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Impact of aggregate grading and air-entrainment on the properties of fresh and hardened mortars

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HIGHLIGHTS

- Fresh and hardened properties of rendering mortars were evaluated.
- The aggregate grading has considerable impact on the fresh state.
- The air-entrainment can lessen the impact of grading variation.
- Hardened properties was governed by the porosity.
- Porosity was mainly influenced by the air-entrainment in the fresh state.

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ABSTRACT

The great variance in the properties of mortars in the fresh and hardened state or during performance in use may be associated with a lack of control over materials and admixtures. Thus, the main purpose of this work is to evaluate the impacts that aggregates size distribution, the proportion of entrained air and the type of air-entraining admixtures have on the fresh and hardened properties of mortars. Mortar mixing behavior and air-entrainment were monitored to understand the changes in the fresh properties while the hardened properties were quantified by the porosity, mechanical strength, modulus of elasticity, adhesion and air-permeability. The results show that variations in the aggregates size distribution cause considerable impact during the mixing stage but these impacts are lessened by the use of air-entraining admixtures. Contrarily, in the hardened state, only the air-permeability was influenced by the size distribution, although, the other properties were impacted by the air-entrainment.

1. Introduction

The solid particles in mortar range a great deal in particle size, from submicron up to millimeters. The large volume of coarse particles used in the formulations (≈60 vol.%) exerts significant contribution in all fresh and hardened properties of mortars. Nevertheless, the resulting behavior depends on the complete particle size distribution [1–3].

Robustness [4,5] is a big challenge in large-scale mortar and concrete production. This quest arises because the flow behavior during the fresh state and the properties on the hardened state may be distinctly affected by the variations in particle size distribution, the proportion of fines-aggregates, the water content and other factors, which are often uncontrolled [1].

The use of air-entraining admixtures (AEA) in the formulation of mortars is an even more common option to improve properties in the fresh state, like density decrease, workability increase. After hardening, a reduction in the modulus of elasticity may also occur. Another aspect regarding AEA is its potential to attenuate errors caused by the variations in mortars particle size distribution, since the air bubbles plays great influence in both fresh and hardened states. However, AEA requests careful use by itself, since the volume of entrained air is very sensitive to the amount and quality of admixture.

Several studies in literature [4–10] reports the individual effects of particle size distribution, water content, air-entrained agents in fresh and hardened state. However, less attention has been dedicated to their combined effects, which are necessary for better understanding and improvement of robustness in mortars production.

Therefore, the main purpose of the present work was to evaluate the associated impacts of aggregate size distribution

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and air-entraining admixtures in the fresh and hardened properties of mortars.

2. Materials and methods

2.1. Materials used

The mortars were formulated using Portland cement blended with 20% limestone filler, Brazilian type-F – 32 MPa, and ground limestone sand (medium and fine). All raw materials were provided by mortar producers. The particle size distributions are presented in Fig. 1, and the solid density and specific surface area (SSA) are presented in Table 1.

Two air-entraining admixtures (AEA) based on anionic sodium lauryl sulfate based molecules were tested. However, one of them is 100% organic molecules and the other is 67%. So, they are designated as AEA-100 and AEA-67, respectively.

This difference may impact the air entrainment, the air-volume generated and the admixture consumption, because organic material is the active agent for producing foams [13]. Just for comparison, the admixtures with distinct quantities of entrained air were defined as distinct PRODUCTS. However, it must be clear that both have the same molecular basis.

Regardless, the reference mortar was mixed without air-entraining admixture and the other mortars were mixed using 0.2 or 2.0 g/L of AEA (or 0.012% and 0.12% in function of cement weight).

2.2. Methods

The methods used in this work are described below. All hardened tests were done after cure for 7 days at 25 °C and 98% of relative humidity.

Mixing rheometry: all dry powder was placed in a planetary rheometer cup and the water was added controlling the flow at 45 g/s. The mix was monitored for 150 s while maintaining the rotational speed at 500 rpm. The result was the equivalent torque in function of time of mix.

Air-entrainment: the tests were performed according to gravimetric method, using a cup of 400 ml volume, and quantifying the mass needed to fill it. The values of air entrainment were calculated based on the mortar's water content and the real density of the dry powder.

Porosity: measured according the Archimedes immersion method, based on the dry, wet and immersed mass. Initially, the dry mass of each sample was estimated, then the samples were completely immersed in water and stays under vacuum for 2.5 h. After this time, the wet and immersed mass were measured. The total porosity was calculated according the Eq. (1), where is ρ_{REL} is the relative density of mortar:

$$\text{Total porosity } (\%) = (1 - \rho_{REL}) \times 100\% \tag{1}$$

Mechanical strength: the tensile strength was determined using the 'Brazillian test'. The tests were carried out in a universal testing machine, Instron, model 5569, controlling the load at 0.05 ± 0.02 MPa/s and using samples with 50 mm diameter and 20 mm thickness.

