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Correlation between mortar and concrete behavior using rheological analysis

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ABSTRACT

Rheological behavior of concrete is closely related to the rheology of its mortar. This paper aims to study the relation between the rheological parameters of mortars and its corresponding concretes. The correlation between the compressive strength of mortars and the corresponding concretes is also considered.

Workability of mortars and concretes, prepared with different amounts of metakaolin and diatomite, were controlled either with water or a water reducing admixture. A direct relationship was observed between the rheological parameters of mortars and its corresponding concretes. Formulations with metakaolin show a linear correlation between the mortars and the corresponding concretes compressive strength. Values of the mortars's compressive strength was 84% of the ones of corresponding concretes. Although without a linear correlation, in compositions with diatomite where the workability adjustment was done with a water reducing agent, the values of mortars's compressive strength were also 85% of the values of corresponding concretes.

1. Introduction

Mortars and concretes generally show in the fresh state Bingham behavior, characterized by a yield stress and a plastic viscosity. The behavior of mortar and concrete, when subjected to a shear action (rotation), can be described by the equation $T=g+hN$, where T is the torque, N is the speed, and g and h are rheological parameters coefficients, proportional to the yield stress and plastic viscosity, respectively [1,2].

The pozzolanic materials, very fine, may partially replace cement on mortars and concretes. The main components in pozzolan are amorphous silica and alumina which, in the presence of water reacts with the calcium hydroxide ($Ca(OH)_2$), forming compounds with cementitious properties. The pozzolanic materials with alumina in their composition, very reactive, during the pozzolanic reaction produce aluminosilicate, such as in cements. The effectiveness of a pozzolanic material depends on its pozzolanic reactivity, which include two factors (i) the maximum amount of calcium hydroxide that reacts with the pozzolan and (ii) pozzolanic speed reaction [3]. A study of metakaolin influence in the properties of mortars and concretes shows that there are several advantages namely the improvement of flexural strength and compression, reducing the permeability, increasing durability, reducing the effects of alkali–silica reaction, reduction of shrinkage of the concrete, increased density due to better particle packing [4].

According to Spoon et al. [5] when replacing cement with metakaolin, it appears that the use of pozzolanic material leads to improvements in the behavior of mortars and concretes. This beneficial effect is due mainly to the metakaolin high pozzolanic reactivity; it reacts rapidly and extensively with calcium hydroxide, resulting from hydration of cement, and accelerates the cement hydration reaction. The reaction of the metakaolin with calcium hydroxide to form additional cementitious material promotes a reduction in the calcium hydroxide content, which improve the resistance to chemical attack and decrease the alkali–silica reactions. The formed calcium silicate hydrate promote a refinement of the porosity which can justify the improvements in mechanical strength, decrease in water absorption by capillarity, the improvement of resistance to chemical attack and increased durability.

Degirmenci [6] studied the effect of introduction of diatomite in cement mortar as partial substitute using replacement levels of 5%, 10% and 15% diatomite, keeping constant the amount of water. The mechanical strength of mortars decreased with increasing content of diatomite. However, the compositions with 10–15% diatomite, showed greater resistance to freeze–thaw cycles. The water absorption of the mortar decreased with the increase in diatomite content except for the composition with 15% diatomite,

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considering that the diatomite natural porosity is the main reason for this behavior. The pozzolanic and hydraulic activity of siliceous mineral additions depend much of its crystalline / amorphous nature and also on their size and particle shape. The study of diatomite as a partial cement replacement is still new; some authors demonstrated that their use in the production of mortar and concrete did not improve their mechanical properties [6,7]. One of the disadvantages of the use of diatomite in the production of mortar and concrete is the need for a very high amount of water which promotes a reduction in the mechanical strength [8,9].

The pozzolans particle size is very important because fine particles have greater pozzolanic reactivity. However, Bouzoubaâ et al. [10] and Felekoğlu et al. [11] have reported the effect of grinding on the physical properties of the fly ash and concluded that the highest compressive strength depends on the fly ash fineness but, increasing the fineness, greater amount of water is needed. This fact implies that for a constant workability, there is an optimum particle size as a function of water content.

The properties of fresh cementitious materials affect their properties in the hardened state. The impact on the quality of application and on the durability of construction materials, such as concrete and mortars, needs a deeper understanding of this correlation. Several studies [12–15] have demonstrated that the rheological behavior of concrete is closely related to the rheology of its mortar. Mortars with higher fluidity promote fluid concretes. Therefore, the rheology evaluation of the concrete's mortar seems an adequate way to predict the rheological behavior of a concrete. On the other hand, the factors with greatest impact on the rheology of the mortar are the water content, packing density and the solid surface area [16]. Rubio-Hernández et al. [17] have also attempted the correlation between the concrete rheology and the corresponding mortar rheology by measuring the latter.

