THE ASSESMENT AND CONTROL OF THE RHEOLOGICAL PROPERTIES OF SELF-COMPACTING CONCRETE IN A CONCRETE MIXER

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ABSTRACT

This paper describes the development of a rheometer for Self-Compacting-Concrete (SCC) that is installed in a concrete mixer and provides results of the rheological properties immediately at the end of the mixing process.

The intention was to find a way, to evaluate the flowability and the rheological properties of SCC automatically, directly after the mixing process has finished. At the end of the mixing process the rheometer immerses in the concrete and starts the measurement. At this time a correction of the mixture is still possible, before it is filled into the truck. In a first step, a laboratory rheometer was built and the measurement procedure was developed. In a second step the laboratory rheometer was installed in a 75 l concrete mixer and data were collected and evaluated. Test results of different mix designs showed to be very accurate.

Keywords: SCC; rheology; concrete rheometer; concrete mixer

INTRODUCTION

Self-compacting concrete (SCC) is a concrete that flows without additional compaction energy under the influence of gravity and completely fills the formwork. Due to these features, SCC comes along with a number of environmental, health and economic benefits. Despite these advantages, the market share is relatively low. The big disadvantage of SCC is its low robustness against fluctuations in the constituent materials. Even small variations in the constituent materials and in water content overwhelm the automatic control mechanisms of ready mix concrete plants, designed only for the production of common vibrated concrete. For normal concrete, the consistency of fresh concrete can be assessed by the power consumption of the concrete mixer. For self-compacting concrete, this information is too inaccurate to conclude about the consistency. Therefore an additional quality check is necessary for the production of SCC.

EVALUATION OF THE RHEOLOGICAL PROPERTIES OF SCC

To make statements about the rheological properties of concrete, rheometers are used. In many cases rotational rheometers are applied. The advantage is that you get more accurate results than using one-point-measurement systems. However, most of these rheometers come along with some problems. Larger particles may cause turbulence and thus preventing a laminar flow. An often observed phenomenon is the appearance of a lubricant film at the interface between the sample and the surface of the measurement container. Usually this occurs when using coaxial cylinder geometries, but it can also be observed with other geometries of rotational rheometers. The lubricant film usually causes results with too low viscosity. Another problem is the constant shearing of the concrete that significantly changes the flow properties of the material. In some cases this can lead to segregation of the sample. In addition, the stiffening and setting is affected as the ongoing shearing destroys the flocculated structures. All these problems can influence the rheological properties of the material. Moreover, the measuring instruments are often very large, expensive and difficult to handle.

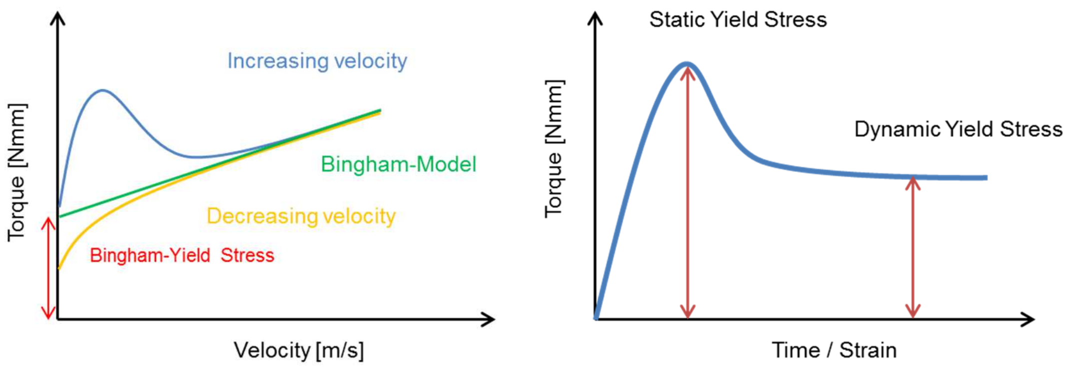
THE BALL-MEASURING-SYSTEM

As mentioned above, rotational rheometers come along with some problems. These problems were already recognised by Yasuo [1] as well as by Tyrach and Müller [2] who developed a measuring system that should avoid these problems. The Ball-

Measuring-System (BMS) by Tyrach and Müller exists of an eccentric rotating ball, fixed on a thin bar that runs in a cylindrical container with a defined low rotational speed. Thereby a drag flow is created instead of a shear flow (laminar flow) as it is usually created with rotational rheometers. The measurement can be finished within one revolution in un-sheared concrete. In order to obtain the flow properties, a relationship between speed and torque and thus a relationship between shear rate and shear stress is established.

