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Development of mortars containing superabsorbent polymer

L. Senff [a,*], R.C.E. Modolo [b], G. Ascensão [c], D. Hotza [d], V.M. Ferreira [b], J.A. Labrincha [c]

[a] Mobility Engineering Center, Federal University of Santa Catarina (UFSC), 89218-000 Joinville, SC, Brazil
[b] Department of Civil Engineering/RISCO, University of Aveiro (UA), 3810-193 Aveiro, Portugal
[c] Department of Materials and Ceramics Engineering/CICECO, University of Aveiro, 3810-193 Aveiro, Portugal
[d] Department of Chemical Engineering (EQA), Federal University of Santa Catarina (UFSC), 88040-900 Florianópolis, SC, Brazil

HIGHLIGHTS

- DoE was used to formulate mortars with superabsorbent polymer.
- The use of rheometer can play a relevant role on the hardened properties.
- Mortars with similar initial yield stress diverged over time.
- Mortars containing SA increased the MBV regarding the reference sample.

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ABSTRACT

The rheological behavior of mortars containing different dosages of superabsorbent polymer (SAP) and distinct water/binder (W/B) ratios was measured. In addition, mechanical properties, capillary index and porosity of samples with 0–0.9 wt.% SAP and 0.66–0.82 water/binder weight ratios were also evaluated at 28 days, using design of experiments (DoE). In general, the yield stress was the rheological parameter that better expressed the continuous absorption of water molecules persistence once the mechanical mixing was concluded. Spread on table and yield stress exhibited an opposite relationship described by a power correlation. Despite being prepared with additional water dosages, SAP-containing mortars showed a capillary index below those estimated for SAP-free mortars, while the flexural strength results remained invariable. As expected, SAP increased up to 18% the moisture buffering capacity of the mortar, when compared to the reference sample (0 wt.% SAP).

1. Introduction

The ability of superabsorbent polymer (SAP) particles to absorb large amounts of liquid without dissolving allowed extensive worldwide industrial applications. In civil construction, the use of SAP in cement-based material or composites has been growing, due to several advantages obtained by the use of such particles, as described below. According to Jensen and Hansen [1], SAP can be used as an alternative to the internal curing agent for the prevention of self-desiccation, avoiding crack formation. Other benefits include the increment of hydration and durability and the reduction of permeability [2,3]. When SAP particles were added to engineered cementitious composites (ECC), the tensile strain capacity and toughness of composites were improved [4].

However, an eventual potential problem concerning SAP is the separation and grinding of particles caused by aggregates during concrete mixing [5]. In addition, the kinetics of absorption of SAP depends on the particle size [6] and chemical composition [7,8]. Correspondingly, the mechanical properties improvement can be significant, small or null [9,10]. In fact, it depends on the combined effect between the porosity generated in the concrete – causing a strength reduction – and the internal curing water provided by SAP particles that will enhance the degree of hydration and the material resistance [11].

Concerning rheology and workability, the evaluation of SAP-cementitious materials has been also carried out using mini-slump spread and marsh cone flow time determinations, which simply give semi-quantitative information. Relevant parameters such as the yield stress and viscosity are not estimated but just approached [2,12].

The combined use of SAP and other additives has been also investigated [2,4,12–15]. Small amounts of nanosilica could offset the negative effect of SAP on compressive strength, but the flexural strength was not fully compensated [2]. Even if the combination between SAP particles and colloidal silica induces positive effects

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[*] Corresponding author.
E-mail address: lsenff@gmail.com (L. Senff).

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on the compressive strength, the flexural strength tends to decrease [12]. For engineered cementitious composites (ECC) specimens with 50% fly ash, the tensile strain capacity incorporating SAP particles can increased by about 80% [4].

The indoor moisture variation might be modulated by suitable SAP-containing composite materials, since they are able to quickly respond to humidity changes [16]. For instance, SAP-containing mortars showed interesting moisture buffering values (MBVs), being classified as “good or excellent” according to the Nordtest protocol [17]. Their performance is superior than the one achieved with porogene additives or lightweight fillers, such as vermiculite, perlite, aluminium powder or sodium olefine-sulphonate [13–15]. However, SAP particles exert a negative impact on the flowability of the mortar mixes [13–15]. This workability loss is commonly corrected by increasing the water dosage, but this action will induce deleterious effects on functional properties (e.g., mechanical strength) of the hardened mortar. For that reason, systematic studies that clarifies the influence of each individual component and the eventual synergetic action on a particular property need to be carried out [18,19].

Therefore, the purpose of this experimental research is estimating the individual and combined influence of SAP particles and W/B ratios, in order to optimize the mortar formulation according to its application. Several properties were evaluated, covering fresh state (rheology and flow table test) and post-cured conditions (flexural strength, capillary index, porosity as well as the moisture buffering capacity).

2. Experimental

2.1. Materials

Portland cement (OPC type I 42.5 R), according to EN 197-1 [20] was used as a binder. It has a specific surface area (SSA) of 0.35 m^2/g (Blaine fineness), an average particle size of 14 μm and its chemical composition is given in Table 1. Hydrated lime (Calcidrata S.A., Portugal), also used as binder, contains approximately 90% $Ca(OH)_2$ and its moisture content is below 0.1 wt%. Superabsorbent polymer, SAP (T 5066 G, Evonik) has an irregular shape and particle size distribution as shown in Fig. 1. The particle size distribution of sand used as aggregate in the mortars ranges between 0.075 and 1.18 mm (average size of 0.45 mm), while the superplasticizer (SP) used to adjust the behavior of fresh mortars is based on a polycarboxylic acid (Glenium 52, Basf).

