How to measure rheological properties of bentonite suspensions on construction sites.

Anja Heinz, Rita Hermanns Stengele

Institute of Geotechnical Engineering, Swiss Federal Institute of Technology, CH-8093 Zurich, Switzerland

ABSTRACT

Yield point measurements were performed on bentonite suspensions. A rheometer and measuring devices that are commonly used on construction sites were used. The results were compared. For the tested HTX bentonite suspensions, the Kasumeter is the most suitable measuring device when testing under the same conditions.

INTRODUCTION

For various construction purposes in ground engineering, suspensions are applied. Generally, these suspensions consist of water and clay (bentonite). Bentonite suspensions are used e.g. for the construction of diaphragm walls or for slurry shield tunnelling where they have a supporting function. Bentonites consist mainly of the clay mineral montmorillonite. The minerals form a three-dimensional network with exchangeable cations, mostly Na^+ or Ca^{2+}, in the interlayers, which affects the rheological behaviour of bentonite suspensions[1]. Bentonite suspensions behave as thixotropic, shear thinning fluids.

The rheological behaviour plays a major role for the successful application of the bentonite suspensions in civil engineering. An important parameter is the yield point, a characteristic value of the suspension which influences the supporting effect and the formation of pressure in the soil. This value which is mainly dependent on the mix design (e.g. concentration) of the suspension but also on the mixing features (e.g. mixing time) has to be determined in the laboratory and on the site with sufficient reliability. For thixotropic fluids, the yield point is dependent on the time of rest and on the temperature. The DIN 4127[2] distinguishes between the dynamical yield point τ_{dyn}, the minimum value at the end of the flow, and the statical yield point τ_{stat}, the maximum limiting value.

This work focuses on the determination of the yield point of bentonite suspensions as part of the quality control on site. For this purpose, measurements with devices generally used on sites were performed and the results were compared with each other and with rheometer measurements. In the experiments, influencing parameters such as concentration of the bentonite in the suspension, type of water and temperature were taken into account.

MATERIALS AND METHODS

Materials and Experimental Methods

Investigations were made on the bentonite HTX (by IBECO, Germany). HTX is an activated Ca-bentonite from Greece. The bentonite powder was dispersed in water, either desalted water or drinking water from Zurich. Different concentrations were considered, namely 35, 40 or 45 kg HTX per m^3 suspension. All suspensions were mixed with an IKA Ultra-Turrax T50 (Janke and Kunkel GmbH & Co., Germany) for 10 minutes by 3000 rpm, the diameter of the dispersing disk was 42 mm.

All tests were carried out in the laboratory to allow for comparison of the results. The samples were prepared and tested at a temperature of 20 ± 2 °C or 10 ± 1 °C. The swelling time was 24 hours.

Measuring devices and tests

Marsh Funnel

The Marsh funnel is a special flow cup that was designed for measurements of drilling mud viscosity. The funnel viscosity is the time required for 1000 ml to flow out of the Marsh funnel, filled with 1500 ml suspension. The dynamical yield point was determined with the diagram given in DIN V 4126-100[3]**.** The input data are the flow times for 1000 ml and for 1500 ml suspension.

Rheometer according to Soos ("Kugelharfe")

The principle of the measurement is that the yield point is determined by the force on a ball in the suspension. Ten balls with different size and weight are immersed into the suspension at the same time. The yield point of the suspension lies between the ball that is still swimming on the suspension and the ball that is just immersed. The number of the ball that is still swimming is noted and the yield point is determined with the suspension density.

Kasumeter

The Kasumeter is a capillary viscosimeter. The diameter of the used capillary was 1.0 cm. The falling part of the flow curve is simulated. The stagnation height of the suspension is reported. Depending on the suspension density and the stagnation height, the dynamical yield point can be determined.

Rheometer Tests

The measurements have been performed on a Physica MCR 300 rheometer. The yield point was determined with an amplitude sweep test[4], i.e. the yield point is the value τ where the storage modulus G' of the function G'(τ) deviates more than 10% from the plateau value. Amplitude-sweep tests were carried out at a frequency $\omega = 10\ s^{-1}$.

RESULTS AND DISCUSSION

Fig. 1 shows the results of the yield point measurements with the above described instruments. The tendency is equal for all measuring systems: The yield point increases with increasing concentration. Due to the different measuring methods, the values of the yield points differ greatly, up to a factor of 14. The values are by far the highest for the rheometer according to Soos and lowest for the Marsh Funnel.

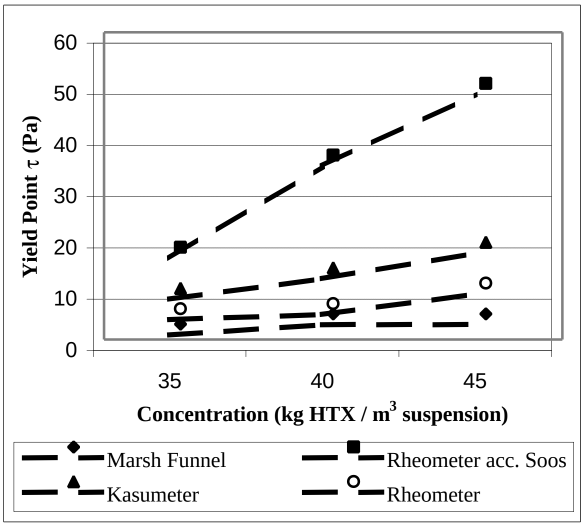

Figure 1: Yield points of HTX bentonite suspensions with different measuring devices at a temperature of 20 °C

The influence of the added water and the temperature are as follows: Generally, lower yield points were measured with all devices for suspensions that were mixed with drinking water. This was expected, because of the increasing Ca^{2+}-ion content in the montmorillonite interlayers. For the temperature change from 20°C to 10°C, a general decrease of the yield point was measured at the lower temperature, however, for the measurements with the rheometer according to Soos there is no difference.