When varying the speed, a flow curve can be generated (Figure 1 (left)). The analysis is then carried out with the Bingham-Modell. Additionally, the measurement of the torque during a period of constant speed is possible (Figure 1 (right)). As a result you get a time-torque or strain-torque curve with a "static yield stress" and a "dynamic yield stress". The results are relative values that depend on the measuring system and its geometry. According to Tyrach and Müller, a transformation in rheological values is possible. However this method is discussed controversial.

Figure 1. Flow curve (left) and Time/Strain - Torque curve (right)



Not only the transformation has been discussed, but also the measuring method itself: According to [3] it is not possible to create a flow curve within one revolution as the acceleration affects the torque. Thus more tests (revolutions) with different continous speeds are necessary. Scientists also discuss whether the time-dependent torque curve gives information about the rheological properties or not. According to [5][6][7][8] the time-dependent torque curve delivers information about rheological properties very well. Figure 1 (right) shows a time-torque or strain-torque curve (or stress growth plot [7]), which 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 [9][6]. Flow starts as soon as the flocculated structures are broken. As a result, the static yield stress gives information about the thixotropic behavior. The "dynamic yield stress" is an indicator for the force that is needed to keep the material up flowing with a defined velocity. Below this value the fluid stops to flow. Simplified the dynamic yield stress can be compared with the slump flow that makes statements about the flowability and the viscosity can be compared with the v-funnel time. In addition, both values are indicators for the resistance of sedimentation.

When working with the BMS some issues have to be considered [3][4]: To achieve a defined speed, the ball has to be accelerated, which accordingly requires an additional torque (force). The additional torque at the beginning depends on the velocity. However, for low velocities the acceleration is almost insignificant. After the acceleration, the torque stays continuous. During this period the measured torque only depends on the rheological properties of the fluid. In addition, in low viscosity fluids a high velocity leads to a wake in front of the ball. Another effect that has to be considered is the shearing of the material. When measuring twice in the same sample, the results may be different. During the first rotation, the ball runs in an un-sheared sample. When measuring a second time, the second revolution takes place in sheared material. Thereby the ball runs on the same track. These measured values can be different, depending on the recovery of the material. Furthermore it has to be observed, weather the measurement is affected by a blocking of the particles and the ball, which may be the case if the distance from the ball to the edge or bottom of the measurement container is too small.

THE DEVELOPMENT OF A NEW CONCRETE RHEOMETER

At the University of Applied Sciences Regensburg a research project, sponsored by the German Federal Ministry of Education and Research, has started, to develop a rheometer that immerses into the concrete mixer during a short mixing break and determines the rheological properties of the concrete and thus make statements about its quality.

In a first step a laboratory concrete rheometer (eBT2) was developed [10][11]: The intention was to create a rheometer with the key benefits: portability, short measurement, no slipping, no segregation during the test and the possibility to test in fresh, un-sheared concrete. The solution for this issue was found in the modification of the existing concrete rheometer BT2 [12][13] and the principle of the Ball Measuring System.

In a second step, the laboratory rheometer (eBT2) was modified again and installed in an Eirich intensive mixer (research mixer) with a volume of 75 l. Thereby some existing electronic components of the concrete rheometer ViscomatXL [12] and its software were applied. The prototype, named RheoCT, is portable and is installed in the charging hole of the mixer. The rheometer can be controlled by a PC and for evaluation the software of the ViscomatXL can be used. After starting the measurement, a cylindrical probe or a ball is drawn through the concrete. Thereby the velocity and torque is measured. You have the choice to generate either a flow curve or a Time/Strain - Torque curve as described above. The test can be finished within one revolution. When filling the mixer and during the mixing process, the prototype is removed. Later on, the rheometer should be placed in the mixer permanently.

