Applied Rheology | DOI: 10.3933/APPLRHEOL-26-42997 | WWW.APPLIEDRHEOLOGY.ORG

Experimental Study on the Influence of Coarse Particle on the Yield Stress of Debris Flows

Bin Yu[1], Yuanjing Chen[2], Qinghua Liu[1]

[1]State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology, Chengdu, Sichuan, 610059, P. R. China
[2]Sichuan Engineering Technical College, Deyang, Sichuan, 618000, P. R. China

* Corresponding author: drbinyu@yahoo.com

Received: 2.3.2016, Final version: 13.6.2016

Abstract:
Former studies show that the coarse particle plays a very important role in the determination of the yield stress of fluid-solid mixtures such as debris flows. The characteristics of the coarse particle in these mixtures include particle size, gradation, shape, and type of material. To assess the influence of these coarse particles on the yield stress the concept of equivalent volumetric solid concentration *C* is introduced. The equivalent concentration can be derived from the volumetric solid concentration by considering the particle size, gradation, shape, and type of material. Laboratory experiments to determine the yield stress of various mixtures were conducted to calibrate the coefficients of these coarse particle characteristics. A yield stress phenomenological expression is proposed using the refined volumetric solid concentration (equivalent concentration), which could be calibrated by the experiments in this study. The validation of this phenomenological expression with data from literature shows good agreements, especially for higher volumetric concentrations of the sediments.

Key words:
Yield stress, coarse particle, gradation, size, shape

1 INTRODUCTION

Suspensions of solid particles are frequently encountered in manufacturing processes and in natural flows. The yield stress is an important parameter to describe the flow characteristics of these industrial mixtures and of natural flows, such as debris flows, which cause fatalities, property damages, and landscape changes each year. Some progress has been made in the determination of the yield stress of fluid-solid mixtures such as debris flows in recent years. For instance, the yield stress of debris flows with coarse particles can be acquired indirectly with yield stress formula using parameters such as density, thickness and gradient of the debris flows on an accumulation fan.

According to Ancey and Jorrot [1] and Yu et al. [2] the yield stress is related to the solid volumetric concentration, coarse particle characteristics, and the type and percentage of clay. The volumetric concentration has a larger influence than the type of clay minerals. Especially the coarse particle characteristics, such as the size and the size distribution, the shape, and the type of material of the particles have a significant effect on the yield stress [2]. Also other stressed the importance of coarse particles for the yield stress of fluid-solid mixtures. Fei and Zhu [3] measured the yield stress of mixtures from a sample of debris flows (eliminating the grains larger than 0.15, 0.5, 1, and 2 mm) with a viscometer. They showed that the yield stress increased with a decreasing diameter of the particles in the test mixtures with the same volumetric concentration. Wan et al. [4] obtained some results from viscometer experiments on slurries with a high concentration. They showed that the yield stress of a slurry is determined by the content of fine particles: the more fine particles in a sediment, the larger the yield stress. Tang [5] concluded that the yield stress increases with the increasing solid concentration, but decreases with increasing diameter of the particles. Zhang [6] studied the influence of solid concentration and particle size distribution on the rheological characteristics of mixtures. He pointed out that for large concentrations the interaction forces between particles increase with increasing uniformity of the particle size distribution.

iments of Ancey and Jorrot [1] and this study were larger than 0.25 mm. So the intermediate particle size lies in the range of 0.005 – 0.25mm. This study did not consider the influence of the intermediate particle size on the yield stress. This may explain the errors in our validation using the data of Coussot et al. [29] with an intermediate particle size fraction of 20 % and the Huoshao Gully [32] with an intermediate particle size fraction of more than 35 %. The influence of the intermediate particle size fraction on the yield stress cannot be ignored in these debris flows. The data of Marr et al. [31] gives also relatively large errors in our validation, for volumetric concentration $C_0 > 0.47$. Here again the influence of the intermediate particle size fraction may have played a role because most of the particles have a size less than 0.25 mm in the experiments of Marr et al. [31]. Therefore the effect of the intermediate particle size fraction on the yield stress should be researched in future work.

The application of the method of Yu et al. [2] to prototype debris flows gave problems in the Xiaogou Gully [33] and the Dagan Gully [34]. Debris flows were triggered by heavy rainfall in these two gullies on July 17, 2010. The debris flow deposits were quite different: muddy clay rich deposits in the Dagan Gully while the deposits in the Xiaogou Gully contained more silty sand and less clay. The yield stresses were about 5400 Pa and 1700 Pa, respectively. The estimated volumetric concentrations C_0 of the debris in the flows were 0.841 and 0.818in the Dagan and Xiaogou Gully, respectively [2]. The calculated equivalent clay mineral percentage of the flow in the Xiaogou Gully was $P = 0.15$, which is too large for this gully because the debris flow deposit contains only a small amount of clay [2]. The refined coefficient a is assumed to be the same as the coefficient of [29] and of the Huoshao Gully is 1.02 (Table 2) [32]. The equivalent clay mineral percentages of $P = 0.075$ and $P = 0.034$ for the debris flows of the Dagan Gully and Xiaogou Gully are now back calculated with Equation 9 for yield stresses of 5400 Pa and 1700 Pa, respectively. These calculated P percentages of the debris flows in the Xiaogou Gully and Dagan Gully may approximate the field percentages because the debris flow deposits contains only a small amount of clay in Xiaogou Gully, and a relatively larger amount of clay in Dagan Gully. The prediction of the yield stress with Equation 9 it is better than with the equation of Yu et al. [2].

