The Determination of the Rheological Properties of SCC with the Ball Measuring System

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ABSTRACT

This paper is about the development of a concrete rheometer that is based on the Ball-Measuring System. With this rheometer it is possible, to measure the rheological properties of Self-Compacting Concrete within a short time in fresh, unsheard concrete. Thereby, the shear rate is lower than it is applied by other concrete rheometers.

INTRODUCTION

For the determination of the rheological properties of Self-Compacting Concrete (SCC) several concrete rheometers and measurement systems exist. Based on the nature of Self-Compacting Concrete, the determination of the rheological parameters is more difficult than for other substances.

This is due to the composition of the mixture, the coarse aggregates used and the ongoing hydration process as well as interaction forces.

As a consequence, the laws of the classical rheology are no longer respected. Therefore, usually the existing concrete rheometers are relative measuring systems, which are modified rheometers of the classical rheology.

However, the determination of the rheological properties of SCC is very inaccurate. Typically for many concrete rheometers are the applied high shear rate and the permanent shearing of the sample. This shear stress usually does not correspond to the actual flow behaviour of Self-Compacting Concrete.

RESEARCH OBJECTIV

The aim was to develop a concrete rheometer that takes into account the special properties of SCC and simulates the actual flow conditions. As a starting point, the eccentric rotating ball (Ball Measuring System) was applied, which is already successfully used for rheological measurements of pastes and mortars (see Fig. 1).

Thereby a ball moves on a circular path through the material and the occurring torque at a defined speed is recorded. Rheometers, based on the ball measuring system allow the determination of several flow parameters in fresh, undisturbed Self-Compacting Concrete.

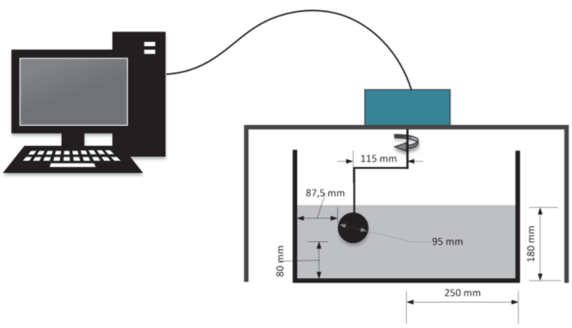

Figure 1. Ball-Measurement System for Self-Compacting Concrete.

By selecting a suitable measurement profile the relevant information regarding the flow behaviour can be found within a short time.

FLUID MECHANICS

The ball measuring system does not cause a laminar flow as it is usual for rotational rheometers. Instead of that, a drag flow is created, which cannot be described with the laws of the classic rheology. The relationship between the flow of the material and the ball therefore must be described in a different way.

As SCC is a fluid with yield stress, the consideration of the fluid mechanics is very complex. Furthermore SCC is a coarse-particle material which is furthermore affected by the hydration process.

Schatzmann[1] and Beris[2] developed a method, to transformation the torque and the velocity into shear stress and shear rate. The transformation is based on a dimensional analysis and can be used for Bingham-Fluids. Lowke[3] used a different way that is based on a mathematical derivation. However, all of these three transformations lead to similar results (see Eq. 1) which only vary in the variable Q_i.

Table 1. Transformation of torque into Yield Stress.

Autor	**Transformation**	Q_i
Schatzmann	$\tau = \frac{0{,}28\, F}{4\pi r^2}$	$Q_S = 0{,}28$
Beris et al.	$\tau_y = \frac{0{,}286\, F}{4\pi r^2}$	$Q_B = 0{,}286$
Lowke	$\tau_0 = \frac{0{,}33\, F_r}{4\pi r^2}$	$Q_L = 0{,}33$

$$\tau = \tau_y = \tau_0 \qquad (1)$$

In this work, not only the transformation of the transformation of the Yield Stress but also the Shear Stress is generally of interest. My approach is based on the assumption, that the measured force F depends on the viscosity and the shear rate, and thus the Shear Stress is only influenced by the force F. To transform the measured torque into Yield Stress, Eq. 2 was applied. For Q_i a mean value of the three mentioned variables was applied ($Q_i = 0{,}3$).

