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# Rheological and thermal properties of aerated sprayed mortar

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## HIGHLIGHTS

- Shootability of aerated cement paste was studied.
- Additions were used to study influence in rheological properties.
- Sepiolite and metakaolin additions increase yield stress and water retention.
- Thermal conductivity of hardened pastes was tested.
- Additions used provide the largest expansion speed increase.

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## ABSTRACT

This paper studies the rheological properties in aerated cement pastes in order to develop an aerated sprayed mortar with low thermal conductivity. For this purpose, different mixtures of cement with additions of metakaolin (MK) and sepiolite (SP) were tested. In addition, influence of yield stress on build-up thickness, as well as expansion speed and pore network were studied using cement pastes aerated with aluminum powder. At the same time, the volume increase during expansion, water retention and yield stress of the fresh foamed cement pastes were studied to characterize the fresh mortar. Results obtained show that the incorporation of siliceous fly ashes (SFA) in ordinary Portland cement together with additions of MK or/and SP provided the largest expansion speed increase and the lowest density of the aerated mortar. Pastes with greater yield stress show higher thermal conductivity but are better to be pneumatically gunited due to its bigger build up thickness. The most suitable paste from all them was selected, sprayed and aerated over ceramic bricks, checking the results on site. Results obtained by means of these tests confirm that is possible to spray an aerated mortar over vertical surfaces. In addition, this mortar has acceptable thermal insulation properties to be used in chambers of building façades and for external wall thermal insulation systems (EWIS).



## 1. Introduction

Insulation products used in the cladding system and extensive cavities of external wall construction should have a small combustibility limit to prevent fire from spreading up through the outer face of the building.

Spray foams are easy and fast to install, leaving no bypasses or air pockets. Polyurethane is the most common type of spray foam insulation, but its compounds break up in case of fire, leading to much larger emissions of isocyanates – a highly toxic substance [1,2]. The strong toxicity by inhalation of polyurethane combustion and decomposition products released, makes these materials not recommended to be used in vent chambers.

Cementitious foams are nonflammable and incombustible, it makes no contribution to combustion; moreover, in the event of fire, there is no risk of the emission of toxic fumes due to the presence of synthetic insulation compounds. Air can be incorporated in cement paste with a preformed protein foam, but this foam has a strong plasticising effect, making foamed concrete to be self-compacting. Therefore, it cannot be sprayed over vertical surfaces without using chicken wire meshes.

Aerated concrete is a lightweight concrete where air is produced by an aerating agent producing air entrapped in the mortar matrix.

This research focuses on an aerated cement paste which can be sprayed replacing polymeric foams in vent chambers and mortars

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with lightweight aggregates in external wall thermal insulation systems (EWIS).

Shotcrete is a special process using compressed air to shoot concrete or mortar at high speed onto a surface. The process can be performed with a wet-mix or a dry-mix, depending on whether water is added in the nozzle,--dry-mix-- or in the concrete mixer, --wet-mix. In order to use fresh concrete as shotcrete, properties such as pumpability or shootability need to be assessed.

Pumpability of a wet-mix process shotcrete depends on the mobility and stability of the paste under pressure within a pipe. Shootability is the ability of concrete to be shot and it is estimated by rebound performance and build-up thickness.

Alkali activated cement based materials have been foamed with hydrogen peroxide [3], with aluminum powder [4] and photocatalytic geopolimers with silicon powder [5]. The novelty of this research is the spray application of a cement paste aerated with aluminum powder. To this end, this work analyzes the effect of yield stress in aerated shotcrete to develop an insulating pumpable and sprayable mortar aerated with aluminum powder. Additions used to modify the yield stress have been fly ash, sepiolite and metakaolin. Calcium aluminate cement was used to speed up the setting, reducing the waiting time to apply the next layer and the risk of slipping down.

Metakaolin (MK) is a pozzolanic material, obtained by dehydroxylation of the kaolinite clay mineral with a very reactive amorphous state that accelerates the reactivity of Al in water [6].

Sepiolite (SP) is a nanoclay with structural cavities that increase the ability to interact with many compounds forming nanostructured materials [7]. SP is a magnesium silicate, and the presence of small amounts of MgO in water, produces a great acceleration of the hydration of Al powder, owed to the existence of $Mg^{+}$ ions [8].

Sepiolite and metakaolin addition in aerated cement pastes, act as a catalyst for the reaction between aluminum powder and water producing $H_2$ gas [9].

This research work is the follow up of a project where the aerating process of cement pastes by means of aluminum powder was studied in relation to different additions, as well as their influence on the microstructure, rheological and thermal behavior [9,7]. As a result of this study, a doctoral dissertation and a patent [8] have been developed.

So far, no studies relating the theoretical processes of flowability and thickness of a fresh mass developed in the laboratory with the shootability of aerated pastes as render have been previously reported.