2.2. Design of experiments

Design of experiments (DoE) is a methodology used to evaluate the effect of the main factors and their interactions on a certain property [21]. In this paper, a factorial design 2^k (k represents the number of factors involved, i.e., water and SAP) was particularly used to adjust the basic formulation of mortars, named experimental plan 1 (Table 2). The statistical significance of this test and the validation of models were carried out by analysis of variance (ANOVA).

2.3. Rheological and flow table characterization

The rheological behavior of fresh mortars was measured in an appropriate rheometer (Viskomat PC) for testing cement pastes and mortars (Fig. 2a). The total test duration was 40 min, applying the speed profile illustrated in Fig. 3. The rheological behavior of mortars may be represented by the Bingham model [22,23],

$$\tau = \tau_o + \mu_p \cdot \dot{\gamma} \quad (1)$$

where τ (Pa) is the shear stress, τ_o (Pa) is the yield stress, μ_p (Pa·s) is the plastic viscosity and $\dot{\gamma}$ (s^{-1}) is the shear rate.

The Bingham model may be also expressed through torque (T, in N mm) as a function of rotation speed (N, in min^{-1}) by the Eq. (2):

$$T = g + h \cdot N \quad (2)$$

where g (N mm) and h (N mm min) are directly proportional to the yield stress and plastic viscosity, respectively.

Mortars were submitted at 5 min intervals to a constant rotation speed in the rheometer (80 rpm) during 50 s and, after this period, speed was brought to zero during 10 s. It is during this decreasing speed period that the plastic viscosity (h) and yield stress (g) were determined. The flow curves were defined according to the Bingham model (Eq. (2)) in which g and h were obtained using the down curve, since it assures a stable behavior, while the upper curve exhibited a more irregular behavior, being affected by the preceding resting period where some restructuring exists [24].

The flow table test (Fig. 2b) was conducted after mechanical mixing, corresponding to the initial testing time for rheological measurements, and following EN 1015-3 [25].

Table 1
Chemical composition of Portland cement CEM I – 42.5R.

Component (in wt.%)	Portland cement
SiO_2	20.37
CaO	63.05
Al_2O_3	4.78
Fe_2O_3	2.96
SO_3	3.70
MgO	2.02
Cl^-	0.018
K_2O	–
Loss on ignition	2.37

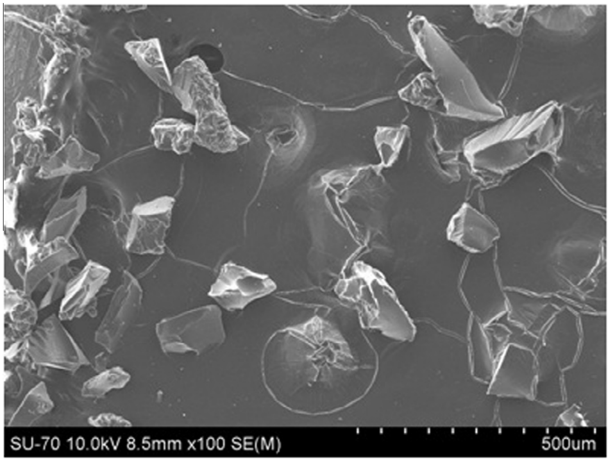

Fig. 1. SEM image showing the shape of dry SAP particles.

2.4. Moisture buffering capacity

The moisture buffering value (MBV) was determined through the Nordtest method [17,26,27], by using a climate chamber (Aralab, model Fitoclima300 EDTU). The weight variation of cylindrical samples (Ø = 120 mm and h = 20 mm) was continuously recorded upon moisture cyclic variation (Fig. 4). A digital analytical balance with 0.1 g accuracy was used and the humidity level in the chamber changed between 33% (16 h) and 75% (8 h) establishing 5 repeated cycles of 24 h (Fig. 4). The temperature remained constant (23 °C) and the MBV was calculated by the Eq. (3):

$$\mathrm{MBV} = \frac{\Delta m}{A \cdot \Delta\%\mathrm{RH}} \quad (3)$$

where Δm is the weight variation, A is the exposed surface of the sample and $\Delta\%$RH the amplitude of the humidity variation.

2.5. Testing procedures

This experimental research aimed first to follow up the rheological behavior over time of mortars containing different dosages of superabsorbent polymer (SAP) and/or distinct water/binder (W/B) ratios. For that purpose, the workability was determined from rheological and flow table measurements (Fig. 2). Three experimental plans were applied (Table 2). The first experimental program followed a factorial design of experiments to estimate the individual and interactive effects of SAP and W/B parameters. The models describe the effect of such additives on the relevant properties. Keeping unchanged other non-studied variables (the basic requirement of DoE), generated mortars that are comparable to the SAP-free ones. However, the strong impact of SAP particles on the workability reduced the maximum dosage of SAP in the mixtures. To overcome this adverse situation, a second experimental plan was set to adjust the workability of SAP-free mortars to the same level shown by 0.3SAP-containing formulations (maximum dosage), defined in the experimental plan 1. To complement the experiments, a third experimental plan was also carried out to evaluate mortars with 0.45 to 0.9SAP particles. In this case,