CONCRETE RHEOMETER ROUND ROBIN TEST (DFG 2005) - UNIQUE FEATURES OF THE IWB RHEOMETER IN TERMS OF SHEAR-INDUCED PARTICLE MIGRATION

RUNDVERSUCH BETON-RHEOMETER (DFG 2005) - ALLEINSTELLUNGSMERKMALE DES IWB-RHEOMETERS HINSICHTLICH SCHERINDUZIERTER PARTIKELMIGRATION

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SUMMARY

Numerous concrete rheometers are available on the market for determining the rheological properties of concrete. In order to counteract the unavoidable structural build-up of the concrete, the material is pre-sheared at high speed immediately before the actual measurement. It is assumed that the homogeneity of the concrete is maintained. The IWB rheometer enables pre-shearing and homogenization before each measurement process. These discrete measurements, with prior homogenization, lead to deviating raw data. A basic assumption of rheology is therefore violated with classic rheometers.

ZUSAMMENFASSUNG

Zur Bestimmung rheologischer Eigenschaften von Beton sind zahlreiche Beton-Rheometer am Markt verfügbar. Um dem unvermeidlichen Strukturaufbau des Betons zu begegnen, wird unmittelbar vor der eigentlichen Messung, mit hoher Geschwindigkeit vorgeschert. Dabei wird angenommen, dass die Homogenität des Betons erhalten bleibt. Das Rheometer des IWB ermöglicht die Vorscherung und Homogenisierung vor jedem Messvorgang. Diese diskreten Messungen, mit vorgeschalteter Homogenisierung, führen zu abweichenden Rohdaten. Eine Grundannahme der Rheologie wird folglich bei klassischen Rheometern verletzt.

1. BASICS OF CONCRETE RHEOLOGY

1.1 Long-standing assumptions that need to be questioned

In order to be able to characterize the properties of concrete, numerous specifications were formulated for the design of concrete rheometers [1]. The main focus was placed on determining the geometry, the design of the surfaces and the rotational speeds used during the test. The simplest - and in practice, with one exception (BTRheom) - structural implementation is the so-called cylinder-in-cylinder system (coaxial cylinder).

In the literature, until a few years ago, the idea was formulated that the speeds used in the rheometer were not sufficient to induce significant particle migration during the measuring process. Coarse concrete particles migrate into areas with low shear stress. If the inner cylinder or the measuring tool is driven, this means that coarse aggregate accumulates in the outer area of the container. This process, known as shear-induced particle migration (SIPM), means that there is no homogeneous concrete in the near field of the measuring tool, but rather a mortar with a reduced proportion of coarse aggregate. The measurements would therefore not be carried out on the concrete, but on a mortar. In particular, if only part of the shear gap is sheared, the measured values will be incorrect. In addition, there are numerous rheological models for concrete, but only the so-called Bingham model is physically based. This model is also considered suitable for normal concretes. Based on this model, shear-induced particle migration leads to lower yield stresses and higher viscosities. In the case of self-compacting concrete, physically impossible negative yield stresses are often calculated, in practice. The yield stress is then set to zero Pascal in the rheometer software (e.g. ICAR).

1.1.1 Assumptions on shear-induced particle migration

Until a few years ago, it was assumed in the literature that rheometer speeds that were at least a factor of 10 higher than the speeds actually implemented are required to segregate the concrete. Consequently, the homogeneity of the concrete was assigned only minor relevance. The simple coaxial design of the known rheometers therefore appeared to be permissible.

1.1.2 "Apparent" control of the measurement results

Concretes develop a structure immediately after being placed in a formwork or in the rheometer, which manifests itself in the fact that the rheological properties change. The speed and extent of the changes are determined by the concrete engineering techniques and environmental influences. This so-called thixotropy of the concrete can be reversed by shearing the material. As the flow behavior of the concrete from a pre-shear is usually relevant (pump or truck mixer), the material must be actively pre-mixed to the required level before measurement in the rheometer. As a rule, the material is pre-sheared in the rheometer for a sufficiently long time at the maximum measuring speed. In order to validate the rheological measurements, the concrete is pre-mixed for a sufficient period of time until the measured values (the torque) converge asymptotically to a final value. The actual measurements are then carried out at different, decreasing rotational speeds. In a second run, the measurement procedure is carried out again. If the raw data from the first and second measurements are at a comparable level, they are considered valid. This procedure assumes that no segregation due to shear-induced particle migration occurs in the pre-shearing phase before the actual measurements. Otherwise, both measurements are carried out in a segregated system and prove an apparent homogeneity of the concrete.