## 2. Materials and methodology

### 2.1. Raw materials

#### 2.1.1. Binders and additions

Cements used in this research were Calcium Aluminate Cement (CAC) from Kerneos Aluminates (France), White Portland Cement (WPC) and Ordinary Portland Cement with Fly Ash (OPC), (designated as BL II 52,5 R and CEM II A/V 42,5 R respectively, according to the European Standard UNE-EN 197-1), both from Tudela Veguin (Spain).

The aerial binder used was high calcium lime (CH), (classified as CL-90-S according to the European Standard ENV 459-1) from Calcasa (Madrid). See Table 1 for chemical composition.

Pozzolanic material used was metakaolin (MK) from Grace, S.A. As viscosity modifiers, dry micronized sepiolite (SP) Pansil from Tolsa, S. L. (Madrid) were also used. See Table 1 for chemical composition.

### 2.2. Experimental techniques

The purpose of this research work was to analyze the effect of a cement selection and the addition of MK and SP in the build-up thickness and thermal properties of aerated concrete. To this end, the main interest of this research lays in the study of properties of fresh and hardened mortar.

#### 2.2.1. Pastes preparation

Two reference pastes were designed, the first one with WPC/CAC/CH with a 5:1:4 ratio, and the second one with OPC/CH with a 4:1 ratio. All mixes have 0.8% aluminum powder content. Water proportion is considered by weight with a water/powder ratio of 0.8 in all pastes. Mixing proportions of this research are given in Table 2. Pastes were mixed with a mechanical kneading machine.

#### 2.2.2. Yield stress of the pastes

The yield stress was calculated with a slump method. According to Murata [10], a slump test is the measurement of the amount of the final deformation of concrete due to its own weight. Yield stress ($\tau_0$) is:

$$\tau_0 = \frac{W_X}{2 \cdot \pi \cdot R^2} \quad (1)$$

where:

$W_x$, is the dead weight of cement paste in the cone.
R, is the radius of the spread paste.

Pastes were poured into a truncated cone cast ($D_1$ = 100 mm, $D_2$ = 70 mm, h = 60 mm). Fresh paste was rodded ten times before unmolding. Aluminum powder was removed from the mixture to avoid the expansion effect throughout the test. Two perpendicular spread diameters were recorded, and this procedure was repeated every five minutes.

#### 2.2.3. Water retention of the paste

Water retention of the pastes without aluminum powder was tested according to European Standard UNE-EN 83-816-93. Freshly-mixed pastes were poured 10 min after blending into a cylindrical mold (D = 70 mm, h = 2 cm) forming the testing samples. Under each specimen, a cotton gauze over two absorbent papers was placed, thereby, establishing an absorbing layer. Water retention capacity was characterized by the mass of water retained after the capillarity action of this absorbing layer.

#### 2.2.4. Gas produced during expansion

To measure the gas produced during the expansion, an adiabatic box built for the experiment with expanded polystyrene walls was used. 300 $cm^3$ of paste were poured in $10 \times 10 \times 10$ $cm^3$ polyethylene molds placed inside the adiabatic box (see Fig. 1). Gas produced was determined by both, fresh cement paste density and volume increase. The latter was measured with a vertical scale marked in the mold.

#### 2.2.5. Density and porosity

Archimedes method was used to calculate the bulk density: samples of $50 \times 50 \times 50$ $mm^3$ were weighed after drying for 24 h in a heater at 105 °C, then, samples were fully saturated with water in a vacuum chamber equipped with precision instruments that supplied subatmospheric pressures between 380 and 450 mmHg and finally immersed in water. Le Chatelier flasks, 80 g each, were used to calculate density of the solid of crushed samples.

#### 2.2.6. Thermal properties

The heat transfer coefficient was obtained with a hot box, quantifying the total heat flow through the material. The heat source was a 100 W bulb and an internal thermal probe connected to a thermal regulator thermostat inside the box. When the heat flow remains stationary, the temperature is measured inside the box, on the inner side of the board to be tested, at the contact surface of the board and the EPS, on the outer face of the EPS and the room temperature. The heat flow was calculated using an insulation material of known conductivity (expanded polystyrene, EPS) applying Fourier's Law, and this value was then used to calculate the U-value of the material [11].

#### 2.2.7. Shootability

A fresh batch of WPC/CAC/CH/MK-10/H-80 was sprayed through a gas-powered airpress-sprayer, manufactured by Graco TM, model GMAX 5900HD (see Fig. 2). This sprayer has a pressure control which supplies a constant pressure during concrete shooting, avoiding any fluctuation in the flow. In our case, the air pressure of the machine was 14 bar. The delivery rating was of 6.06 liters per minute, and the gun used had a 1.09 mm tip.

The fresh mass was sprayed over the dry surface of several ceramic bricks in a vertical position, as can be observed in Fig. 3. As the pressure of the spraying was high, the width obtained was limited to 12–15 mm, because the fresh mass was pushed away when a new layer was applied. The average distance for spraying the fresh mass was 1–1,5 meter from the application surface.

Samples were stored in a vertical position for another 24 h and afterwards, the samples were cut into smaller samples to evaluate the final width of the hardened mortar. Some samples were coated with a sand/cement mortar as render.