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Rheological properties of cementitious materials containing mineral admixtures

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Abstract

The rheological properties of cementitious materials containing fine particles, such as mineral admixtures (MA), were investigated using a Rotovisco RT 20 rheometer (Haake) with a cylindrical spindle. The mineral admixtures were finely ground blast furnace slag, fly ash and silica fume. The cementitious materials were designed as one, two and three components systems by replacement of ordinary portland cement (OPC) with these mineral admixtures. The rheological properties of one-component system (OPC) were improved with increasing the dosage of PNS-based superplasticizer. For two-components systems, yield stress and plastic viscosity decreased with replacing OPC with blast furnace slag (BFS) and fly ash (FA). In the case of OPC-silica fume (SF) system, yield stress and plastic viscosity steeply increased with increasing SF. For three components systems, both OPC-BFS-SF and OPC-FA-SF systems, the rheological properties improved, compared with the sample with SF. In the two and three components systems, the rheological properties of samples containing BFS improved much more than with FA replacement alone.

Keywords: Rheology; Workability; Granulated blast-furnace slag; Filler; Pozzolan

1. Introduction

Mineral admixtures (MA) have been used in order to increase strength and improve durability and flowability of cementitious material. Blast furnace slag (BFS), fly ash (FA) and silica fume (SF) are typical mineral admixtures for achieving these properties. These minerals significantly affect rheology of cementitous material in the fresh state, which is directly related with developing strength, durability and engineering properties of hardened structures. Generally ultra durable cement concrete structures with high strength are closely associated with densified microstructures which are strongly controlled by rheology properties in the fresh state of concrete.

Much research has been conducted for improving rheology properties and mechanical properties using various fine particles, and reported that BFS and FA could contribute to increase flowability in the fresh state, and densify microstructures and develop higher mechanical properties due to their latent hydraulic properties and pozzolanic reaction, respectively [1,2]. The silica fume, very fine particle—average particle size less than 1 ìm, was studied as a densifing additive for cementitious materials, and showed that the silica fume affected flowability in the fresh state of concrete and liberated much heat of hydration, resulting in causing drying shrinkage in the hardened state of structures [3].

Since these additive materials have their particular properties, rheological properties of cementitious materials should be controlled by mix design of admixtures. For the high performance concretes these mineral additives have been used for developing special performances, such as self compacting and leveling concrete, long-time workable concrete, low heat of hydration and high strength development concrete, high durability concrete, etc. [4,5].

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Table 1
Chemical compositions of the materials used in the study (wt.%)

Compositions	OPC[a]	BFS[b]	FA[c]	SF[d]
SiO_2	21.10	34.81	49.91	92.0
Al_2O_3	5.13	16.19	22.54	1.3
Fe_2O_3	3.30	0.47	11.37	2.4
CaO	62.51	41.25	5.84	–
MgO	2.72	8.05	1.25	0.4
SO_3	2.37	0.16	–	–
C	–	–	4.1	1.2
Na_2O_3	–	–	0.39	0.1
K_2O	–	–	0.87	1.2
Loss on ignition	1.39	0.32	0.5	–

[a] OPC: ordinary Portland cement.
[b] BFS: blast furnace slag.
[c] FA: fly ash.
[d] SF: silica fume.

As the rheology of cementitious material is closely related with developing performance of concrete, the rheology is considered one of the most important factors for the high performance concrete. For predicting concrete flowability many attempts have been carried out measuring rheological properties in the fresh state of cement paste and mortar, from conventional measurements, flow test and slump test, to more quantitative fundamental methodology, rheometer [5–9]. Recently the quantitative fundamental methodology, which was developed to assess the rheology of fluid state, has been used for analyzing cement paste and mortar. This method introduced rheological parameters, such as yield stress and plastic viscosity, for quantifying the flowability. Recent research indicated that the yield stress of cement paste showed the same trend of slump in concrete, and the plastic viscosity was associated with the stickness, placeability, pumpability, finishability and segregation in the concrete [10–12].

In this work, for developing macro-defect-free concrete highly compacted cementitious matrixes were developed using various kinds of mineral additives and investigated rheologically. The cementitious materials were prepared with OPC, two and three components systems (OPC-MAs). In order to analyze rheological properties of cementitious materials the parameters of rheology were measured and investigated. In addition, the effects of each mineral additive on the flowability of cementitious paste were discussed.

2. Experimental

2.1. Materials

Ordinary Portland cement (OPC) and mineral admixtures (MAs) were used as binder components. OPC with Blaine specific surface area 3290 cm^2/g and three types of MAs, finely ground blast furnace slag (BFS) with 5962 cm^2/g, Fly ash (FA) with 3650 cm^2/g and very fine Silica fume (SF) with 200,620 cm^2/g were used. As a superplasticizer (SP), commercial polynaphtalene sulfonate (PNS)-based product (PNS, 40% solids) was used during the mix.

The chemical compositions of OPC and MAs, and the physical properties of used materials are given in Tables 1 and 2, respectively.

2.2. Mix design

Cementitious pastes were designed as one component (OPC), two-components and three-components with replacing OPC with MAs. The mix designs in the study are shown Fig. 1, and the mix proportions of specimens are listed in Table 3. For preparing pastes the ratio of water to binder and the dosage of SP were fixed as 0.35 and 2.0 wt.% of binder (OPC+MA), respectively.

2.3. Test apparatus

Rheological properties were measured using Rotovisco RT 20 rheometer (Haake) having a cylindrical serrated spindle, which is able to plot the continuous rheological curve of paste from the relationship between shear rate and shear stress at physically defined condition. The plastic viscosity η_{pl} and the yield stress τ_o were calculated as

Table 2
Physical properties of the materials used in the study

	OPC	BFS	FA	SF
(a) Properties of binders				
Density (g/cm^3)	3.15	2.91	2.25	2.20
Specific surface area (cm^2/g)	3290	5962	3650	200,620
Mean particle diameter (μm)	18.07	8.07	19.56	0.1
Particle shape	Angular	Round edges cubic	Spherical	Spherical
(b) Properties of superplasticizer				
Main ingredient	Polynaphtalene sulfonate based (PNS)			
Color	Dark brown			
Specific gravity (20 °C) (g/cm^3)	1.3±0.05			
pH	8–9			
Solid content (%)	40±2			