# Rheologycal Characteristics of Hyperconcentrated Sediment Laden Flows

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## 1. Introduction

Hyperconcentrated flows containing high concentration of fine sediment can be observed in various conditions such as mudflows, rivers in the Yellow River Basin, and tidal currents containing lagoon sediment near the Rokkaku River estuary in the Ariake sea. In particular, a large amount of sediment flows into the river causing an increase in the number of raised riverbed and a decrease in the capacity of flood control in the lower reaches of the river. Hyperconcentrated sediment-laden flow, in which a wide range of studies have been conducted are known to have non-Newtonian Properties. Chien Ning et al.[1] used a Bingham fluid model while P. Coussot [2] used a pseudoplastic fluid model having yield stress to study the numerical relationship of yield stress and viscosity coefficient with particle concentration and particle size distribution. Ashida et al. [3] used a Bingham fluid model to evaluate bonding power between particles, and deducted expressions on yield stress and viscosity coefficient based on bond cutting energy associated with shearing. Ohmoto et al. [4] reported that the flow can be approximated with the Bingham fluid model and the resistance increase as volume concentration of sediment increase.

Concerning hyperconcentrated sediment-laden flows in an open channel, less studies have been conducted to obtain detailed measurement data on the changes of flow velocity because the difficulty to get the accuracy data in measurement. The influences of non-Newtonian fluid properties on resistance and the internal flow structures still poorly understood.This experimental study was conducted to investigate the influence of hyperconcentrated sediment-laden flows on the friction characteristics and the structure of such flows through comparison with clear water flow by using sodium polyacrylate (PSA) solutions with viscosity characteristics similar to hyperconcentrated sediment-laden flow.

## 2. Experimental apparatus and methods

The materials used for viscosity measurement are suspensions of the Yellow River sediment, suspensions of kaolin and PSA solutions used as polymer solutions. The Yellow River sediment samples used were taken from Yellow River bed material in Jinan City located along the lower Yellow River in China. The median particle size of the Yellow River sediment was $d_{50}$ = 16.2 μm, and that of the kaolin was $d_{50}$ = 5.3 μm. For viscosity measurement, Brookfield's DV-II+ PRO Digital Viscometer which excels in the measurement of viscosity at low shear rates was used. Since the viscosity of non-Newtonian fluids is highly dependent on temperature, we kept the water temperature at 20°C during the experimental. The kaolin suspensions and PSA solutions used in the viscosity experiment were made to flow in a circulating variable-slope flume made of acrylic resin measuring 10 m in length, 0.4 m in width and 0.2 m in height.The experimental conditions are shown in Table 1 and Table 2. Hyperconcentrated sediment-laden flow can be reproduced by using a PSA solution as a simulant fluid. Flow velocity measurement was conducted by applying PIV to open-channel flow of a PSA solution. The origin of the coordinate system was defined at the midpoint of the bottom of the flume where a uniform flow field was formed. As a PIV light source, an air-cooled double-pulse YAG laser was used. The laser light sheet was set to a thickness of 1 mm, a width of 10 cm and a pulse interval of 1,000 μsec was directed vertically upward from the flume bottom toward the water surface. Images of visualized particles passing through the laser light sheet were recorded in pairs with a CCD camera (Kodak Megaplus ES1.0; 1,008 × 1,008 pixels) installed on the sidewalls of the flume. Flow velocity sampling frequency was 15Hz, and 1,000 images were statistically processed for each measurement plane. Nylon particles 5 μm and specific gravity 1.02 were used as tracers.

Table 1 Experimental conditions (Kaolin suspension)

| | $C_v$(%) | Q (l/s) | $I_0$ | H(cm) | $U_m$(cm/s) | Fr |
|---|---|---|---|---|---|---|
| Clear water | 0 | 6.0 | 1/400 | 3.07 | 48.9 | 0.891 |
| Kaolin suspension | 5.04 | 6.0 | 1/400 | 3.15 | 47.6 | 0.857 |
| | 6.50 | 6.0 | 1/400 | 3.15 | 47.6 | 0.857 |
| | 7.33 | 6.0 | 1/400 | 3.23 | 46.4 | 0.825 |
| | 8.15 | 6.0 | 1/400 | 3.25 | 46.2 | 0.818 |
| | 9.38 | 6.0 | 1/400 | 4.15 | 36.1 | 0.567 |
| | 10.2 | 6.0 | 1/400 | 4.72 | 31.8 | 0.467 |
| | 11.3 | 6.0 | 1/400 | 5.30 | 28.3 | 0.393 |
| | 11.9 | 6.0 | 1/400 | 5.61 | 26.7 | 0.361 |

