螺旋状毛細管粘度計における凝集系モンモリロナイト懸濁液の低圧力勾配下の流れ
Rheological Behaviors of Coagulated Montmorillonite Suspension under the Condition of Low Pressure Gradient Measured by Spiral Capillary Viscometer

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1. Introduction

Clay suspension exhibits unique rheological properties which are important in many industrial, agricultural, and environmental applications. In soil, erosion and clogging of clay suspension are closely related to the nature of the formation of fragile flocs. Therefore it is important to analyze the rheological properties, such as viscosity and yield stress in relation to floc formation under very weak stress conditions. In our previous study, Kobayashi *et al.* have developed the Spiral Capillary Viscometer with which viscosity and non-Newtonian behavior can be analyzed under a very low pressure gradient [1]. Although they have demonstrated several examples of clay suspension flowing with a very week stress condition, they have not carried out an intensive analysis on the basis of a mechanical model. This is the motivation to revisit the same system to examine the validity of analysis in a quantitative sense.

2. Materials and Methods

2.1 Na-montmorillonite

Na-montmorillonite dispersion was prepared from “Kunipia-F” powder (Kunimine Industry Co. Ltd.). The refining technique was followed the pattern described by Kobayashi *et al.* [1].

2.2 Spiral Capillary Viscometer

The capillary spiral viscometer with two cylinders and a 1 m long spiral joint capillary was used. The viscosity of suspension η and shear stress τ_w at the capillary wall are calculated by Eq. (1) and Eq. (2), respectively.

$$\ln\left[\frac{h(t)}{h_0}\right] = -\frac{\pi D^4 g\rho}{64AL\eta}t \quad \ldots(1) \qquad\qquad \tau_w = \frac{D}{4}\frac{\rho g h(t)}{L} \quad \ldots(2)$$

where D, ρ, g, $h(t)$, A, L, and t stand for the inner diameter of the spiral capillary, the density of the suspension, the gravitational acceleration, the water head difference between the two cylinders, the cross-sectional area of the cylinders, the length of the capillary, and the duration time respectively.

The effective volume fraction of particles Φ_{eff} was estimated from the relative viscosity η_r by using Mori-Ototake (M-O) equation [2] given as

$$\eta_r = \frac{\eta}{\eta_0} = 1 + \frac{3}{1/\Phi_{eff} - 1/0.52} \ldots(3).$$

2.3 Experimental Procedure

Solid volume fraction Φ and NaCl concentration of Na-montmorillonite suspension were adjusted to 0.002 and 0.005 - 1 M. The value of pH was 6.0 ± 0.1. After ultrasonicating the suspensions for 30 minutes, the flowing experiments were initiated to measure the relationship between the water head difference $h(t)$ and the time t. All the experiments were conducted at the temperature of 20±0.5℃.

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3. Results and Discussion

Fig.1 shows the temporal change of $h(t)/h_0$ for the Na-montmorillonite suspensions at different NaCl concentrations. The suspensions showed two different non-Newtonian behaviors under low shear stress. One was the gradual slowing down of the flowing behavior with decreasing the water head difference. Another one was the faster flowing behavior with an abrupt stop. As shown in Fig.2, the relative viscosity of the suspension increased apparently under low shear stress. Since the flocculation did not happen at I=0.005 M, so the reason for the increase may be related to the electroviscous effect. Increasing the ionic strength to 0.01 M, the suspensions started to form flocs. It leads to an increase in viscosity. When ionic strength reached 0.5 M, the abrupt stop appeared. The initial low viscosity may due to the slipping effect [3] and the abrupt stop may due to the clogging with big flocs. The reason why the stopping point appeared earlier at I=1 M than that at I=0.5 M probably because the yield stress (τ_y) of suspension is larger at high ionic strength. This assumption is supported by Bingham model analysis (Fig.3).

Effective volume fraction was calculated by M-O equation. Ohgaki *el at.* verified the validity of this equation for sludge and coagulated Kaolin suspension at low effective volume fraction [4]. For Na-montmorillonite suspensions, Fig.4 shows the trend of the theoretical value of Φ_{eff} with decreasing shear stress (Fig.4). However, the change of relative viscosity with decreasing shear stress is not well represented by Φ_{eff} except the one at I=0.005 M. The reason may be the interaction between particles/flocs and the structure of particles/flocs.

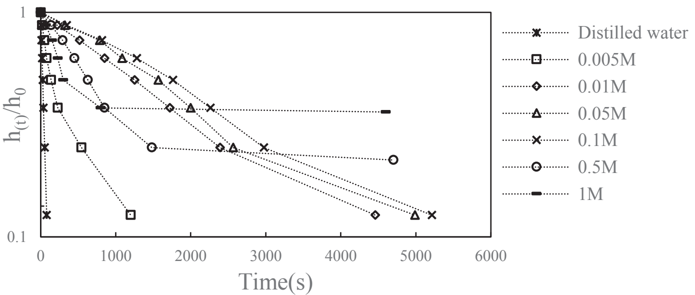

Fig.1 $h_{(t)}/h_0$ vs. time at $\Phi=2.0\times10^{-3}$

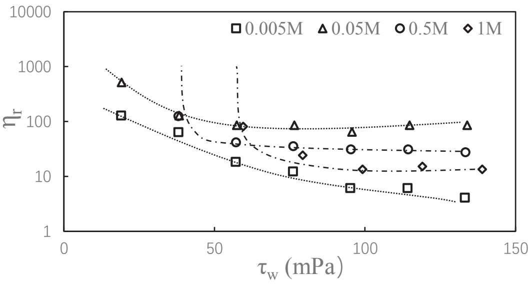

Fig.2 Two types of trends of η_r of suspensions

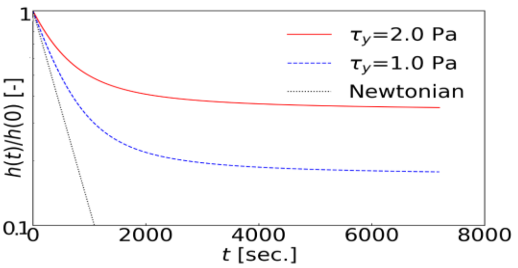

Fig.3 Calculations of $h_{(t)}/h_0$ as a function of time based on Bingham model

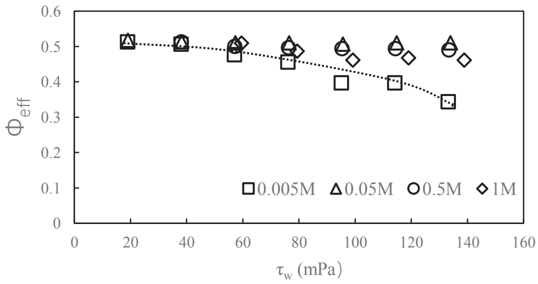

Fig.4 Effective volume fraction caculated from relative viscosity though Mori-Ototake equation

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