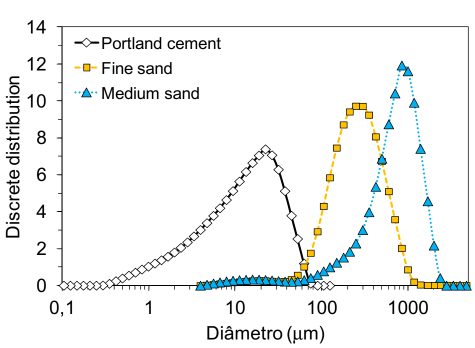

Fig. 1. Particle size distribution, real density and specific surface area of the sands and cement used in the mortar formulations.

Table 1
Solid density and specific surface area (SSA) of raw materials.

Raw material	SSA (m^2/g)	Real density (g/cm^3)
Portland cement	1.75	3.01
Fine sand	0.32	2.79
Medium sand	0.19	2.79

Modulus of elasticity: measured according to Brazilian standard NBR 15630/08 using equipment with frequency transducers of 200 kHz, and a circular transversal section with 20 mm diameter.

Pull-out test – adhesion: the tests were performed using a digital dynamometer, Imada, model ATX-500 DPU, with a load cell of 5 kN, Dynatest, accuracy 1.0 N (Fig. 2a). The samples were cast in a different manner than the conventional method, to try to reduce the high variability caused during preparation in accordance to the Brazilian standard (where the sample is cut, generating stresses). This methodology was developed by Romano et al. [13] and consists of:

i. washing the standardized substrate with water and drying for 48 h;
ii. placing the molds with diameters of 50 mm and 20 mm thickness on the slab (8 per slab) as shown in Fig. 2b;
iii. casting the mortar in two stages: fill half the mold and give 20 scams using a metallic pestle, then fill the other half and give 20 more scams using a metallic pestle;
iv. leveling the surface using a metallic spatula.

As observed in previous studies variations due to the standardized substrate are very high, so different compositions of mortar were cast on the same substrate to try to reduce its variations even more. After removing the samples from the molds, aluminum plates were fixed onto the samples using epoxy cement, as illustrated in Fig. 2c, and then waiting for about 3 h to complete drying and begin testing.

Air-permeability: measured according to the vacuum-decay method [11–13]. The apparatus employed was a vacuum pump connected to a suction chamber that is in contact with the surface of the mortar. When the vacuum pump is turned on a transducer registers the pressure variations in function of time until the pressure stabilizes. The test starts when the vacuum is turned off and the time it takes for the pressure to subside is quantified. The permeability (expressed in k_1 (m^2) values) is calculated using the Forchheimer equation (Eq. (2)), considering two basic hypotheses: negligible air-compressibility and using just the linear part of the equation [16].

$$\frac{\Delta P}{L} = \frac{\mu}{k_1} v_s + \frac{\rho}{k_2} v_s^2 \tag{2}$$

L is the sample thickness, μ and ρ are, respectively, the fluid viscosity and density, v_s is the speed of air-percolation and ΔP is the pressure variation, for which v_s, μ and ρ are measured or calculated. The term $\mu v_s/k_1$ shows the viscous effect of fluid–solid interaction, while the term $\rho {v_s}^2/k_2$ represents the inertial effects. The terms k_1 and k_2 are thus known as *Darcian* and *non-Darcian* permeability constants, in reference to Darcy's law, a simpler and earlier empirical model for permeability description. However, k_2 was not used to compare the results in this work [16].

2.3. Compositions evaluated

The mortars were formulated using different sand proportions (illustrated by the Table 2) fixing the cement-to-aggregates ratio, 1:3 in mass, and resulting in the particle size distribution shown in Fig. 3. The resulting packing porosity (estimated according the Westman and Hugill model [17]) and specific surface area are presented in Table 3.

Up to 75 μm the particle size distribution was the same for all mortars and the differences between them is due to the aggregate particle size distribution: C1 was formulated only with medium sand, resulting in a particle size distribution with greater gap between fine and coarse particles and worse packing than C2, which was formulated using just fine sand, and C3 was formulated with 50% fine sand and 25% medium sand.

These changes directly affect the water demand, but in this work the water content was fixed at 15% in relation to the dry powder and the changes in consistency were evaluated.

3. Results and discussions

3.1. Air-entrainment

This effect of air-entraining admixture on the air-incorporation is observed in Fig. 4. All mortars were mixed for 150 s ant the tests were carried out 2 min after stop the mix.

The air-entrainment level presented indicates the absolute value and is equivalent to an average of three measurements. This kind of evaluation was adopted to show the sensibility of the mortar to the mix process, using the same equipment but in distinct batches.

Air-entrainment was observed even in the mortars without admixture due to the shear history, and the values were from 5% to 10%, without any dependency on the aggregate size distribution.