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Rheological characterization of the structural breakdown process to analyze the stability of flowable mortars under vibration

Yared Assefa Abebe, Ludger Lohaus *

Leibniz Universität Hannover, Institute of Building Materials Science, Hannover, Germany

HIGHLIGHTS

- An adequate rheological method is introduced to quantify the structural breakdown.
- Dynamic stability depends on the interparticle structural strength (A_s) and viscosity (η).
- The dynamic stability depends more on the paste composition than the paste amount.
- Higher solid concentration of paste enhances the group/lattice effect of aggregates.
- Exceeding the critical dynamic viscosity, i.e. $\eta \geqslant \eta c$, guarantees mortar stability.

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ABSTRACT

The performance of fresh concrete could be evaluated in terms of its ability to maintain adequate stability while showing good flowability and deformability during pumping and casting operations. During such operations, the concrete is exposed to very intense external stresses which usually cause a complete breakdown of the interparticle structure, thereby affecting both the rheological and the stability properties of the mix including the resistance against segregation. Hence, guaranteeing the dynamic stability of concrete, which mainly depends on the interparticle structural strength and the viscosity, is of paramount importance. However, unlike the static stability of concrete where a critical yield stress serves as a stability criterion, there is no rheological criterion yet upon which the dynamic stability could be evaluated. In this paper, new rheological measurement and evaluation techniques are introduced with which the yield stress, the viscosity and the interparticle structural strength could be quantified, taking the structural breakdown process into consideration. Moreover, the stability of different mortar compositions was investigated under the influence of vibration in order to assess the effects of the structural breakdown process on the segregation potential. Finally, based on the results of the rheological and the stability investigations, a new rheology based criteria is introduced with which the dynamic stability of mortars under the influence of vibration could be assessed.

1. Introduction

Today's modern structures, which are usually characterized by dense reinforcements as well as slender and geometrically complex elements, require a concrete with higher flowability, deformability and stability. These fresh concrete properties are mainly dependent upon the rheological properties of the suspending medium, namely the cement paste or the mortar. While the flowability and workability of concrete is mainly governed by the yield stress and the viscosity, the stability property could depend on the yield stress, viscosity and thixotropy. As such, the relevance of each rheological parameter to the stability of concrete depends on the state of stress to which the concrete is exposed to.

On the one hand, the static stability, which is relevant to the segregation process in a state of rest such as the sedimentation of coarse aggregates after casting of self-compacting concrete (SCC), depends first and foremost on the yield stress. At rest, no segregation of coarse aggregates would take place as long as the yield stress of the suspending medium (τ_o) remains higher than a certain critical yield stress ($\tau_{o.c}$), i.e. $\tau_o > \tau_{o.c}$. However, sedimentation of the coarse aggregates would be inevitable if $\tau_o < \tau_{o.c}$ [1,2]. In this case, the rate at which the inter-particle structures get re-built after the structural breakdown, i.e. thixotropy, determines the extent of the segregation. Hence, a concrete with a strong thixotropic behavior rebuild its interparticle structures in a relatively short

* Corresponding author.
E-mail address: lohaus@baustoff.uni-hannover.de (L. Lohaus).

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time, thereby increasing its viscosity and yield stress which ultimately enhance the resistance against segregation [2,3].

The dynamic stability, on the other hand, is relevant to the segregation process under the action of stress such as during mixing, pumping, casting and vibration processes. Here, the extent of segregation depends on the magnitude of the applied stress. In this regard, the stress caused by vibration could be expected to have a pronounced influence on the rheological properties as well as the segregation process. Hence, the rheological characterization of concrete under vibration should focus on the structural breakdown phenomena rather than the structural build-up process [4,5]. Under such considerations, the thixotropic behavior becomes irrelevant as it is more related to the structure build-up process. Instead the interparticle structural strength takes a prominent role in determining the rheological as well as other fresh concrete properties under the action of external stress. The interparticle structural strength designates the overall shear resistance of the system which is contributed by the interparticle surface forces at the paste level and the friction between the aggregates. A complete breakdown of the interparticle structures caused by high level of stress in concrete results into a significant reduction of the yield stress (τ_o), which triggers the sedimentation of coarse aggregates [6,7]. As a result, the resistance against segregation during vibration emanates primarily from the viscosity which mainly affects the velocity of the settlement of the coarse aggregates. Moreover, the stability properties under the influence of vibration are directly dependent upon the interparticle structural strength (A_s) [5]. The higher the value of A_s of the suspending medium, the lower the extent of segregation or sedimentation of the coarser particles. However, the question as to whether there exists a certain rheological criterion such as a critical viscosity (η_c) for vibrated concrete, in compliance with the critical yield stress ($\tau_{o.c}$) for SCC, is not yet answered on a rheological basis.

