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Influence of bentonite clay on the rheological behaviour of fresh mortars

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ABSTRACT

Fine mineral additives are often used in the formulation of ready-mix mortars as thickeners and thixotropic agents. Yet, these attributed fresh state properties are not clearly defined from the rheological point of view. In the present study, we consider the influence of bentonite (montmorillonite-based clay mineral) on the rheological behaviour of mortars, including in particular creep and thixotropy. The mortar pastes are subjected to different shear-rates and then allowed to creep under fixed shear stresses until reaching steady state, which corresponds to either rest if the applied stress is smaller than the yield stress or permanent flow otherwise. The evolution of the creep strain is investigated depending on shear history for different contents of bentonite. The microstructure rebuilding kinetics after shear (thixotropy) is considered by analysing the temporal evolution of the creep strain for different applied shear stresses (lower than the yield stress). As expected, bentonite is found to enhance the mortar creep (or sag) resistance. This enhancement consists of both an increase of the yield stress recovered after shear, and a diminution of the characteristic time for yield stress recovery (related to microstructure rebuilding).

1. Introduction

Ready-mix mortars, including among others tile adhesives, rendering and repairing mortars, are often characterised by a highly complex formulation. In particular different types of organic and mineral admixtures are included in their mix-design in order to meet a number of requirements related to their placement processing (pumpability, workability, sag-resistance, etc.), their hardening properties (open-time, cracking-resistance, etc.) and their long-time behaviour (water-proofing, mechanical properties, durability, etc.).

Ready-mix mortars are generally provided to the construction site in a dry power form. A given dosage rate of water is then added and the mix is kneaded to obtain a homogeneous mortar paste that can be mechanically or handily placed on vertical or horizontal supports. The rheological behaviour of the mortar paste will clearly determine its placement properties. Yet, the relationship between the rheological properties of these materials and their on-site placement behaviour are far to be clearly established [1,2]. Most of the rheological studies devoted to fresh mortars, which are usually assumed to behave as Bingham fluids, have focused essentially on two rheological parameters, namely the yield stress and the plastic viscosity [3,4]. These investigations are related in particular to the self-compacting/self-levelling issue. The transient rheological properties of cementitious materials, including mortars, are much less considered [5–7]. Moreover these investigations are mostly related to the practical issue of successive concreting and pressure on formworks. Paiva et al. [8,9] reported some rheological studies concerning specifically render mortars, considering in particular the influence of water-retaining agents [8], without however considering the issue of thixotropy.

When dealing with the problem of pumpability, as in the present study, a more extensive rheological characterisation is required since in such a process the material experiences a highly complex flow. During a machinery application process the mortar is sheared under varying rates, leading to an irreversible evolution of its microstructure, and subsequently its rheological properties. The crucial practical question is then: Does the mortar have enough thixotropy to recover a sufficient yield stress once on the support to avoid creeping under its own weight?

In the present study, to reproduce approximately the pumping process from the rheological point of view, the mortars are subjected to different shear-rates in a rheometer and let to creep under a given applied shear stress. This stress may correspond in practise to the one exerted by gravity, which intensity can be estimated as (one assumes a vertical wall): $\rho g a$, where ρ is the mortar density, a the applied layer thickness and g the acceleration of gravity. Once on the wall the material must quickly recover a yield stress higher than the gravity stress in order to avoid sagging. For a typical render mortar application ($\rho = 1800$ kg/m^3, $a = 2$ cm, $g = 10$ m/s^2), the yield stress must exceed 360 Pa once on the wall in order to avoid sagging.

We consider both the level of the yield stress recovered after shear and the dynamics of the microstructure recovering (thixotropy). We focus in particular on the influence of a bentonite clay mineral on these rheological properties.

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2. Materials and experimental procedure

2.1. Materials

The base mortar considered in the present investigation includes Portland cement (CEM I 52.5 N CE CP2 NF BLANC), hydraulic lime (NHL 3.5Z), siliceous sand with a controlled granular size distribution and an air-entraining admixture (NANSA LSS 495 / H) (see Table 1). This mortar composition is a very simple version of commercially available render mortars. The only variable mix parameter is the dosage rate of a commercially available sodium bentonite. Bentonite is composed essentially of montmorillonite which is a clay mineral [10]. The Bentonite grade used here is commercialised as additives for drilling fluids.

The recommended dosage rate of kneading water for render mortars in field applications is around 15% by weight of the dry mix, and will be retained in all the mixes considered.

In order to minimise the granular skeleton's porosity, several sands and charges with different granulometries are generally used in practise. For the present simple formulation, rolled siliceous sand is sieved to obtain two contrasted granulometries, designated as (d1) and (d2), whose diameter sizes are respectively within the intervals [0.16 mm, 0.315 mm] and [1.25 mm, 2.5 mm]. The percentages of (d1) and (d2) in the sand part are set to 30% and 70% respectively. The latter values are based on an on-going study on the influence of sand granulometry on the properties of fresh mortars, which results are intended to be submitted for publication in the future.