The maximum diameter of solid particles of debris flows in our experiments was 20 mm, which is 2 orders of magnitude smaller than the dimension of large blocks often found in prototype debris flows (e.g. order of magnitude around 1 m). The effect of large particles on the yield stress has not been considered in the research presented in this paper, but the problem will be tackled in future work.

7 CONCLUSIONS

Through experimental research on the yield stress of fluid-solid mixtures such as debris flows, in relation to the characteristics of coarse particle such as the size, gradation, shape, and type of material, the following conclusions can be made:

- The coarse particles influence the yield stress through the effective volumetric solid concentration. The effective solid concentration can be refined by the coarse particle characteristics such as the size and shape of the particles, the size distribution, and the type of material. Therefore we introduced the concept of the equivalent volumetric solid concentration C.
- The refinement coefficient for the gradation obtained by calibration using the experiments with sand is $C_1 = 0.18$.
- The refinement coefficient for the size expressed as the volume average diameter obtained by calibration using the experiments with sand is $C_2 = -0.01$ (with the refinement coefficient $C_1 = 0.18$).
- The refinement coefficient for the shape obtained by calibration using the experiments with glass and POM is $C_3 = -0.4$ (with the refinement coefficient $C_1 = 0.18$, and $C_2 = -0.01$).
- The values for the material refinement coefficient n are obtained by calibration using the experiments with glass, PVC, and POM (with the refined coefficient $C_1 = 0.18$, $C_2 = -0.01$, and $C_3 = -0.4$). The values for the coefficient n of sand, glass, PVC, POM, and POM with 5 % of glass fiber are 1, 1, 0.93, 0.9, and 0.95, respectively.
- The validation of the revised formula for predicting the yield stress, including the effect of coarse particles, with data from the literature shows a good agreement with the measured yield stress, especially for higher volumetric concentrations of the sediments.

Further tests including particles of an intermediate size should be carried out to check its effect on the yield stress. Another point which also deserves further investigation is the unique role of the chemical conditions of the surface for each material type which also have a significant effect on the yield stress. More attention should be paid in the future to the mechanisms related to the chemical conditions.

ACKNOWLEDGEMENTS

This work was supported by The National Nature Science Foundation of China (NSFC, contract number: 41372366) and The State Key Laboratory of Geohazard Prevention and Geoenvironment Protection Founda-

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org

tion (contract number: SKLGP2014Z012). We thank the reviewers for their comments that helped us to greatly improve the presentation of this work. We are grateful to Dr. Theo van Asch for having provided a very helpful review of the manuscript, and for help on the English editing of the manuscript.

REFERENCES

[1] Ancey C, Jorrot H: Yield stress for particle suspensions within a clay dispersion, J. Rheol. 45 (2001) 297 – 319.

[2] Yu B, Ma Y, Qi X: Experimental study on the influence of clay minerals on the yield stress of debris flows, J. Hydraul. Eng. 139 (2013) 364 – 373.

[3] Fei X, Zhu P: The viscous debris flow and its determination method, J. Railway Eng. Soc. 4 (1986) 9 – 16 (in Chinese).

[4] Wan Z, Qian Y, Yang W: The experimental study on hyper concentrated sediment flow, Yellow River 1 (1979) 5 – 6 (in Chinese).

[5] Tang C: The calculating model of yield stress of slurry, J. Sediment Res. 2 (1981) 60 – 65 (in Chinese).

[6] Zhang S: The rheological characteristics of slurry with coarse particles, J. Hydraul. Eng. 11 (1990) 34 – 40 (in Chinese).

[7] Coussot P, Piau JM: A large-scale field concentric cylinder rheometer for the study of the rheology of natural suspensions, J. Rheol. 39 (1995) 105 – 124.

[8] Banfill PFG: Use of the ViscoCorder to study the rheology of fresh mortar, Mag. Concr. Res. 42 (1990) 213 – 221.

[9] Banfill PFG: The rheology of fresh mortar, Mag. Concrete Res. 43 (1991) 13 – 21.

[10] Banfill PFG: Proceedings of the British Masonry Society 8, British Masonry Society, London (1998).