Table 2 Experimental conditions (PSA solution)

| Case | | Q (l/s) | $I_0$ | H(cm) | $U_m$(cm/s) | Fr |
|---|---|---|---|---|---|---|
| W1 | 0 | 3.0 | 1/1000 | 2.53 | 29.6 | 0.595 |
| P-a1 | 400 | 10.0 | 1/1000 | 5.20 | 48.1 | 0.674 |
| P-b1 | 250 | 3.0 | 1/1000 | 2.62 | 28.6 | 0.565 |
| P-b2 | 300 | 3.0 | 1/1000 | 2.63 | 28.5 | 0.562 |
| P-b3 | 400 | 3.0 | 1/1000 | 2.65 | 28.3 | 0.555 |
| P-b4 | 500 | 3.0 | 1/1000 | 2.85 | 26.3 | 0.498 |
| P-b5 | 600 | 3.0 | 1/1000 | 3.05 | 24.5 | 0.448 |
| P-b6 | 800 | 3.0 | 1/1000 | 3.50 | 21.4 | 0.366 |

## 3. Results and Discussion

To investigate the flow structure of hyperconcentrated sediment laden flows, it is necessary to identify its viscous properties in which characterized by the particle size distribution, sediment concentration and temperature. Fig.1 shows the relationship between apparent viscosity, shear rate and volumetric concentration. Apparent viscosity tends to decrease as shear rate rises and tends to increase as volumetric concentration increases. Regarding apparent viscosity of Kaolin at Cv=5.4% and at Cv=10%, the shear rate are 264 l/s and 6.61 l/s, which are 2.6 and 136 times higher than clear water, respectively. Fig.2 shows the relationship of the total resistance coefficient and concentration of kaolin suspension and PSA solution. The vertical axis shows the ratio of the total resistance coefficient of the kaolin suspension ($C_{fk}$) and the ratio of the total resistance coefficient of the PSA solution ($C_{fPSA}$) to the total resistance coefficient of clear water ($C_{fw}$), respectively. From this figure, the ratio of resistance coefficient $C_{fk}$/ $C_{fw}$ changed within the range 1.08 to 6.10. The significant change as a linear tendency occurred in kaolin suspension in the range of Cv=8.15% to 11.9% . The total resistance coefficient of the PSA solution tends to increase sharply at the weight concentration of 400 mg/l or more.

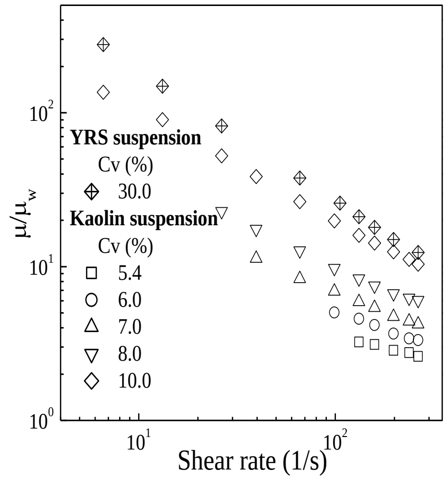

Fig. 1 Relationship of apparent viscosity, shear rate and volumetric concentration.