1.1.3 Imaging techniques as a moment of awakening

Imaging methods used by French scientists [1] prove, without a doubt, that shear-induced particle migration reaches relevant proportions within a few seconds. However, pre-shearing is absolutely necessary to reduce the thixotropic properties of the concrete. The two phenomena cannot be distinguished by measurement with existing rheometers.

1.1.4 International round robin tests in the past decades

In recent decades, several round robin tests have been carried out with the rheometers currently on the commercial market. The majority of rheometers provide results in absolute units and should therefore generate values at a comparable level. However, the measured values differ (Bingham parameters yield stress and plastic viscosity) several times.

2. ROUND ROBIN TEST CONCRETE RHEOMETER AT THE TU DRESDEN (DFG 2005)

2.1 Ensure homogeneity with sufficient pre-shear before the individual tests and consideration of plug flow

In November 2023, 17 different mix designs with a maximum aggregate size of 8 mm were measured at several times using different rheometers. The concretes were delivered in a truck mixer and mixed in several identical mixers until shortly before the respective test. After the test, the concrete was poured from the rheometers back into the mixers and mixed again.

2.1.1 Determining the individual pre-shearing time

During the filling of the rheometer, the concretes form a structure at rest, which depends on the mix design of the concretes and the filling time, and is therefore individual. In order to reduce this thixotropy, the concrete was pre-sheared for each concrete in a preliminary test with an ICAR rheometer at maximum test speed until the torque asymptotically approached a final value. After this pre-shear time, it can be assumed that the thixotropy has been reduced. However, the shear-induced particle migration is superimposed on the shear and has reached an unknown extent.

2.1.2 Consideration of the plug flow

Concrete rheometers require a large shear gap due to the granular material. Only if the concrete has a very low yield stress it can be assumed that the material is sheared in the entire shear gap between the two cylinders. If the shear stress is below the yield stress of the concrete, only a part of the concrete is sheared and a ring of unsheared material is formed. In order to be able to calculate the actual sheared radius within the rheometer, the Reiner-Riwlin approach has become established.

In each of the tests, 8 pairs of measured speed/torque values were determined and the shear radius was calculated using Reiner-Riwlin. As most of the concretes tested can be classified as normal concretes, the yield stress is high and the shear radius correspondingly low. According to the findings of [3], shear radii below the simple maximum grain diameter should be classified as questionable. According to a “traffic light system”, the classification is made into questionable, realistic and very realistic measurements.

3. SOLUTION APPROACH SHEAR-INDUCED PARTICLE MIGRATION (SIPM)

A modified rheometer based on the commercial ICAR was developed at the IWB. All classic rheometers allow pre-shearing of the material and inevitably also cause deshomogenization as a result of SIPM.

In order to be able to pre-shear the material and homogenize it at the same time, the cylindrical container of the ICAR was replaced by a new structure. A significantly larger container with a volume of approx. 45 l is mounted on a motor-driven turntable. A container with the dimensions of the ICAR container (without base) is mounted on a vertically movable unit and dips eccentrically into the container described above. If the vertically movable small container is positioned above the larger container, the mix in the large container can be pre-sheared and homogenized at the same time using a high-speed hand whisk. Pre-shearing the material to reduce the thixotropy is therefore always associated with an increase in the homogeneity of the mix in this design and differs from all commercial rheometers.

3.1 Comparison of traditional / new approach

The IWB was participating with the described rheometer and carried out each measurement with two different measuring regimes:

3.1.1 Traditional approach:

Based on the ICAR measuring regime, the rheometer was filled and pre-sheared for the time determined in the preliminary tests using the rheometer's measuring tool. The thixotropic effects were reliably reduced after this time, but there was also a shear-induced particle migration of unknown extent.

3.1.2 New approach:

In the first step, the mix was pre-sheared with a whisk over the time determined in the preliminary tests. With a speed of 650 rpm and a diameter of the whisk of 100 mm, the tool speed at the outer edge of the tool is over 3 m/s. This speed corresponds to the lower range of an intensive mixer and is considered sufficient.

This speed corresponds to the lower range of an intensive mixer and can be considered sufficient. Although the mix is not sheared continuously, a partial volume is sheared with above-average intensity as the large container rotates. After pre-shearing, the material is therefore homogeneous and pre-sheared to a high level. As the concrete is more homogeneous, higher torques can be expected compared to the traditional regime. After the first measurement at the highest speed, the mix is homogenized again and pre-sheared with high intensity by the mixer. This procedure is repeated for all individual measuring speeds. This means that a homogeneous, pre-sheared mixture is also present at the last measurement, at the lowest speed.

