80.0 mm × 30.0 mm × 10.0 mm) with an optical glass window (φ30.0 mm) for observation to visualize the flow birefringence caused by the squeezing motion. The upper and lower parts of the flow channel are fixed to a movable stage, which is moved by rotating a ball screw with a stepping motor. The ball screw is divided into a right-hand thread and a left-hand thread, and the stage moves symmetrically up and down when the axis is rotated. The gap between the plates in the squeeze region H changes according to cosine wave. In this experiment, the amplitude A, the squeeze frequency ω, and the initial gap H_0 were used as variables.

CTAB/NaSal aqueous surfactant solution with surfactant concentration 10mM and salt/surfactant ratio 3.00 was used as the test fluid.

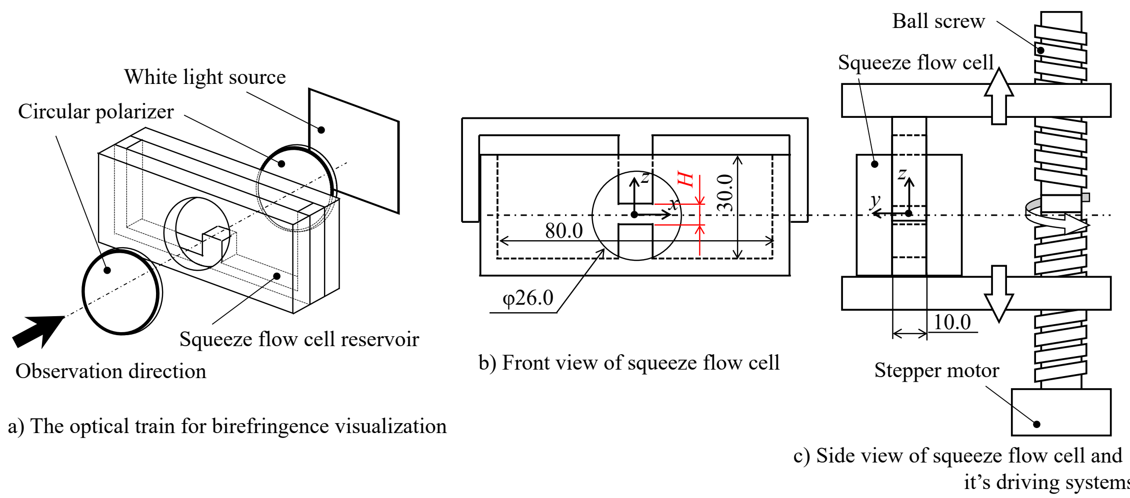

Figure 1 : The experimental apparatus and it's coordination system.

EXPERIMENTAL RESULTS AND DISCUSSION

Flow birefringence immediately after the start of squeeze motion

Fig. 2 shows a visualization of flow birefringence under the squeezing motion at an initial gap H_0=2.0 mm, amplitude A=2.0 mm, and frequency f=1.0 Hz. The image shows one cycle of squeeze motion divided into ten segments. **Fig. 2(a)** shows the image before the start of the flow, and **Fig. 2(k)** shows the state in which the squeeze plates return to its initial position. The dark background in **Fig. 2(a)** shows no birefringence. **Fig. 2(b)** and after show the results during the squeeze motion, and the change in color indicates the measure of birefringence. Squeeze motion begins in the direction which H increases. Therefore, the fluid is deformed in the z-axis direction from **Fig. 2(b)** to **(e)**. **Fig. 2(f)** is the top dead center, and the fluid is deformed in the x-axis direction from **Fig. 2(g)** to **(j)**. **Fig. 2(k)** is the initial position. Flow birefringence due to the deformation was observed very strongly in the z-axis direction from the stagnation point immediately after the start of flow. The birefringence around the stagnation point reached a maximum at **Fig. 2(e)** and entered a decreasing process at **Fig. 2(f)**. From **Fig. 2(g)** to **(j)**, the fluid is deformed in the x-axis direction, but no strong birefringence is observed in the x-axis direction. It indicates that the flow birefringence that occurred in the z-axis direction is relaxing during this period. Birefringence is also observed in **Fig. 2(k)**, which returns to the initial position. Furthermore, the birefringence in **Fig. 2(k)** is larger than that in **Fig. 2(j)**, confirming the phase difference to the variation in the strain.