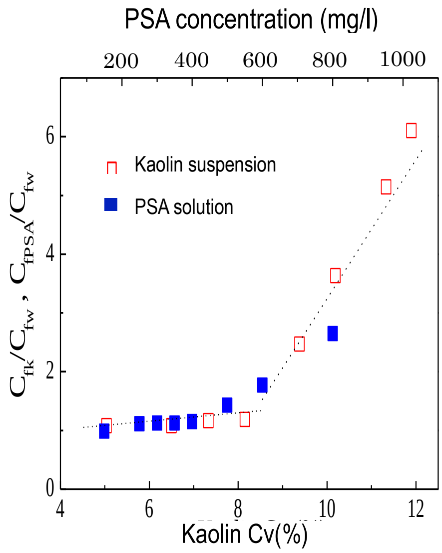

Fig. 2 Relationship between flow resistance and concentration

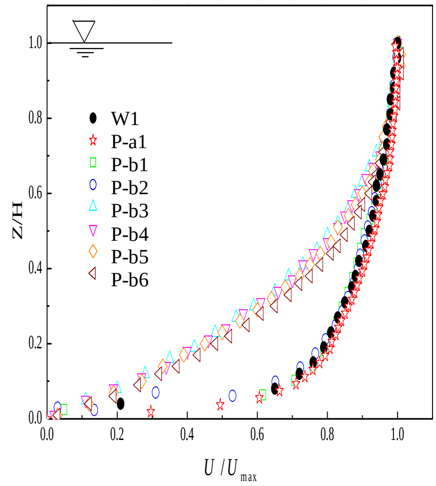

Fig. 3 Main flow velocity

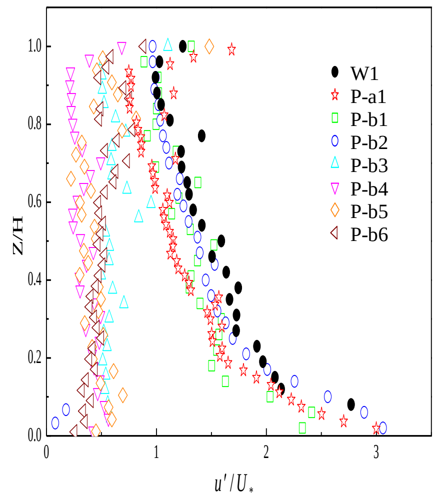

Fig. 4 Vertical distribution of u'/U*

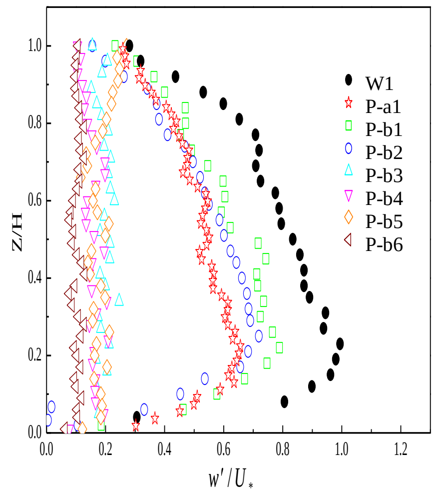

Fig. 5 Vertical distribution of w'/U*

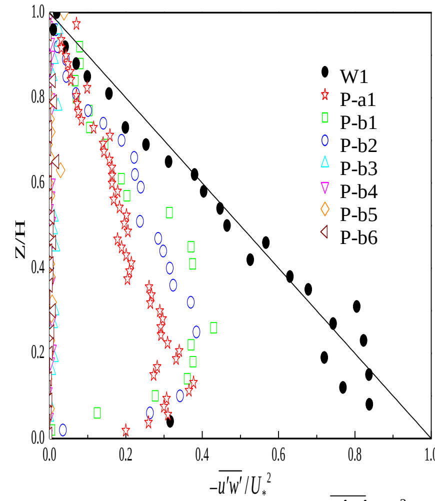

Fig. 6 Vertical distribution of $-\overline{u'w'}/U_*^2$

Fig. 3 shows the vertical distribution of main flow velocity. As shown, in Cases P-a1, P-b1 and P-b2, the main flow velocity distributions are close to those of clear water flow. In P-b3 to P-b6, the distributions differ considerably from those of clear water flow that the main flow velocity is kept low in the near-bottom zone, and the distributions show gentle curves. The fact that the spatial distribution of main flow velocity changes sharply as the concentration of the PSA solution increases from 300 mg/l to 400 mg/l indicates that the internal structure of flows has changed substantially.

Fig. 4 and Fig.5 show the vertical distributions of streamwise turbulent intensity U' and vertical turbulent intensity W'. Fig. 6 show the Reynolds stress $-\overline{u'w'}$ . Turbulent intensity and the Reynolds stress tends to decrease as the concentration of the PSA solution increases. In Case P-b3 to Case P-b6, in which the vertical distribution of main flow velocity differed considerably from that of clear water flow, changes in the vertical direction are small for the Reynolds stress and it is close to zero. This indicates that although the flow field influences and is influenced by kinematic viscosity and kinematic eddy viscosity, viscous stress becomes the dominant resistance component if the kinematic viscosity at the bottom is greater than that of clear water flow by a factor of 10 or more so that the flow field becomes laminar. This is consistent with the results related to resistance properties.

## 4. Conclusions

(1) Apparent viscosity tended to decrease as shear rate increased, while it tended to increase as volumetric concentration and weight concentration increased.

(2) The total resistance coefficient showed the tendency to increase as the volume concentration of kaolin suspension and the weight concentration of PSA solution increased.

(3) In case the weight concentration of PSA solution as 400 mg/l or more, the turbulent intensity and the Reynolds stress were uniform in the vertical direction and tended to decrease compare to clear water flow.

## References


**(1)** Chien Ning, Zhaohui Wan:Mechanics of Sediment Transport,ASCE Press,1988

**(2)** Coussot P.:Mudflow Rheology and Dynamics,IAHR/AIRH Monograph,1997

**(3)** Ashida K.,et al.:Study on Hyperconcentrated Flow (1),Viscosity and Fall Velocity, Disaster Prevention Research Institute Annuals,No.28B-2,1985

**(4)** Ohmoto T., et al.:On Rheology of Hyperconcentrated Sediment Laden Flow in Open Channel,1994