To this end, this paper presents results of investigations with regard to the rheological investigation of different paste compositions and the stability properties of mortars made from these pastes under the influence of vibration. The rheological investigations were carried out using a rotational viscometer (Viskomat NT from Schleibinger). The yield stress (τ_o) and the dynamic viscosity (η) of the pastes were determined by combining the Herschel-Bulkley and Bingham models. The interparticle structural strength (A_s) was quantified by making use of the breakdown area between the static yield stress ($\tau_{o.s}$) and the dynamic yield stress ($\tau_{o.d}$) determined at different shear rates [5,8]. The stability properties of the mortars under vibration were investigated using a combined sedimentation - sieve test (SST) as well as by visual assessment of the segregation tendency on dry mortar specimens. Based on the results of the investigations, it could be concluded that the dynamic viscosity (η) is the only rheological parameter that could reliably be adopted to quantify the structural breakdown process. Furthermore, a new rheology based evaluation criteria – the so called critical viscosity (η_c) with the corresponding funnel flow time (FFT) – is introduced with which the stability of mortar compositions under the influence of vibration could be assessed.

2. Materials and experimental methods

2.1. Paste and mortar compositions

The reference paste compositions (REF) were extracted from concrete compositions having different water–fines ratios (V_W/V_F) ranging from 0.8 to 1.2 with a constant w/c = 0.6 and superplasticizer (SP) content of 5.41% of the amount of water. A constant air void volume of 1.5% was also assumed for all mixtures. The flowable mortars with a constant slump flow of about 290 mm ± 10 mm were produced by combining the paste compositions with sand (0/2 mm), see Fig. 1. Here, the paste contents were adjusted in order to maintain the constant slump flow. The robustness of the mortar compositions in terms of their stability against water overdosage was also investigated by adding extra water of 10 L (ROB + 10 L) and 20 L (ROB + 20 L) to the reference concretes.

2.2. Rheological measurement and evaluation techniques

The rheological investigations on the paste compositions were conducted using a rotational viscometer (Viskomat NT from Schleibinger), see Fig. 2. Moreover, the standard flowability tests such as slump flow and funnel flow time were also carried out.

The applied measurement profile, which also considers the time and loading influences on the rheological properties, is shown in Fig. 3. The first shear rate of 150 U/min is applied for ca. 3 min for the purpose of homogenizing the mixtures in order to start the measurements under similar conditions. The advantage with this measurement profile is that in addition to the relative yield stress (τ_o) and relative dynamic viscosity (η), which are determined in a steady state condition, the interparticle structural strength (A_s) could also be determined by quantifying the magnitude of the applied stress required to breakdown the interparticle structure and to bring the system to a steady state as illustrated in Fig. 4.

The Herschel-Bulkley model was applied to determine the relative yield stress values τ_o, since the classic Bingham model has at times led to negative values. These τ_o values were then integrated in the Bingham model in order to determine the relative dynamic viscosity (η).(see fig. 5)

The Y-intercept (b) and the gradient (tan α) of the dynamic yield stress curve $T_d = f(\tau_{od,i})$ represent the relative yield stress (τ_o) and relative dynamic viscosity (η) respectively. The area (A_s) between the two curves $T_s = f(\tau_{os,i})$ and $T_d = f(\tau_{od,i})$ as determined using Eq. (1) represents the interparticle structural strength.

$$A_s = \int_{50}^{150} (T_s - T_d)\,dv \quad (1)$$

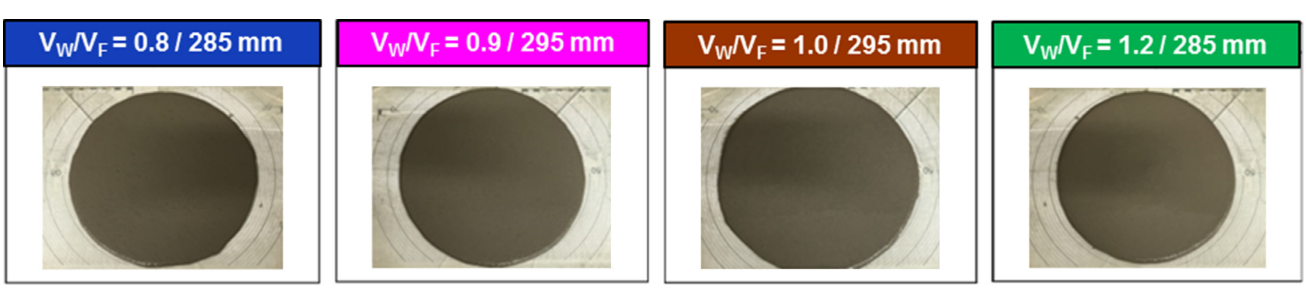

Fig. 1. Slump flow of the reference mortar mixtures [REF].