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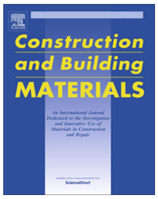

Influence of grains distribution on the rheological behavior of mortars

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HIGHLIGHTS

- The influence of the granulometric composition of sand on rheological behavior of mortars is investigated.
- Rheological behavior of mortars is observed whit rotational rheometer and squeeze-flow tests.
- It is identified mortar flow is directly dependent on particle packing and uniformity index of the fine aggregate.

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ABSTRACT

The objective of this study was to analyze the influence of different proportions of mortars and different granulometric compositions on the rheological behavior of these materials through squeeze-flow and rotational rheometry trials. To this end, mortars with proportions of 1:0:3, 1:1:6 and 1:2:9 (cement:hydrated lime:sand, in volume, dry materials) were produced. Each proportion was dosed with three different granulometric compositions (GC), produced in the laboratory. These mortars were subjected to characterization trials in the fresh state, in addition to rheological analysis by squeeze-flow and rotational rheometry. The results demonstrated that mortar flow is directly dependent on particle packing, in addition to the uniformity index of the fine aggregate. The proposed rheological trials were efficient in identifying the different rheological behaviors of the produced mortars.

1. Introduction

Understanding the flow behavior of mortars is essential to project their settling, coating or repair behavior in buildings. A suitable flowability may increase the contact area of the mortar with the substrate where it's applied, making systems more stable and durable.

In this context, rheology studies the deformation and flow of matter. It's the science that describes the deformation of a solid, liquid or gaseous body under the influence of stresses [1,2]. It should be noted that, despite being an ancient science, rheology is very current and used in the development of new substances and products that are putting traditional concepts of this science to the test, requiring more detailed and innovative studies from researchers to accompany this development.

The flow parameters are essential to understand the viscosity of a fluid. Flow means the continuous increase in the deformation of a material's structure under the effect of finite forces [3].

In the study of mortars, viscosity is the crucial parameter for the understanding of its rheological behavior [3]. According to Betioli [4] and Machado [5], viscosity is the directly proportional relationship between the shear rate and shear stress. The shear stress (τ) is the force (F) per unit area (S) to maintain the flow of the fluid and is expressed by the Eq. (1). The shear rate (γ) is the relative displacement of the particles or fluid planes and is also known as the "degree of deformation" or "velocity gradient". It can be represented by the difference in the velocities (Δv) between two particles or neighboring planes and the distance (Δy) between them (Eq. (2)) [5].

$$\tau = F/S \tag{1}$$

$$\gamma = \Delta v/\Delta vy \tag{2}$$

And, finally, the viscosity (μ) is represented graphically by Eq. (3).

$$\mu = \tau/\gamma \tag{3}$$

The appropriate measurement of viscosity requires test conditions that provide laminar flow, steady flow, absence of slip, homogeneous samples, no physical or chemical changes during the test and no elasticity [1].

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To perform the measurement of these parameters, several authors across the world [6–13] employ rotational rheology. In Brazil and other countries of the world, the squeeze-flow test has been used constantly for the measurement of the rheological parameters of cementitious materials, since it evaluates the flowability of mortars in a simple way and with equipment that is available in most laboratories (axial compressor) [14,8,15].

Mortars tend to display complex rheological behavior that is difficult to measure [16], a consequence of its multiphase nature, with formulations that may include: cement, lime, fibers and additions and additives, in addition to conventional materials.

Because they are composed of high concentrations of particles, which interact intensely, mortars have a different rheological behavior than the ideal model by Newton. When submitted to shear conditions, the coarse fraction (sand) of the mortar is predominantly subjected to attrition and mass flow phenomena (attrition and impact), while the fine fraction (<100 µm) is affected by surface phenomena and hydration reactions [15].

Over time, mainly due to the reaction of the cement with water, the behavior of this material changes, going from the fluid to the elastic solid state (hardened). This behavior is a result of various phenomena, such as dissolution, agglomeration, precipitation of hydrated binder phases, changes in pH and the effect of any additives [15,17].

There are a great number of published studies that suggest that the cement paste has a behavior similar to a Bingham fluid [18], which belongs to class of non-Newtonian fluids that are not dependent on time. It is emphasized, however, that this paste can have a behavior that varies from a viscous Newtonian fluid to a solid pseudoplastic [19]. Bauer [20] explains these investigations by the fact that the Bingham Fluid incorporates a second factor, in addition to viscosity, in its equation: the yield stress (Eq. (4)). This represents the stress that needs to be applied to a given material before flow starts [20].

$$\tau = \tau_0 + \eta_p \gamma^{\bullet} \tag{4}$$

where T is the shear stress; $\gamma^{\bullet}$ is the shear rate and η_p is the plastic viscosity.

Other flow behaviors have been studied and represented by scholars, such as the Herschel-Bulkley model (Eq. (5)), which describes the behavior of a fluid with yield stress (T_0) and with a non-linear relationship between shear stress and shear rate. When n = 1, the model results in Bingham model, with k representing the plastic viscosity of the fluid. When 0 < n < 1, the fluid displays a pseudoplastic behavior [21].

$$\tau = \tau_0 + k \overset{\bullet}{\gamma}^{n} \tag{5}$$

In this context, the present study sought to measure the rheological properties of mortars, varying the proportion and granulometric composition, parameters that vary widely from region to region, in addition to the type of material used in the composition of the proportions.