$$\tau(\dot{\gamma}) = \frac{Q_i\, F(\eta, \dot{\gamma})}{\;} \qquad (2)$$

To convert the velocity into Shear Rate, the influenced zone by the ball has to be considered. For Newton Fluids, this zone equates the radius of the ball. Hence, the Shear Rate can be calculated (Eq. 3)

$$\dot{\gamma} \quad v \qquad (3)$$

MEASURING PROCESS

For the measuring process two basic measurement profiles were used: For the first profile an increasing and decreasing speed was pretended and the measured values were plotted as a flow curve (see Fig. 2). The curve starts with a linear increase, which can be evaluated as an elastic deformation at the beginning of the test. The end of this elastic range characterizes the Static Yield Stress.

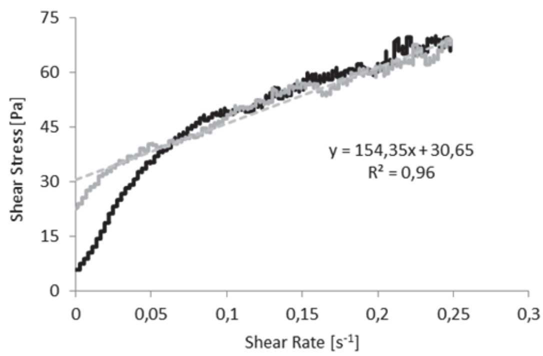

Figure 2. Flow Curve.

After the elastic range, the plastic range follows. For high Shear Rates, the up- and downward curves are identical. The reason is, that both curves result from measurements in unsheard concrete. For low Shear Rates, the downward curve declines sharp. The downward curve can be evaluated with the Bingham-Model.

For the second profile, a continuous speed was pretended and the determined Shear Stress was plotted (see Fig. 3).

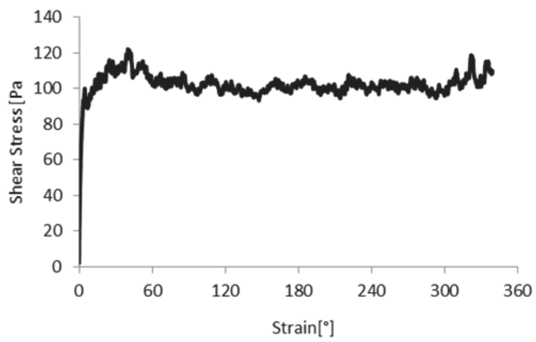

Figure 3. Shear Stress vs. Strain.

This plot gives information about the Static and Dynamic Yield Stress. The Static Yield Stress is an indicator for the force that is needed to start the flow process. Flow starts as soon as the flocculated structures are broken. As a result, the Static Yield Stress gives information about the thixotropic behaviour. However, the Static Yield Stress can also result from transient effects at the beginning of the measurement which depend on the acceleration of the ball. The Dynamic Yield stress is an indicator for the force that is needed to keep up flowing with a definite velocity. The Dynamic Yield Stress can be used to compare mixtures with different water content.

EXPERMINETAL WORK

An important issue was the consideration of the ball speed, moving through the material. This circumstance has a significant impact on the results of the measurement. At too low speed, neither the flow curve, nor the trend of shear stress at a continuous speed could be recorded. At high speeds, however, an additional torque due to the acceleration of the ball was recorded.

In addition to the speed, the structural build-up during a certain rest period (one, three, five, ten and 20 minutes after the first measurement) was of interest. It was observed, that the structural build-up that results from hydration and different interaction forces, significantly affects the measured yield stress (especially the static yield stress) and the viscosity.

Moreover, the impact of variations in mix-design of several SCC mixtures was evaluated. Even small fluctuations in water content (3 to 5 l/m^3) were visible.

The modified Ball Measuring System was then compared with other measuring systems. A direct comparison of the results was difficult because of the different measurement systems. Therefore, only a qualitative comparison was possible.

CONCLUSION

It was shown, that it is possible, to determine the rheological properties of Self-Compacting Concretes with a measuring device, based on the Ball Measuring System. Thereby the demand of a low shear velocity and the measurement in fresh material were achieved.

Details of the development of the new concrete rheometer and the experimental work can be found in [4].

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