[11] Banfill PFG: The influence of fine materials in sand on the rheology of fresh mortar, in Proceedings of the International Conference on Utilizing Ready Mix Concrete and Mortar, Thomas Thelford, London (1999) 411 – 420.

[12] Banfill PFG: Rheological methods for assessing the flow properties of mortar and related materials, Constr. Build. Mat. 8 (1994) 43 – 50.

[13] Mansoutre S: Des suspensions concentrées aux milieux granulaires lubrifiés: Étude des pâtes de silicate tricalcique, Thesis, Université d'Orléans, Orléans, France (2000).

[14] Chateau X, Ovarlez G, Trung KL: Homogenization approach to the behavior of suspensions of noncolloidal particles in yield stress fluids, J. Rheol. 52 (2008) 489 – 506.

[15] Mahaut F, Chateau X, Coussot P, Ovarlez G: Yield stress and elastic modulus ld stress fluids, J. Rheol. 52 (2008) 287 – 313.

[16] Mahaut F, Mokéddem S, Chateau X, Roussel N, Ovarlez G: Effect of coarse particle volume fraction on the yield stress and thixotropy of cementitious materials, Cement Concrete Res. 38 (2008) 1276 – 1285.

[17] Krieger IM, Dougherty TJ: A mechanism for non-Newtonian flow in suspensions of rigid spheres, Trans. Soc. Rheol. 3 (1959) 137 – 152.

[18] Vu TS, Ovarlez G, Chateau X: Macroscopic behavior of bidisperse suspensions of noncolloidal particles in yield stress fluids, J. Rheol. 54 (2010) 815 – 833.

[19] O'Brien JS, Julien PY: Laboratory analysis of mudflow properties, J. Hyd. Eng. ASCE 114 (1988) 877 – 887.

[20] O'Brien JS: Physical processes, rheology and modeling of mudflow, Thesis, Civil Engineering Department, Colorado State University (1986).

[21] Muramoto T, Ito K, Kitano H: Gathering of changed colloidal particle near a like-charged glass plate, J. Am. Chem. Soc. 119 (1997) 3592 – 3595.

[22] Takahashi T: Debris flow, Ann. Rev. Fluid Mech. 13 (1981) 57 – 77.

[23] Egashira S, Itoh T: Constitutive equation of debris flow and their applicability, Debris-flow Hazards Mitigation: Mechanics, Prediction, and Assessment: Proceedings of First International Conference Water Resources Engineering Division, San Francisco, USA (1997) 340 – 349.

[24] Johnson AM: Physical processes in geology, Freeman Cooper and Co., San Francisco, USA (1970) 577.

[25] Mbasha W, Masalova I, Haldenwang R, Malkin A: The yield stress of cement pastes as obtained by different rheological approaches, Appl. Rheol. 25 (2015) 53517

[26] Soualhi H, Kadri E, Ngo T, Bouvet A, Cussigh F, Kenai S: A new vane rheometer for fresh mortar: Development and validation , Appl. Rheol. 24 (2014) 22594.

[27] Boisly M, Kastner M, Brummund J, Ulbricht V: General aspects of yield stress fluids - Terminology and definition of viscosity, Appl. Rheol. 24 (2014) 14578.

[28] Qian N, Wan Z: Dynamics of sediment movement: Beijing, Science Press of China (1991) 43 – 81, 464 – 514 (in Chinese).

[29] Coussot P, Laigle D, Arattano M, Deganutti A, Marchi L: Direct determination of rheological characteristics of debris flow, J. Hydraul. Eng. 124 (1998) 865-868.

[30] Yu B: Research on the calculating density by the deposit of debris flows, ACTA Sedimentoloical SINICA 26 (2008) 789 – 796 (in Chinese with English abstract).

[31] Marr JG, Harff PA, Shanmugam G, Parker G: Experiments on subaqueous sandy gravity flows: The role of clay and water content in flow dynamics and depositional structures, Bull. Geol. Soc. Am. 113 (2001) 1377 – 1386.

[32] Institute of Glaciology and Cryopedology and Institute of Sciences of Department of Communications of Gansu Province: Debris Flow in Gansu, China, Communications Press, Beijing (1982) 11 – 43 (in Chinese with English abstract).

[33] Zhang H, Ma Y, Zhang J, Li L, Yu B: Study on the disaster of earthquake debris flows of Xiaogou Gully, Hongkou, Dujiangyan in Wenchuan earthquake area, Sichuan, China, J. Chengdu Univ. Technol (Sci. & Technol. Ed.) 38 (2011) 42 – 48 (in Chinese with English abstract).

[34] Zhang J, Ma Y, Zhang H, Li L, Yu B: Study on earthquake debris flow in Dagan Gully, Dujiangyan, Sichuan, Journal of Mountain Sci. 28 (2011) 623 – 627 (in Chinese with English abstract).

This is an extract of the complete reprint-pdf, available at the Applied Rheology website
http://www.appliedrheology.org