3.1.3 Results:

The measured values were evaluated according to Reiner-Riwlin for the Bingham model. In order to compare the effects of the two measurement regimes, the rheological parameters were normalized. For this purpose, the yield stresses and plastic viscosities of the new measurement regime were related to the basis of the traditional one. The modified pre-shear proves the deficits of the classic measuring regime. The structure at rest is reliably minimized, but with the acceptance of an unknown shear-induced particle migration. This in turn leads to calculated rheological properties with a large systematic error. The following illustration for the first tests after delivery of the concretes shows the differences. The new measurement regime consistently leads to (significantly) higher yield stresses and often to (significantly) lower plastic viscosities.

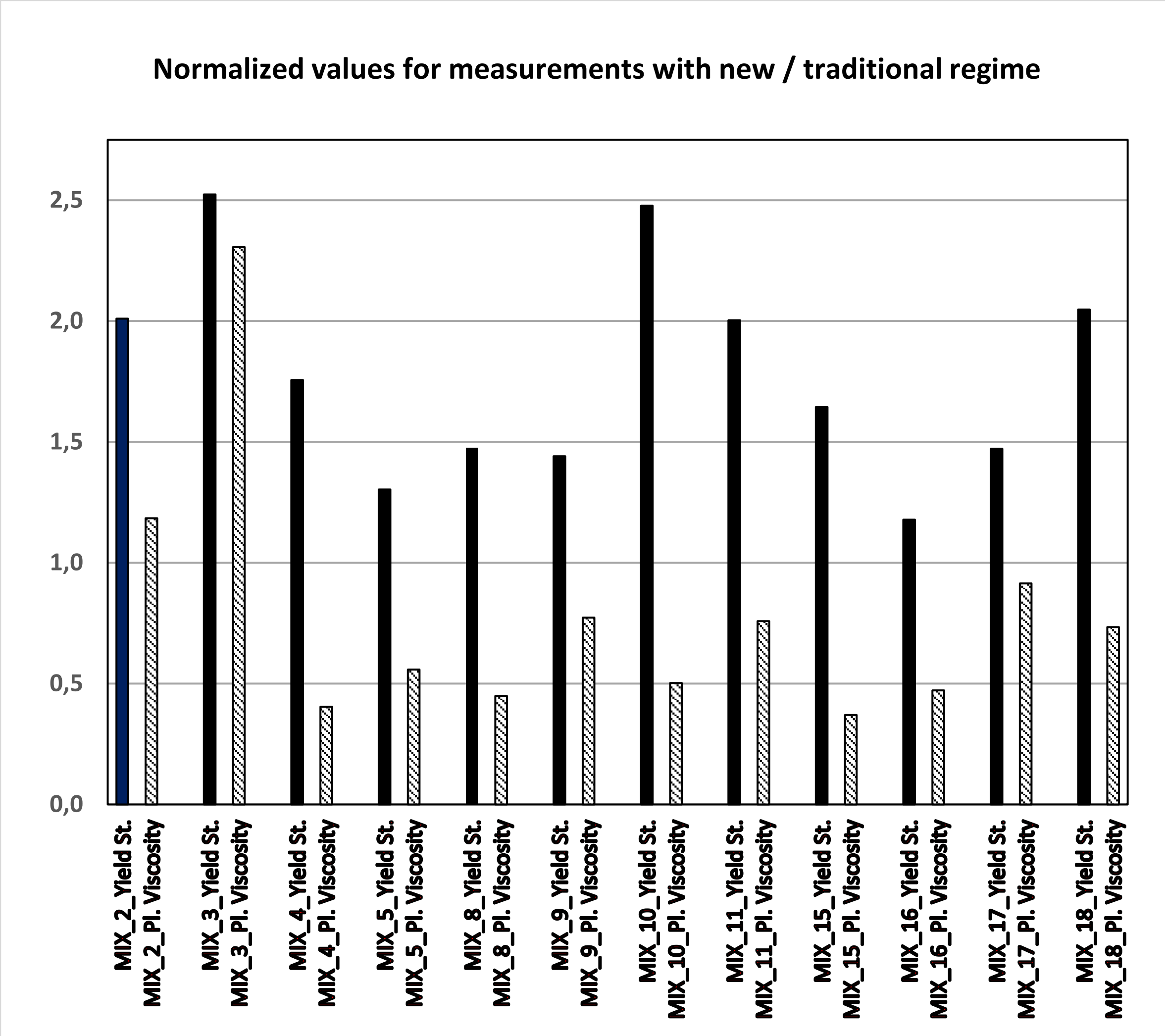

Fig. 1: Normalized comparison between traditional and new approach

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