Assessment of Penetrometry Technique for Measuring the Yield Stress of Muds and Granular Pastes

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Abstract:
We discuss the possibility of using penetrometry technique for measuring the yield stress of concentrations made of grains immersed in a colloidal phase, such as concrete or muds. In that aim we used model materials made by suspending glass beads at different concentrations in a kaolin-water paste. We then show that a uniform shear stress develops along the object (plate or cylinder) beyond the entrance length. This shear stress plotted versus the object velocity exhibits a shape similar to the flow curve of the material determined from rheometry. For materials exhibiting the typical flow curve of a simple yield stress fluid, i.e. at bead concentrations smaller than 30 %, the stress associated with an inflection point located at low velocities of this curve appears to correspond to the material yield stress. At larger concentrations of beads the suspensions have a more complex behaviour likely affected by its granular nature at a local scale and the possibility of migration or frictional effects, so that neither conventional rheometry nor penetrometry provide relevant data. We conclude by describing two practical penetrometry techniques for precisely measuring the yield stress of simple pastes.

Zusammenfassung:
Wir diskutieren die Möglichkeit, mit Hilfe der Penetrometer-Technik, die Fließspannung von Getreide zu messen, das in einer kolloidalen Phase (z. B. Beton oder Schlamm) dispergiert ist. Dazu verwendeten wir Modellsubstanzen, die aus Glaskugeln unterschiedlicher Konzentrationen bestanden, die in einer Kaolin-Wasserpaste suspendiert waren. Weiterhin zeigen wir, dass sich eine homogene Scherspannung entlang dem Werkzeug (Platte oder Zylinder) hinter der Eingangslänge ausbildet. Wird diese Scherspannung gegen die Werkzeuggeschwindigkeit aufgetragen, so gleicht diese Kurve der Fließkurve aus rheologischen Messungen. Bei Materialien mit der typischen Fließkurve eines einfachen Fließspannungsfluids, d. h. bei Glaskugelkonzentrationen kleiner als 30 %, scheint die Spannung am Wendepunkt bei niedrigen Geschwindigkeiten der Fließspannung zu entsprechen. Bei höheren Kugelkonzentrationen besitzen die Suspensionen ein komplexeres Verhalten, das vermutlich von dem granularen Charakter auf lokaler Skala und möglichen Migrations- und Reibungseffekten beeinflusst wird, so dass weder konventionelle Rheometrie noch Penetrometrie relevante Daten liefern können. Zusammenfassend beschreiben wir zwei praktische Penetrometer-Techniken für die genaue Bestimmung der Fließspannung einfacher Pasten.

Résumé:
Dans cet article on étudie dans quelle mesure il est possible d'utiliser une technique de pénétrométrie pour determiner le seuil de contrainte d'une suspension concentrée constituée d'un mélange de grains et de particules colloïdales, tel qu'un béton, un mortier ou une boue. Dans ce but on se focalise sur un matériau modèle constitué d'une pâte de kaolin avec différentes concentrations de billes de verre. On montre que lorsqu'on enfonce une plaque dans ce fluide une contrainte uniforme se développe rapidement le long de la plaque. Les évolutions de cette contrainte en fonction de la vitesse de déplacement sont similaires à celle de la contrainte tangentielle en fonction du gradient de vitesse (courbe d'écoulement) dans une expérience de rhéométrie classique. Pour des suspensions modérément concentrées (< 30 %) en billes on peut estimer la contrainte seuil à partir du niveau du semi-plateau observé aux faibles vitesses. A des concentrations plus élevées le fluide a un comportement plus complexe probablement affecté par des phénomènes de migration de particules, si bien que ni la rhéométrie conventionnelle ni la pénétrométrie ne permettent d'obtenir des données pertinentes. On conclut en décrivant deux techniques de pénétrométrie adaptées aux suspensions simples (pour lesquelles la phase granulaire n'a pas un impact critique).

Key words: penetrometry, yield stress fluids, muds, granular pastes

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one. Then the yield stress is deduced from the following equation, which directly derives from Equation 1:

$$\tau = \frac{1}{P}\left[\frac{F_2 - F_1}{H} - \rho g S\right] \qquad (2)$$

In which F_1 and F_2 are the two force values and H the length of penetration between the two times. In this approach the buoyancy stress ($\rho gS/P$) can be determined from a separate test with a bath of simple liquid of known density.

4.2. CONTROLLED FORCE PENETROMETRY

If we apply a given force to a long object it will penetrate through the paste until the force component due to the stress applied along the object surface is equal to this force. At that time the object stops moving. In practice it may be difficult to appreciate the effective stoppage of the object since for a simple yield stress fluid this velocity in theory tends to zero progressively and a perfect stoppage is attained after an infinite time. In fact the maximum length of penetration is generally closely approached after a relatively short time. Anyway, with concentrated suspensions such a kaolin pastes we know that artefacts tend to occur at low velocities or for long tests. As a consequence it is critical not to try to wait for a strictly complete stoppage. For example the maximum time for measurement must be smaller than the time at which the velocity is of the order of 0.1 mm/s (since at smaller velocities artefacts were observed), which means that the object moves over less than 2 mm in 20 s.

A simple test consists in measuring the (approximate) depth of complete penetration for two different forces (see Figure 9). The additional force between the two tests is strictly used for balancing the additional buoyancy force and the shearing the material at a stress almost equal to the yield stress along the object over the additional length of penetration H. It is important to have an initial distance of penetration (for the first force) of the order or larger than ten times the characteristic width of the object, and an additional distance (for the second force) of the same order. In essence such a test is similar to that of Uhlherr et al. [4] in that it uses a controlled force and measure the stoppage conditions. The fundamental difference is that, with the help of measurements for two force levels and a substraction, we remove the force contribution due to the (unknown but constant) deformation of the material at the front of the object, and that due to deformation of the free surface of the sample. Finally one can simply estimate the yield stress from Equation 2. We know from our experimental data that such an approach is relevant for estimating the yield stress of a simple yield stress fluid material.

Note that in practice a cone is often used instead of a long object such as a plate or a cylinder, likely because this is a more stable geometry. However, with such a geometry the above approach cannot be used. In fact we can even suspect that the entrance length is never overcome with such a geometry. We are never in a well-developed liquid regime around the object since the deformation and flow around the object tip continuously evolves as the object penetrates farther. Such a geometry can be interesting to make comparative measurements but cannot be used to get a relevant estimate of the yield stress.

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