2. Experimental program

2.1. Materials and methods

The cement used for making the rendering mortars is a Portland CPIV-32 cement (equivalent to the American IP (MS) grade), classified according to NBR 5736 /1991 as a pozzolanic cement. Its characterization is shown in Table 1.

Table 1
Cement chemical and physical properties.

Experiment		Method	Results
Blaine specific surface		NBR NM 76/98	4398.5 cm^2/g
Density		NBR NM 23/01	2.76 g/cm^3
Medium diameter		Laser diffraction	16.95 µm
Fineness sieve #200		NBR 11579/91	0.27%
Initial curing period		NBR NM 65/02	243.25 min
Final curing period		NBR NM 65/02	284.80 min
Compressive strength	7 days	NBR 7215/96	25.03 MPa
	28 days	NBR 7215/96	36.20 MPa
Insoluble residue		NBR NM 22/04	35.84%
Sulfur trioxide (SO3)		NBR NM 146/04	2.28%
Magnesium Oxide (MgO)		NBR NM 14/04	4.61%
Loss on ignition			3.64%

The hydrated lime used to make the rendering mortars was high calcium lime (specific mass 2.37 g/cm^3, mean particle size 22.4 µm), classified as hydrated CH-I according to NBR 7175/2003.

The sand used was of quartzous origin. It was dried and sieved through four fractions of sieves, as shown in Table 2. With these four fractions, three different granulometric compositions (GC) were produced, based on the results of the study conducted by Bonin et al. [22], in which the authors evaluated the influence of five different grain size distributions of sands on the workability of mortars. Among the GCs studied by the authors, those that presented opposite compositions, and one with an intermediate composition, were selected for this study.

GC1 has a continuous distribution, with a constant percentage retained in the successive sieves. GC2 is very similar to the natural sands available in Porto Alegre/RS/Brazil, i.e., it is a uniform sand with a predominance of grains of similar diameters, and of low compactness. GC3 is a mirror of GC2, with a particle size distribution that is typical of a mixture of two natural sands of the region under study, with a predominance of grains retained in sieves with quite different diameters, resulting in a non-uniform sand with good compactness.

When the Uniformity Index (UI) of the selected granulometric compositions is considered, one can see that although GC1 and GC2 have very distinct curves, they have a very similar UI, which is considered as very uniform. GC3 has a UI greater than 5, which is classified as average uniformity. Additionally, one can see that the less uniform the GC is, the lower its void volume, as is to be expected.

2.2. Dosage and production of mortars

Three mortars were produced, called A3, A6 and A9, with proportions of 1:0:3, 1:1:6 and 1:2:9 (cement:hydrated lime:sand, dry materials in volume), respectively, dosed by mass in the laboratory. These proportions were composed of fine aggregates with the three granulometric compositions (GC1, GC2 and GC3).

The mortars were produced according to the Brazilian standard NBR 13276/2005 in an automatic mortar mixer with automatic digital controllers, planetary movement and a capacity of 5 L. All mortars were produced with 1.5 kg of dry material so that the amount of material wouldn't influence the mixture and, consequently, its rheological behavior.

The tests performed to characterize the mortar in the fresh state were: Bulk Density, according to Brazilian Standard NBR 13278/2005, Air Entrainment Rate (pressometric method), according to the Brazilian standard NBR NM 47/2002, and Water Retentivity, according to Brazilian standard NBR 13277/2005.

The rheological analysis tests performed were Squeeze-flow and rotational rheometry trials.

The squeeze-flow test, recommended by NBR 15839/2010, has been used for the rheological characterization of mortars and pastes by several authors in recent years [8,15,23–26]. It is based on the amount of force required for the uniaxial compression of a cylindrical sample of the material between two parallel plates, generating deformations through shear and elongation of the sample, as can be seen in Fig. 1 [15,23].

Its results are expressed in the form of a load (N) versus displacement (mm) chart, and according to Cardoso et al. [15], it presents a curve with three distinct regions, as shown in Fig. 2. According to the authors, stage I is a smaller displacement that shows the elastic deformation of the material, stage II is an intermediary displacement that reflects the plastic deformation or viscous flow, and stage III is a large displacement and hardening by deformation, influenced by the approximation of the aggregates and the friction caused by them.

The mortars under study were submitted to the test, molded on a smooth and non-porous metal base (standard).

The displacement speeds used were 0.1 mm/s and 3 mm/s, with a maximum displacement of 9 mm and maximum force of 1 kN. The execution times of the tests were 10 and 60 min for the speed of 3 mm/s, and 15 and 65 min for the speed of 0.1 mm/s, which are the parameters established by the applicable Brazilian standards.

The rheological characterization with the rotational rheometer was performed on a Brookfield R/S plus rheometer (Fig. 3a).

These tests were performed with a vane spindle, V, 30 × 15, of 30 mm in height and 15 mm in diameter, in a standard container for all mortars (Fig. 3b). This type of vane was used because it's the most recommended for rheological tests of rendering mortars and high viscosity suspensions. The size of the vane was determined through preliminary tests, which revealed the most adequate dimensions for the