UNUSUAL RHEOLOGICAL BEHAVIOUR OF A NATURAL SOLID DISPERSION

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Abstract: Recent studies of some solid natural dispersion like quick sand evidenced their unusual rheological behavior. Quick sand might be regarded as a bridge between dry granular materials and wet tixotropic gels. In this work, we have studied the behavior of a natural quick sand. We determined the rheological behaviour following the evolution of viscosity as function of time and composition at different weight concentrations. The mechanical behaviour results from the competition between aging and progressive rejuvenation by the shear flow. The incipient flow destroyed the structure of the materials, entailing a viscosity decrease, which in turn accelerates the flow: avalanche behaviour results.

Introduction

In the Geological literature survives the opinion that "quicksand" is more a taken condition than a propriety that might be attributed to a specific material. The phenomenon is "quickness," described as the way, in which water flows through sand, clay, or other material, lifts and separates its small grains. In ordinary sand, whether wet or dry, sand particles are shoved up against each other. When sand becomes quick, an invisible cushion of water holds sand grains a bit apart. Even if it looks like a solid surface, in reality is really liquid, like a very thick soup of water and sand.

In a typical patch of quicksand, ordinary sand is sitting above a body of water, such as a bubbling spring. The water is trying to push upward; the sand is pushing water down. The sand becomes "quick" when the water pressure underneath balances or exceeds the weight of the sand above. Because a thin film of water surrounds each grain, the sand grains lose contact and friction.

In this work, we study the structural and dynamical properties of quicksand using rheometric experiments. Its rheological behavior is function of the composition of the material as well as a function of the particle size. Quick sand is composed from a large number of interacting particles. The particles can flow like fluids under certain conditions, but resist flow otherwise. They are able to support their own weight to a certain extent. We can say that at rest quick sand does not flow, but it starts flowing (particles unjam) when

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the load to which they are submitted increases beyond a critical value (yield stress). When submitted to flow, the microstructure of the system is partially destroyed, which is observed in rheological tests as a viscosity that is decreasing in time: the system is said to be tixotropic. At rest the microstructure reforms or evolves spontaneously: the system is said to age. The mechanical behaviour results from the competition between aging and progressive rejuvenation (destruction of the microstructure) by the shear flow. The incipient flow destructures the materials, entailing a viscosity decrease, which in turn accelerates the flow and so on: avalanche behaviour results. [1] Combined with the spontaneous restructures at rest, we show that a bifurcation in the rheological behaviour of the quick sand takes place. The origin of the avalanches is the un-jamming of a jammed system.

After an X-ray analysis was found that the main components of the quick sand as shown in the Table 1 are:

Table 1: Quick sand composition as retrieved from X-Ray analysis.

Gypsum	50 %
Quartz	25 %
Cristobalite, Hematite, Feldspar	< 5%
Clay	5 - 7 %

Experimental

Materials

The quick sand particle's size is approx. 20 μm (determined as the average size of the particles seen on the microscope). From the 5-7 % clays (table 1), 70% are swelling clays.

Quick sand, as found in nature, has itself a certain amount of water. To determine the water quantity, a small amount of quick sand was weighted then dried in the oven at 110^{o}C then weighted again.

In order to prepare the samples for the experiments water was added to the natural quick sand, a small amount was weighted, dried and weighted again. In this manner, three different samples with three different concentrations of quick sand were prepared (table 2)

Table 2: Different quick sand concentrations

Quick sand (wt %)	Water (wt %)
30	70
40	60
50	50

Methods

Experiments were performed on a stress controlled Paar – Physica MCR 300 rheometer that is a very accurate instrument. It is equipped with a Peltier plate temperature unit that gives a very good temperature control over an extended time. The software used in combination with the MCR 300 rheometer is US200. All experiments were performed at a constant temperature of 20^{o} C. The measurements were done using vane geometry. In case of the quick sand's rheological experiments, the use of the vane geometry enables us to reach higher rates than a cone and plate or Couette one, because the ejection of the sample and slip at the rotating surface are restricted. The vane induces a flow very close to that of coaxial cylinders, actually is considered the equivalent of the conventional Couette geometry. [2,3]

Since the quick sand is a viscoelastic material and we want to determine what in its composition is inducing the "quick" condition a certain initial status of the sample might be of a crucial importance in order to have reproducible results.

To achieve this goal we presheared all the samples prior to each test. First a high value of shear stress was used (10 Pa) for 100 s then the sample was at rest at (0 Pa) for another 100s. In this way the same initial status was induced.