Further tests were carried out with other bentonites than HTX, e.g. a natural Na-bentonite. It should be noted that the results presented here do not necessarily apply to suspensions with different bentonite types.

Appraisal of the measuring devices

Marsh Funnel

This device is very simple to use and suitable for relative comparisons. However, for the determination of the yield point, it is of small importance. The diagram for the evaluation of the dynamical yield point given in DIN V 4126-100[3] is very sensitive to normal variations in reading (± 1 s) and gives sometimes a yield point of $\tau < 0$. For suspensions with high concentrations, the flow time for 1500 ml cannot be measured, as the suspension will not flow but drop and part of the suspension will remain in the Marsh funnel, stuck on the walls. Nevertheless, the consideration of the 1000 ml flow times gives satisfactory results.

Rheometer according to Soos

Its largest disadvantage lies in the judgment and the accuracy of the obtained results. The test procedure allows only for the determination of a yield point interval. Due to this fact, the test is relatively unsusceptible to different treatments (i.e. different shear history) of the samples. But even notable changes, such as a temperature difference of 10 °C, will not be registered by the test. On the other hand, the device is easy to handle.

Kasumeter

The Kasumeter is a robust device that is easy to use. The test allows for reproducible results, provided that the treatment and the shear history of the samples is the same. Fig. 2 shows the behaviour of similar suspensions (HTX 40 kg/m^3, temperature 20 °C, swelling time 24 h) that were exposed to different shear conditions. Several tests were performed, showing good reproducibility. For greater clearness, only one curve of each of the three suspensions with different shear histories is presented in Fig. 2. One suspension was tested after 30 s mixing with an ordinary mixer of 240 Watt. The other suspensions were tested after a whole test series (Marsh funnel, Rheometer according to Soos, Kasumeter) had been performed and after 30 s or 300 s mixing.

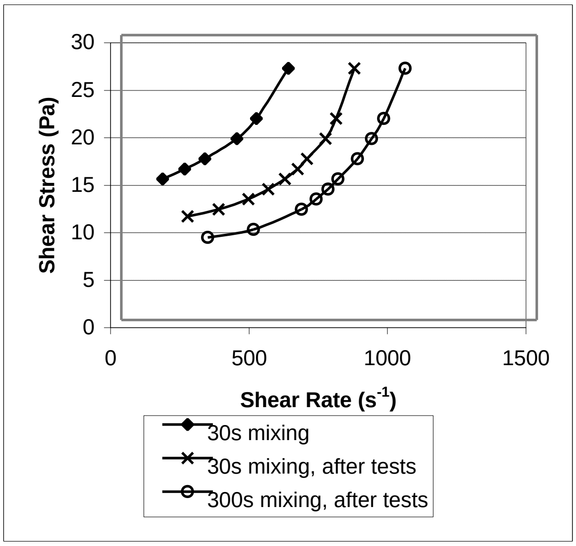

Figure 2: Kasumeter tests of suspensions HTX 40 kg/m^3, exposed to different shear conditions.

Rheometer Tests

The rheometer is a very sensitive device and is therefore not suitable for the use on a construction site. Its measurements are considered to be the most accurate. The time factor, that influences the rheological behaviour of thixotropic fluids, is taken into account with the input of the frequency. When performing the test at different frequencies, different yield points will be evaluated.

CONCLUSION

As for all thixotropic fluids, the main problem for the yield point determination is the different shear history of the samples. In the laboratory, the test procedures and the test sequence were the same for all mixes. Thus, a comparable shear history was achieved. However, for the quality control on site, ideal conditions can be hardly achieved.

According to the test results, the Kasumeter is the most suitable device when testing under the same conditions. Consequently, for the practical application on site, the test conditions shall be well defined to gain comparable results. Thus, it is noted when the quality of the bentonite suspension changes.

ACKNOWLEDGMENTS
Many thanks to the staff of the clay mineralogical laboratory of the Institute of Geotechnical Engineering.

REFERENCES

1. Luckham, P. F., Rossi, S. (1999), “The colloidal and rheological properties of bentonite suspensions”, Advances in Colloid and Interface Science, 82, 43-92.

2. DIN 4127 (1986), “Schlitzwandtone für stützende Flüssigkeiten“, Beuth Verlag, Berlin.

3. DIN V 4126-100 (1996), “Schlitzwände“, Beuth Verlag, Berlin.

4. Mezger, Th. (2000), “Das Rheologie-Handbuch“, Vincentz Verlag, Hannover.