Due the fact that the characteristics of the mortar in the fresh state affect the properties of fresh concrete, which in turn, determine the material properties in the hardened state, the aim of this work was to study the rheological behavior of related mortars and concretes using specific rheometers for these materials and establish a correlation between the results of rheometry of mortars and concretes containing pozzolans, namely, a metakaolin and a diatomite. In addition to rheological correlation it is also aimed to obtain a correlation between the compressive strength of mortars and its corresponding concretes. This correlation is also expected to be important for the understanding of the dependence of the fresh and hardened state properties of mortars and corresponding concretes.

2. Materials and methods

2.1. Materials characterization

In this study, the formulation for the reference or base concrete mixture was determined using the Faury method [18]. The standard concrete, or base concrete (B_0.6W) constitution involves Portland cement (CEM type I 42.5R) as a binder, a siliceous natural sand (S) and two types of crushed limestone as aggregate (B1 and B2), the particle size distributions of which are presented in Table 1. Sand, aggregate B1 and aggregate B2 specific gravity is 2.60, 2.62 and 2.62 respectively.

Table1
Aggregate particle size distribution.

Sieve size (mm)	**S** (Cumulative % passing)	**B1** (Cumulative % passing)	**B2** (Cumulative % passing)
31.5	100.0	100.0	100.0
16	100.0	100.0	100.0
8	100.0	100.0	24.5
4	100.0	59.9	0.6
2	99.8	12.2	0.5
1	98.8	4.9	0.5
0.500	82.9	3.8	0.5
0.250	19.4	3.3	0.5
0.125	1.3	0.9	0.4
0.063	0.5	0.3	0.0

Two pozzolans, physically and chemically different (metakaolin and diatomite), were used as a partial cement substitute. Metakaolin (MK) is an artificial pozzolan that results from clay calcination. In addition to silica fume and fly ash, metakaolin (MK) is the most widely studied pozzolanic material. Sabir and Arikan [19,20] consider that the calcination temperature of the clay rich in kaolinite affects the pozzolanic reactivity of the resulting product (metakaolin). Metakaolin is an amorphous non-crystallized material, constituted of lamellar particles, which result from the clay calcination process above 600 °C.

Diatomite (D) is a natural material from a sedimentary rock, formed mainly by the deposition of microscopic organisms with a crystalline and amorphous silica shell [6]. Diatomite can be used as a pozzolan, directly after milling or after a heat treatment at about 1000 °C followed by grinding. The diatomite subjected to thermal treatment shows an increase in the content of amorphous silica and has a smaller particle size after grinding. The diatomite calcination burns the organic material, which facilitates its use as a partial substitute for cement [8]. Table 2 presents the cement, metakaolin and diatomite chemical analysis. The X-ray diffraction (XRD) was also performed and the cement presents as major elements tricalcium silicate (C3S) and dicalcium silicate (C_2S). As minor elements also shows tricalcium aluminate (C3A) and tetracalcium aluminoferrate (C_4AF). The other XRD peaks are related to anhydrous compounds and gypsum, present in the composition of the used Portland cement (type I). The diffraction pattern of metakaolin is essentially amorphous but presents some crystalline silica and a clay mineral (muscovite), which is an aluminosilicate (Fig 1). Regarding XRD analysis of the diatomite, it was essentially amorphous but with some crystalline peaks of quartz, calcite and aragonite (Fig. 2).

The surface area determination was made using the BET method (Micromeritics brand, model Gemini 2380) [21]. The cement presents a surface area of 0.35 m^2/g, the metakaolin presents a surface area of 16.18 m^2/g and the diatomite presents a surface area of 8.90 m^2/g.

Cement, metakaolin and diatomite specific gravity is 3.06, 2.44 and 2.24, respectively. The water reducer admixture (WR) is a commercial product (BASF) based in polycarboxylic acid, with a density between 0.67 and 1.1 and a solid content between 28.5% and 31.5%.

2.2. Fresh state characterization

2.2.1. Mortar and concrete compositions

A concrete with 350 kg of cement per m^3 of concrete and having a water/cement ratio of 0.6 was used as the reference sample. The maximum aggregate size used was limited by the concrete rheometer (16 mm).

Table 3 shows the fundamental formulation for 1 m^3 of base concrete and the formulation in terms of weight percentage for the solid components; while the water/cement ratio is always kept at 0.6. This ratio was set to obtain a concrete inside the workability desired range of 8–10 cm (slump). This chosen slump (8–10 cm) is due to the fact that it was desired to produce concretes with very similar workabilitiy.

For the base mortar (A_0.6W), the formulation was determined by the ratio of cement and sand in the composition of the base