Results and discussion

The objective of the rheological experiments performed on quick sand is to follow the evolution of viscosity η (t) as a function of time.

The rheological behaviour of the 30 wt %, 40 wt %, and 50 wt % suspensions of quick sand (QS) was studied and the results are shown in figures 1, 2, and 3.

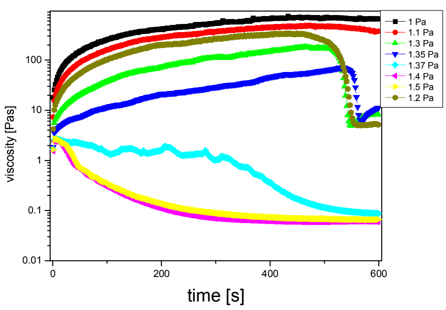

Fig. 1*: Viscosity bifurcation for 30-wt% QS*

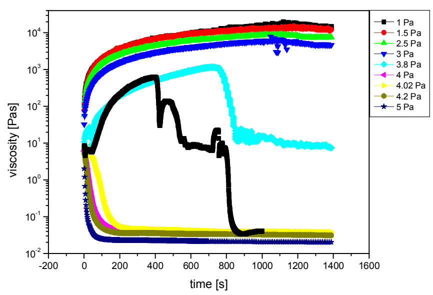

Fig. 2*: Viscosity bifurcation for 40-wt% QS*

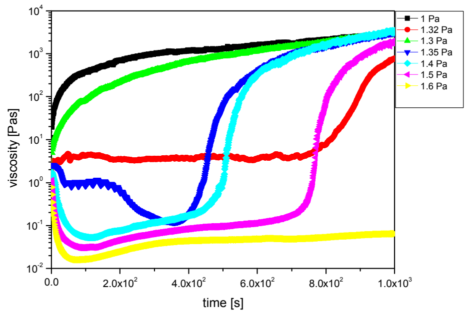

Fig. 3: *Viscosity bifurcation for 40-wt% QS*

Table 3: Value of critical stress for different concentrations

Quick sand concentration (wt %)	Yield stress value (Pa)
30	1.37
40	3.9
50	1.32

According to the description given to the yield stress by Coussot et al [1] we can say that the yield stress cannot be exactly and easily caught. Taking into account the comparable values for the yield stress found for 30-wt% and 50-wt% we can assume that the yield stress of this system after the preshear is around 1.3Pa. The higher value found for 40w% might be due to the history of the system.

Conclusions

1. When submitted to flow, the microstructure of the studied dispersion (quick sand type) is partially destroyed, which is observed in rheological tests as a viscosity that is decreasing in time: the system is said to be tixotropic. At rest the microstructure reforms or evolves spontaneously: the system is said to age. The mechanical behaviour results from the competition between aging and progressive rejuvenation (destruction of the microstructure) by the shear flow. The incipient flow destructures the materials, entailing a viscosity decrease, which in turn accelerates the flow and so on therefore avalanche behaviour results.[1]
2. We found a characteristic yield stress value of the dispersion, which is around 1.37 Pa for 30 wt % dispersion (table 3). For higher values, that the yield stress value the viscosity is increasing in time (rheopex behaviour) and for lower values the viscosity is decreasing in time (tixotropic behaviour).
3. For stresses slightly above the yield stress value the viscosity decreases with time: for long times it reaches a low steady state value which implies that at the yield stress, the steady-state viscosity jumps discontinuously from infinity to a finite and low value at the yield stress value. This shows the existence of a bifurcation of the viscosity for the

material, which abruptly passes from a flowing state above the yield stress to a jammed state below the yield stress value. Such a bifurcation has been observed previously for yield stress fluids such as hair gel or shaving mouse.

4. In time the dispersion presents a complex rheological behaviour (figure 3). Depending on the applied stress, in the same time period, same samples become rheopex (curves for1.0 to 1.3 Pa), and some others become tixotrop and rheopex (curves for1.4 to 1.5 Pa).
5. The same complex rheological behaviour as quick sand was given by mimetic coloidal systems made from natural clays and sand. Such mimetic colloidal dispersions may be used in cosmetic and medical care.

REFERENCES

1. Coussot,P., et al (2002) *Physical Review Letters* **88**(17), 175501
2. Garido – Rolon, V.H., Gonzales – Perez, J. and Vega Acosta Montalban L.A. (2003) *Revista Mexicana de Fisica* **49**(1), 40-44
3. Turian, R.M., et al (1997) *Powder Technology* **93**, 219-233
4. Ferroir, T., et al (2004) *Physics of fluids* **16** (3)