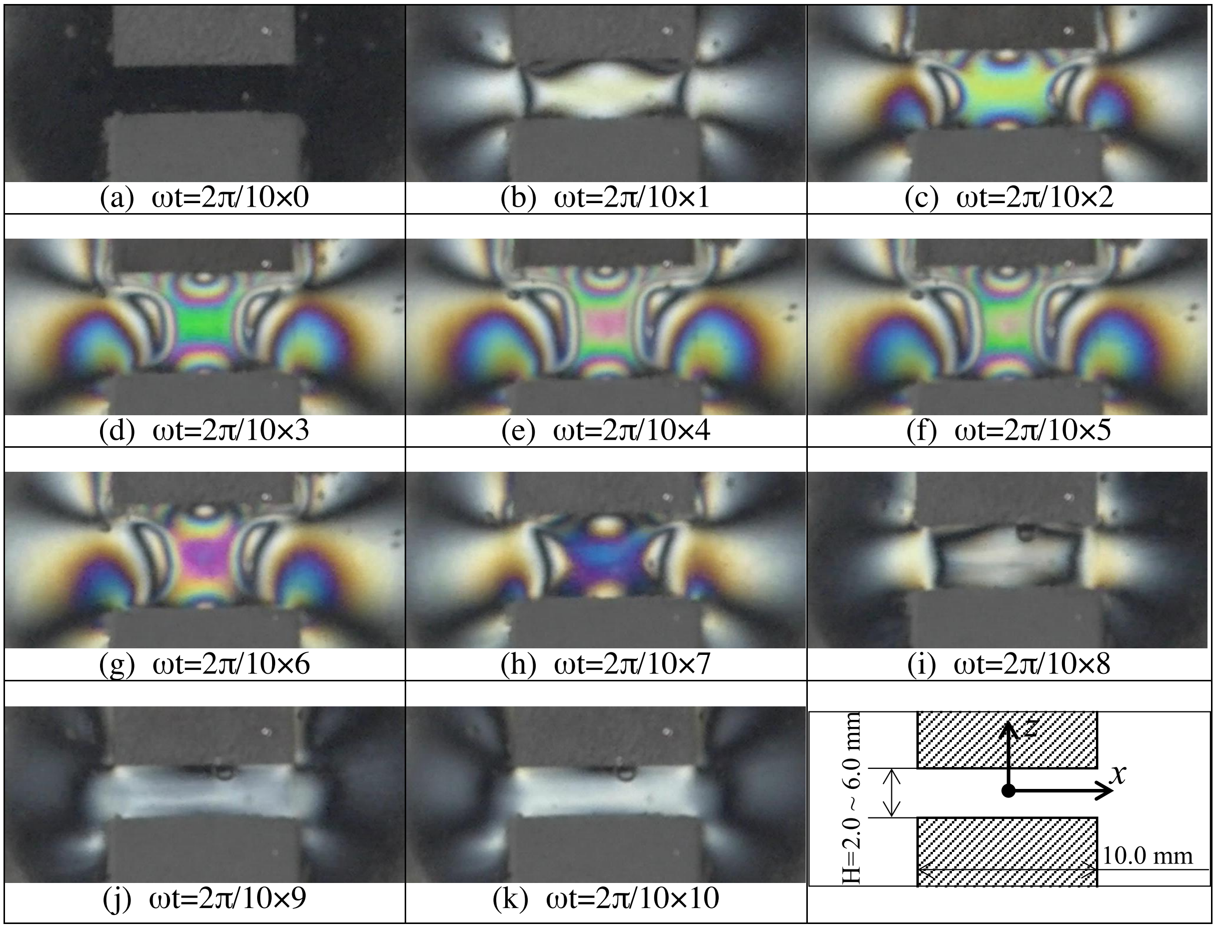

Figure 2 : Birefringence observation in the first cycle of squeeze motion.

REFERENCES

1. Kato, M., Takahashi T., and Shirakashi M., Influence of planar elongation strain on flow-induced structure and flow instability of CTAB/NaSal aqueous solution, *Trans. Jpn. Soc. Mech. Eng. Ser. B,* **72**, 1935–1942, 2006. https://doi.org/10.1299/kikaib.72.1935

2. Takahashi, T., and D. Sakata, Flow-induced structure change of CTAB/NaSal aqueous solutions in step planar elongation flow, *J. Rheol.,* **55**, 225–240, 2011. https://doi.org/10.1122/1.3528042

3. Sachsenheimer, D., Oelschlaeger, C., Müller,S., Küstner, J., Bindgen,S., and Norbert Willenbacher, N., Elongational deformation of wormlike micellar solutions, *J. Rheol.*, **58**(**6**), 2017-2042, 2014. https://doi.org/10.1122/1.4897965

4. Ito M., Yoshitake Y., Takahashi T., Shear-induced structure change in shear-banding of a wormlike micellar solution in concentric cylinder flow, *J. Rheol.*, **60**, 1019-1029 (2016). https://doi.org/10.1122/1.4961034