2.2. Rheological measurements

2.2.1. Apparatus

The rheological measurements were performed using a stress-controlled shear rheometer (AR-G2 from TA Instruments) equipped with a four-blade vane geometry (Fig. 1). Using this geometry, the tested material is not subjected to a uniform shear rate. This condition is usually required in rheological experiments in order to measure actual material properties, and to have an analytical relationship between the measured torque/rotational velocity and shear-stress/shear-rate. Nevertheless, vane geometry has been retained since it is appropriate for high yield stress fluids such as dense granular suspensions, including mortars [11,12], as slippage can be avoided and the material can be sheared in volume. The shear-rate and shear-stress are inferred from the measured torque and rotational velocity of the vane using a calibration method described in details in Refs. [13,14].

The gap, which represents the distance between the periphery of the vane and the outer cylinder, is equal to 8.3 mm, which is only about three times the maximum grain size. As a result, the influence of the discrete aspect of the suspensions on the rheological measurements should be considered. However, this will not change fundamentally the results reported here. The temperature has been regulated at 25 °C (to within 0.1 °C) thanks to a circulating water system. In order to minimise water evaporation the cup of the measurement system was sealed.

2.2.2. Measurement procedure

All the mortars have been mixed (using a Perrier laboratory mixer) using the same procedure, that comprises the following steps:

i) mixing of the dry components at low speed (60 rpm) for 30 s
ii) addition of the required quantity of kneading water
iii) mixing at low speed for 30 s
iv) scraping down the sides of the mixer bowl for about 30 s
v) mixing at low speed for 60 s.

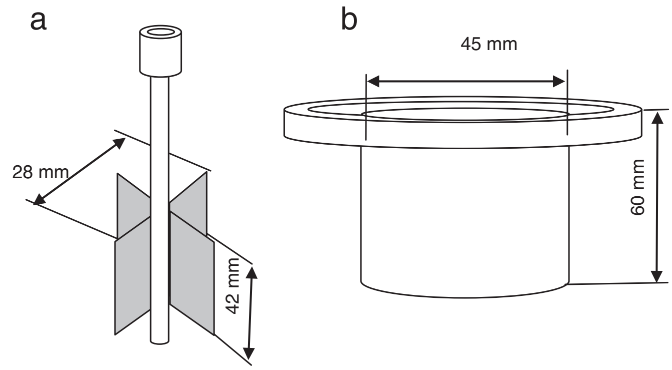

Fig. 1. Rheological measurement system: a) vane tool and b) outer cylinder (cup).

The rheological measurements started after 5 min resting from the end of mixing.

The measurements were undertaken during the induction period, characterised by a very low hydration rate, which may not influence the rheological response of the material. In order to check that this was actually the case, two successive and identical rheological measurements were performed on the same sample, indicating that no mechanical irreversible transformations (hydration) of the material were detected within two hours after mixing.

The sample was subjected to the solicitation history illustrated in Fig. 2. It was first sheared at a given controlled shear-rate $\dot{\gamma}$ during T_s (shearing time). This was followed by the application of a relatively small controlled stress σ_1 during T_c (creeping time). The value of σ_1 was chosen to be smaller than the yield stress, which was *a priori* inferred from the flow curve determined at controlled shear-stresses. The sample was sheared again at $\dot{\gamma}$ during T_s and a higher stress σ_2 ($>\sigma_1$) was applied during the same creeping time T_c. This procedure was repeated for increasing applied stresses. To account for the influence of the value of the applied shear-rate before creep, freshly prepared samples were used and the same procedure was repeated.

The shearing time T_s and creeping time T_c were taken to be long enough to reach steady state with all the shear rates and shear stresses considered. In order to fulfil this criterion, we took $T_s = 60$ s and $T_c = 30$ s.

In a typical rendering mortar application using a plastering machine the maximum flow rate (Q) generally encountered is around 10 l per 30 s, that is $Q = 3.33 \times 10^{-4}$ m^3/s. The product is subjected to varying shear-rates throughout the pumping circuit. For a given flow rate the shear rate is the highest in the regions where the duct section is the smallest. The duct would be the tightest at the spray gun level. In this region the minimum duct radius (r) is about r = 0.5 cm. The maximum shear-rate experienced by the product during a typical application can be then estimated as: $\dot{\gamma}_{max} = (Q / \pi r^2) \times 1 / r \approx 850\,s^{-1}$ In this estimation, it is assumed that the material is sheared all through the duct section (Poiseuille flow). Yet, since it possesses a yield stress, one has rather a plug flow in which it is sheared only near the duct surface. The value above of the maximum shear rate may be then underestimated. We cannot apply such a high shear rate with our rheometer equipped with a measurement system with a gap of 8.3 mm. The maximum shear rate that can be applied with our apparatus is estimated to be 600 s^{-1}.

Table 1
Mix design of mortar.

Constituent	Cement	Hydraulic lime	Sand	Air entraining	Bentonite clay	Water
% (by weight)	15	5	80	0.01	Varied: 0 → 1%	15

3. Results and discussions

3.1. Steady state rheological behaviour

Similar to other types of fresh cement-based materials, mortars are often modelled approximately as Bingham fluids [4]. For theses fluids