Measuring Yield Stress to Correlate Slump of Concrete and Cement Paste

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Rheology, Yield Stress, Concrete, Cement Paste, Slump Test

Introduction

Concrete is the most widely used man-made material (measured by tonnage made) in the world. One of the most important characteristics of these materials is the so-called workability. The workability is the ability of a fresh (plastic) concrete mix to fill a given form/mold properly with the desired work (vibration) and without reducing the concrete's quality. Workability depends amongst others on water content, aggregate (shape and size distribution), cementitious content and age (level of hydration) and can be modified by adding chemical admixtures, like super plasticizer or rasing water content. However, excessive water leads to increased bleeding (build-up of surface water) and/orsegratation aggregates (when the cement and aggregates start to separate), with the resulting concrete having reduced quality [1].

Workability can be measured by the "concrete slump test", a simplistic measure of the plasticity of a fresh batch of concrete following ASTM C 143 [2] or EN 12350-2 [3] test standards. Slump is normally measured by filling an "Abrams cone" with a sample from a fresh batch of concrete. The cone is placed with the wide end down onto a level, non-absorptive surface. It is then filled in three layers of equal volume, with each layer being tamped with a steel rod to consolidate the layer. When the cone is carefully lifted off, the enclosed material slumps a certain amount, owing to gravity. However, it was shown in the past that determining the yield stress rheologically is a fast and easy method to correlate slump [4]. As soft foods like concrete are often difficult to work with when using conventional plate/plate or concentric cylinder geometries on rotational rheometers because of the possible wall slip and excessive sample disruption during loading into narrow gaps vane geometries are recommended here.

When a vane rotor is fully immersed in the sample, the yield stress itself can then be calculated according to Boger [5]:

$$\tau_0 = \frac{M_{max}}{K} \qquad [a]$$

With M being the maximum Torque and K the vane parameter that depends on the height (H) and the diameter (D) of the paddle according to:

$$K = \frac{\pi \cdot D^3}{2}\left[\frac{H}{D} + \frac{1}{3}\right] \qquad [b]$$

Fig. 1: Thermo Scientific HAAKE Viscotester iQ

Experimental Results and Discussion

As described earlier it is recommendable to rheologically test concrete with vane rotors. Figure 1 shows the new Thermo Scientific™ HAAKE™ Viscotester™ iQ with vane configuration.

For the tests, a standard Portland cement was mixed with water at typical concentrations and then fine gravel was added at three different concentrations w/w. Please find an overview of the sample compositions in Table 1.

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Sample	Portland Cement/g	Water/g	Fine Gravel/g
1	275	75	0
2	275	75	125
3	275	75	75

Table 1: Composition of tested concrete samples.

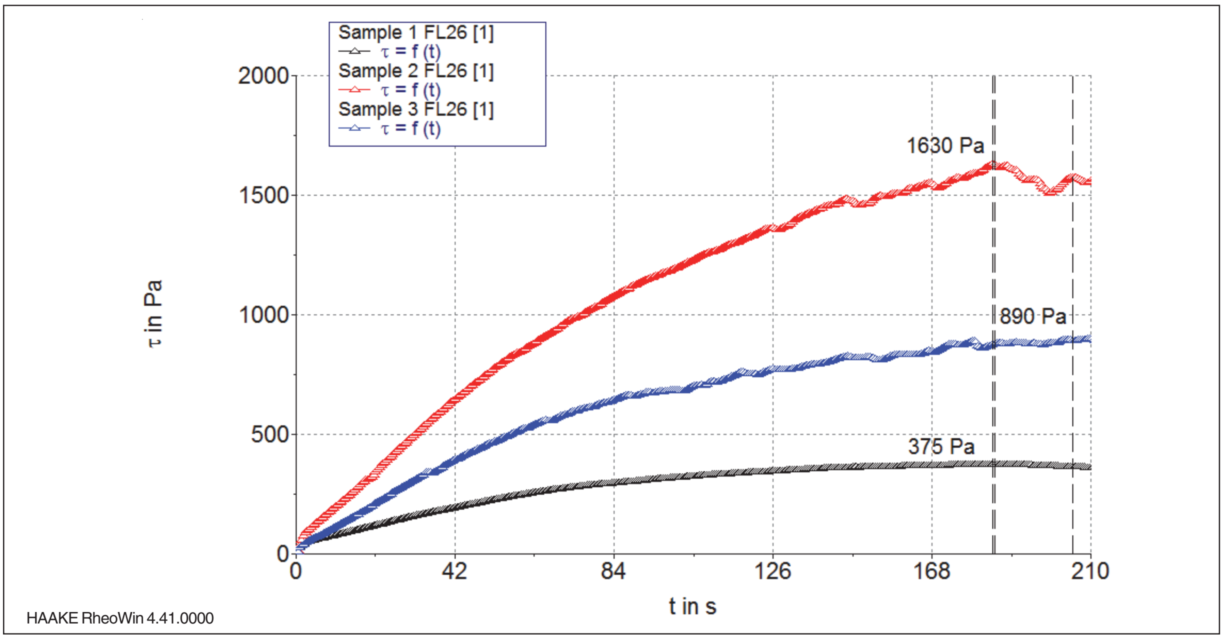

Fig. 2: Shear Stress versus Time for the three different concrete formulations at 25 °C after 5 min. waiting period after mixing.

After the samples have been formulated by thorough mixing they have been tested after 5 min. waiting time. The test was conducted as follows.
After the vane rotor has been fully immersed into the sample a constant rotational speed Ω = 0.05 rpm was commanded. Then the shear stress is monitored as a function of measuring time. After an initial purely elastic response in the sample the structure collapses and the shear stress is decreasing again. The maximum value in shear stress then corresponds with the yield stress.
Figure 2 shows the results for the three formulations 5 min. after mixing at 25 °C.
As can be seen in Figure 2 the yield stress for the pure cement paste is 375 Pa compared to 890 Pa with 75 g of fine gravel and 1630 Pa with 125 g of fine gravel. Those easily determined yield stress values can now be transferred into the slump values (mm) determined with the ASTM Abrams cone according to the semi-empirical relationship by Hu et. al. [6]:

$$s = 300 - 347\frac{(\tau_0 - 212)}{\rho} \qquad [c]$$

with s being the slump in mm, τ_0 being the yield stress and ρ being the density of the fluid.

Conclusion

The vane method on the Thermo Scientific HAAKE Viscotester iQ is a quick, simple and accurate approach to measure the yield stress of cement paste and concrete. Those values can then be easily transferred into slump values via semi-empirical relationships.

Literature

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