Construction and Building Materials 151 (2017) 615–624

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

Experimental assessment of the effect of particle characteristics on rheological properties of model mortar

K. Daddy Kabagire [a,*], Paco Diederich [a], Ammar Yahia [a], Mohamed Chekired [b]

[a] Université de Sherbrooke, 2500 Boulevard de l'Université, Sherbrooke, QC J1K 2R1, Canada
[b] Institut de Recherche d'Hydro-Québec, Varennes, QC J3X 1S1, Canada

HIGHLIGHTS

- Dry packing density was determined for glass beads and sand particles.
- The rheological properties of limestone filler paste and mortar were investigated.
- The intrinsic and modified intrinsic viscosity are a function of particle shape and rheological testing protocols.
- The suspending phase composition affects the measured values of intrinsic viscosity.

ARTICLE INFO

Article history:
Received 12 January 2017
Received in revised form 19 June 2017
Accepted 20 June 2017

Keywords:
Rheological properties
Particle characteristics
Mortar
Prediction models
Intrinsic viscosity
Static yield stress

ABSTRACT

The rheological properties of self-consolidating concrete (SCC) are strongly influenced by the volume, shape, and grading of solid inclusions of its corresponding mortar. Understanding the rheology of the mortar phase is important in the design of SCC with proper flow properties that ensure successful casting and good hardening performance. In this study, the rheological properties of various model mortar mixtures are evaluated. The paste portions of mortar mixtures were proportioned using inert limestone powder with water-to-powder ratios (W/P) of 0.30 and 0.35. Spherical beads, crushed limestone, and siliceous sand particles were used to prepare model mortar mixtures. The influence of solid fraction and particle characteristics, including shape and grading, on rheological properties was evaluated. Test results show that Krieger-Dougherty (KD) and Chateau-Ovarlez-Trung (COT) models are adequate to predict plastic viscosity and static yield stress, respectively, of the investigated mortar mixtures. On the other hand, the intrinsic viscosity commonly associated with particle shape is found to be a function of shear regime, suspending phase composition, and the rheological model used to describe the flow behavior.

Contents

* Corresponding author.
E-mail address: d.kabagire@usherbrooke.ca (K.D. Kabagire).

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.122
0950-0618/

1. Introduction

Self-consolidating concrete (SCC) is a multiphasic material containing coarse aggregate particles suspended in mortar. SCC is used in various applications, such as repair, casting of congested sections, and pumping in high-rise buildings. Because of the complexity of achieving SCC mixtures with targeted rheological properties, efforts are needed to better understand the rheology of the suspending mortar phase. For a given aggregate size and grading, the rheology of mortar should be tailored to ensure adequate flow and stability performance.

Cement-based materials, including SCC and its mortar phase, exhibit a yield stress and behave as viscoelastic materials below the yield stress [1–3]. Above the yield stress, they behave as liquids, and their steady flow behavior is usually well represented either by a Bingham or Herschel-Bulkley (HB) models [4–8]. Various models to predict the rheological properties of concrete, which is simulated as a suspension of solid particles in a fluid phase, have been proposed [9–12]. The complexity in simulating SCC as a multiphase material is due to the wide range of solid particle size as well as the multiple interactions between cement, sand, and coarse aggregate. To overcome this complexity, the flow properties of the suspending phase can be used to predict SCC flow properties [13]. Various analytical and empirical models have been developed to predict the viscosity and yield stress of concentrated suspensions [11,14,15]. For example, a powerful semi-empirical model to predict the yield stress of concrete was proposed by de Larrard [10]. The authors reported that the yield stress is function of the solid volume fraction and packing density of different components of the granular skeleton. Although this model can help explain the flow properties of conventional concrete, it is not suitable for SCC, which contains fewer coarse particles and higher paste volume than conventional concrete. This can therefore lead to underestimating the inter-particle friction. Also, this model is not suitable for mixtures containing more than one binder.

Mahaut et al. [16] conducted an experimental study to evaluate the mechanical effect of monodisperse particles on the rheology of yield stress fluid. The study revealed that the relative yield stress value can be predicted using the Chateau-Ovarlez-Trung model [17]. A maximum packing density of monodisperse spherical particles of 0.570 [13] for isotropic dispersion was reported, while Ovarlez et al. [18,19] proposed a packing density of 0.605 for anisotropic dispersion. On the other hand, Flatt [20] proposed a theoretical model to predict yield stress of cement paste by taking into account particle size distribution, solid volume fractions, and maximum packing density. This model seems to include parameters linked to both mix design parameters and physico-chemical interactions between particles. However, further investigations were required to adapt it to mortar and concrete mixtures [15].

The effects of size, shape, and grading of solid particles on the rheological properties of concrete, mortar, or cement paste are documented in the literature [16,21–23]. Westerholm et al. [24] reported that the shape and volume of fine aggregate particles strongly influence the plastic viscosity of the mortar phase. Recently, Hafid et al. [25] evaluated the effect of morphological parameters of sand particles in water-oil emulsions and revealed that the shape of particles is a dominant morphological parameter affecting the packing density. Although these investigations provided an insight into the effect of sand particles on the rheological properties of mortar, prediction of these properties remains a complex task. This complexity may be due to the inadequacy of rheological measurement techniques and the wide range of material properties. An alternative way to overcome this complexity is to establish analytical approaches to predict the rheological properties of a given suspension as a function of the solid fraction taking into account the contribution of particle shape and grading. This study considers mortar as a two-phase material in order to evaluate the effect of particle inclusions on the rheology of suspensions. This approach may be useful to understand the influence of aggregate characteristics (shape, size, distribution, and specific surface) and the composition of the suspending phase on the rheological properties of mortar. This approach can then be applied to concrete given the rheology of the suspending phase (i.e. mortar) and aggregate characteristics of the solid fraction.

2. Prediction models

2.1. Krieger-Dougherty model

The prediction of relative viscosity (dimensionless) of mortar can be described using the Krieger-Dougherty [11] model, where the paste portion of mortar is considered as a suspending phase and solid particles (sand and beads) as rigid inclusions. The model is described by the following relationship:

$$\frac{\mu_\varphi}{\mu_0} = \left(1 - \frac{\varphi}{\varphi_m}\right)^{-[\eta]\varphi_m} \tag{1}$$

where, μ_φ is the plastic viscosity of the mortar, μ_0 is the plastic viscosity of the paste portion of mortar, φ is the solid volume concentration of inclusion (i.e. beads or sand particles), φ_m is the maximum volume concentration of solid particles, and $[\eta]$ is the intrinsic viscosity, which is a measure of the effect of individual particles on viscosity and is a function of particle shape. Finally, the parameter φ_m corresponds to the random packing density.

2.2. Chateau-Ovarlez-Trung model

The theoretical model developed by Chateau-Ovarlez-Trung [17] was recently employed to predict the evolution of relative static yield stress. This model provides a general relationship between the relative elastic modulus of suspension G'_φ/G'_0 (G'_φ is the elastic modulus of suspension—mortar in this study and G'_0 is the elastic modulus of the suspending phase, in this case the paste portion of mortar) and the relative static yield stress τ_φ/τ_0 of the same suspension, which consists of a suspension of rigid particles in yield stress fluid (τ_φ is the static yield stress of the suspension or mortar phase and τ_0 is the static yield stress of the suspending phase or paste portion of the mortar phase). This model is valid for rigid and non-colloidal inclusions, thus the physico–chemical interactions between paste and particles cannot be considered. Furthermore, the distribution of particles in paste (suspending phase) is assumed to be isotropic. The authors reported that the following relationship fit their experimental results well: