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Evaluation of rheological parameters of mortar containing various amounts of mineral addition with polycarboxylate superplasticizer

M'hamed Adjoudj [a,b,c,*], Karim Ezziane [b], El Hadj Kadri [c], Tien-Tung Ngo [c], Abdelhak Kaci [c]

[a] University of Tissemsilt, 38000 Tissemsilt, Algeria
[b] Laboratory Geomaterials, University Hassiba Benbouali, 02000 Chlef, Algeria
[c] Laboratory L2MGC, University of Cergy Pontoise, F9500 Cergy Pontoise, France

HIGHLIGHTS

- Natural pozzolan decreases slump of mortars and needs more superplasticizer dosage.
- Slag and limestone powder increase the workability at 10% of replacement rate.
- BFS and LP decrease the viscosity of mortars even without superplasticizer.
- The new relationship predicts the rheological parameters with a high correlation.

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ABSTRACT

The presented study explores the effect of limestone powder (LP), finely blast furnace slag (BFS) and natural pozzolan (NP) on mortar rheology and the interaction of these additions with polycarboxylic-based superplasticizer (PC). It was found that LP and BFS are more effective than NP. The viscosity and yield stress of mortar are obviously decreased with increasing dosage of PC. PC superplasticizer loses its positive effect where NP is added and becomes more effective with LP and BSF. Mathematical relationship is proposed to express the variation of each rheological parameter which provides a more convenient prediction with an acceptable accuracy.

1. Introduction

Currently, it is necessary to reduce the amount of mixing water to improve rheological and mechanical performances of mortar and concrete. This requires the use of superplasticizers that reduce significantly the amount of water (30% or more) necessary to obtain acceptable rheological properties which promote well concreting. Adding superplasticizer in such systems reduces the yield stress value, the plastic viscosity and the thixotropy of the materials [1,2]. The action mechanism of these molecules has been studied by many researchers [3–5]. When cement grains are in contact with water, superplasticizer is involved in the saturation surface charges as well as other ions present in the solution [6]. Superplasticizer molecules are fixed by adsorption on the interface between cement grains and mixing water. Once adsorbed, they form a negative charge around each cement grain and generate electrostatic repulsion between the adjacent cement grains leading to particles dispersion [7]. In addition, the steric effect appears when the adsorbed molecules form a multilayer structure around the cement particles as long as they are not physically close to one another [8]. The efficiency of superplasticizer depends on its molecular weight [9,10], its concentration [4], its density charge [11], its structure [12], the type of cement [13], the W/C ratio and the presence of mineral additions [2]. The incorporation of mineral additions causes changes in the granular distribution, an appearance of new nucleation sites and a new activity of surface grains. Gallias et al. [14] showed that the reduction in water demand in mortars increases with increasing superplasticizer dosage regardless of the mineral additions used. Uchikawa et al. [12]

* Corresponding author. Address: Department of Civil Engineering, Hassiba Benbouali Chlef University, BP 151, 02000 Chlef, Algeria. Tel.: +213 27 72 23 85; fax: +213 27 72 17 94.
E-mail address: adjoudj@hotmail.fr (M. Adjoudj).

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concluded that the addition of superplasticizer based on naphthalene produces a very large dispersion in the aqueous solution of all the cement particles and the mineral additions disperse well in the cement paste.

The effect of mineral additions on the rheological properties of cement pastes was studied by Zhang and Han [15] where the yield stress increased with the ultrafine addition content and the plastic viscosity varied with the nature and the amount of the addition. Similarly, the effect of mineral additions on superplasticizer demand depends primarily on the amount and the fineness of the addition, regardless of the cement type [16].

The limestone powder seems to have little effect on water demand and can lead to a slight decrease in the viscosity of the cement mixture [14,15]. This may justify the use of this addition to high content in the formulation of self compacting concrete. However, several authors [15,17] have observed that for a constant cement content (or constant W/C ratio), the addition of limestone powder helps to reduce the viscosity of cement paste before causing an increase in viscosity when the content exceeds a certain critical value which depends on W/C ratio. Also, El Hilali [18] noted that the fine limestone powder has a significant influence on the amount of water needed to fill the voids in the cement paste. Also, it was shown that self-compacting paste viscosity decreases slightly with increasing fineness of limestone additions, implying a reduction in the yield stress of cement pastes [18].

Blast furnace slag has an interesting characteristic as mineral addition [19] especially in relation to the consistency of its chemical composition. In lightweight concrete, Shafigh et al. [20] reported that 30% of replacement cement by BFS increased the workability of concrete. The same observation was made by Boukendakdji et al. [21] where the addition of BFS by substitution to cement was found to be very beneficial to fresh self-compacting concrete. An improvement of workability was observed, using up to 20% of slag content, with an optimum content of 15%. Park et al. [22] observed that the replacement of part of cement with BFS generally reduces the yield stress and the viscosity of the cement paste. Also, the increase of slag content with smaller fine fraction portion leads to a decrease of yield stress value and plastic viscosity of the pastes [23]. Some researchers [24,25] found that the rheological parameters, the yield stress value and the plastic viscosity can increase or decrease with slag additions; this depends on the relation between the fineness of cement and BFS. Shi et al. [24] showed that BFS adsorbs superplasticizer, causing a greater demand for superplasticizer to obtain the same flow or the same threshold yield stress value. Moreover, the presence of superplasticizer causes a lower plastic viscosity of slag cement pastes; because of bigger fine particles content in cement (20 μm below) [23].

According to Şahmaran et al. [26] results, the addition of natural zeolite modifies both rheological and workability properties of grouts. For constant superplasticizer (SP) content, an increase in the zeolite amount significantly increases the yield stress and the plastic viscosity. Moreover, an increase in the amount of SP causes a significant reduction in both yield stress and plastic viscosity of the grouts. The same observation was made by Chan et al. [27] in which the replacement of 5–15% of cement by zeolite, can slightly increase the viscosity of fresh concrete. Many researchers [27–30] confirmed that the higher the replacement of cement by natural zeolite, the more the superplasticizer was required to maintain consistency, which can be attributed to the large amount of pores in its frame structure and high surface area. Therefore, using more natural zeolite leads to increase the viscosity of fresh concrete.

When mineral addition with a wide particle size distribution is used in cement, small particles fill the pores, thus, increasing the packing density while decreasing the retention water, and increasing the free water relating to the fluidity of cement pastes. In case of a narrow particle size distribution, the pore between particles is bigger, thus, having more retention water and decreasing fluidity [31,32]. Both yield stress and viscosity are strongly dependent on the particle characteristics of the mineral additions used. It was found that particles sizes distribution, particle densities and particle surface areas are critical parameters influencing rheological response [33]. Yield stress is dominated by the particle density of the cement component but viscosity is influenced by both particle surface area and total particle density [33].

The objective of this work is to evaluate the interaction between polycarboxylate superplasticizer (PC) and mineral additions (MA) on the rheological proprieties of mortars. Tests on mortars are simple and very useful for predicting the behavior of fresh and hardened concrete. The rheological parameters of mortars are investigated using rheometer apparatus and mini cone test for several mixtures. The obtained results are used to identify a new relationship giving the rheological parameters of mortar according to mineral additions content and superplasticizer dosage.

2. Experimental program

2.1. Materials

Ordinary Portland cement (OPC) was used for all the mixtures and its chemical composition and physical properties are given in Table 1. The sand used in the mortars mixture is standard sand for cement mortar according to NF P 15-403 [34]. The mineral additions used are limestone powder (LP), finely blast furnace slag (BFS) and natural pozzolan (NP). The chemical compositions and physical properties of these mineral additions are summarized in Table 1. The particles size distribution of these materials which were obtained using a laser scattering technique, are given in Fig. 1. A polycarboxylic-based superplasticizer (SP) was used in all mixtures with a specific gravity of 1.07, a solid content of 30% and a pH of 7.

2.2. Mixture proportions

Several mixes were performed incorporating different replacement levels of limestone powder (LP), finely blast furnace slag (BFS) and natural pozzolan (NP) (0–30% weight of cement), in order to evaluate and compare their effect on rheological properties of mortars. A W/C ratio of 0.55 is used. This value was chosen after making several mixes with different W/C and cementitious materials contents. Various dosages of superplasticizer were used in the range of 0%, 0.2%, and, 0.4%. Thus, there were a total of 30 distinct mortars mixtures as shown in Table 2. The whole samples preparation and testing procedures were carried out in a laboratory at a temperature maintained at 20 ± 2 °C.

2.3. Mixing procedure

The pastes were made in Hobart type mixer with a capacity of 5 l, and using two different speeds (low and high). The procedure used in all tests was as follows: a dry cement, mineral addition and sand were firstly mixed at low speed for 1 min, then 2/3 part of mixing water were added and the paste was mixed for 2 more minutes at low speed; finally, 1/3 part of water and superplasticizer were added and the paste was mixed for 2 more minutes at high speed. After mixing, the samples of mortars are subject to slump and rheological measurements.

Table 1
Chemical analysis and physical properties of cementitious materials used.

	OPC (%)	LP (%)	BFS (%)	NP (%)
SiO_2	19.8	2.5	34	46.4
Al_2O_3	5.14	0.6	12.4	17.5
Fe_2O_3	2.3	0.9	2.5	10.5
CaO	64.9	52.6	45	10.5
MgO	0.9	0.5	8.6	3.8
SO_3	3.4	–	0.097	0.4
K_2O	2.1	0.05	5.42	1.5
Na_2O	0.05	0.02	5.42	3.4
Blain fineness (cm^2/g)	4000	3400	3900	3200
C_3S	58	–	–	–
C_2S	13	–	–	–
C_3A	10	–	–	–
C_4AF	7	–	–	–