With the end of the research program, a prototype of the concrete rheometer should run in a ready-mix concrete plant.

Figure 2. Concrete Rheometer RheoCT – application in a laboratory concrete mixer

EXPERIMENTAL WORK

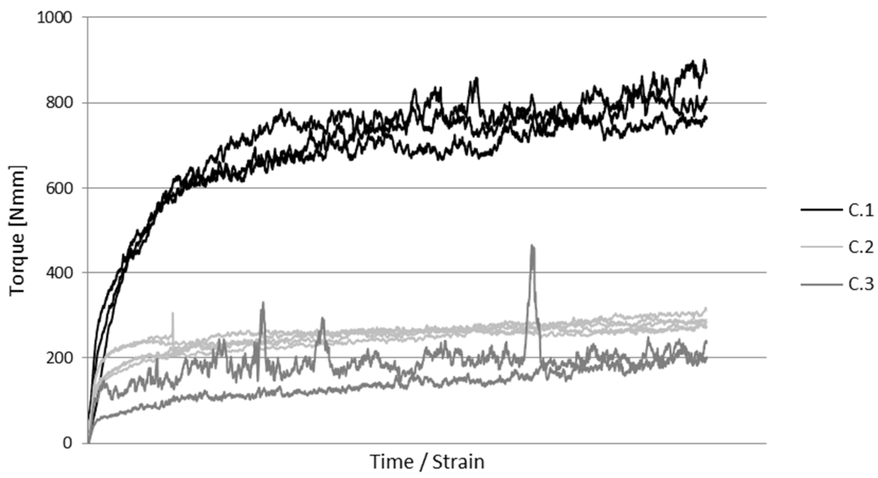
Numerous tests have been done with the new concrete rheometer ("RheoCT"). Some tests were performed with the RheoCT installed in the laboratory mixer and some with the RheoCT placed on a container outside the mixer. As the RheoCT is installed askew (due to the construction of the Eirich mixer), the gravity has an impact on the results. Furthermore measurement takes place in different depths. For this reason additional tests were performed in a container. Later on the rheometer will be installed in a horizontal position. Below, only the results performed in the container are presented. Mix design and water content have been varied in order to see the impact on the rheological properties. Here, one mix design with different water content will be discussed only. The results are comparable to the results achieved by the eBT2 [11].

Table 1. Concrete mix design

Concrete				**C.1**	**C.2**	**C.3**
cement	c	CEM II/A-M 42,5 N	kg/m³	407,2	388,9	380,4
additions	f	fly ash	kg/m³	212,7	203,1	198,6
water	w		kg/m³	177,7	187,9	192,7
sand	s	0/4 mm	kg/m³	747,3	747,3	747,3
coarse aggregate	g	4/16 mm	kg/m³	779,1	779,1	779,1
superplasticizer	SP	PCE-typ	M.-% of c.	2,40	2,40	2,40
water-cement-ratio	w/c			0,44	0,48	0,51
water-binder-ratio	w/(c+0.4f)	max f = 0.33c		0,39	0,43	0,45
water-powder-ratio	Vw/Vp			0,76	0,84	0,88
v-funnel time			sec	11,1	6,3	4,8
slump flow			mm	630	790	820

To prove the repeatability, several tests with the same mix design were performed. Figure 3 shows the Time/Strain - Torque curve of mixes with different water content. It can be seen that the water content has impact on the dynamic and static yield stress. With increasing water content the yield stress decreases. As the tests were made right after the mixing process of a SCC, the static and the dynamic yield stress are the same.

Figure 3. Time/Strain - Torque curves of three different mix designs



In addition, a ramp profile with increasing (up) and decreasing (down) speed was used to generate a flow curve (Figure 4). Furthermore the down curve was evaluated with the Bingham-Model. It can be seen that the Bingham Yield Stress (234,01 Nmm) is not identic with the real (relative) yield stress (~ 180 Nmm) which demonstrates that the Bingham-Model is only an approach model.

Figure 4. Flow curve – up and down curve including evaluation with Bingham-Model

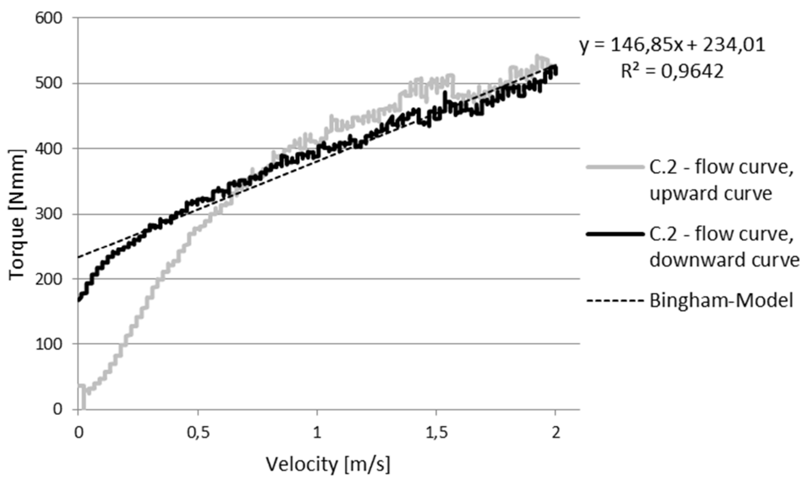
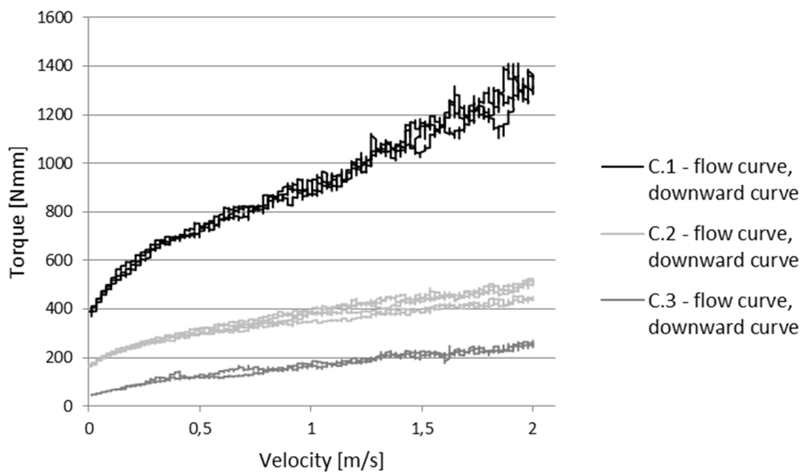


Figure 5 shows the down curves of the flow curves for three different mix designs which were repeated two to four times. It can be seen that the repeatability is very high. The Figure shows how the water content affects the flow properties of SCC. With increasing water content the curves become flatter and the torque values at a low velocity become lower. By using the Bingham-Model the result would be a decreasing yield stress as well as a decreasing viscosity.

Figure 5. Flow curve – down curve of three different mix designs



CONCLUSION

The target of the presented investigations was to develop a rheometer that evaluates the rheological properties of SCC directly in the mixer. First a laboratory rheometer (eBT2) was developed. The hardware is based on the BT2 by Schleibinger Testing Systems and the measuring procedure is based on the Ball Measuring System (BMS). Both, the BT2 and the BMS were modified to meet our requirements. The next step was the development of a prototype for a laboratory concrete mixer with a volume of 75 l. The developed prototype consists of a single probe that moves through an undisturbed SCC with defined velocity, while registering speed and torque. The results are a flow curve and a time-torque or strain-torque curve that deliver information about the rheological properties of the tested SCC. Changes in the water content can be easily recognized and several rheological properties may be generated. Further tests are planned to make the RheoCT more accurate and applicable for the use in concrete plants.

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