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Influence of silica fume and viscosity modifying agent on the mechanical and rheological behavior of self compacting concrete

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HIGHLIGHTS

- Characterization of the effect of VMA and silica fume on the behavior of SCC.
- The role of the VMA and silica fume for the stability and robustness of SCC.
- VMA and SF influence rheology (stability, filling capacity...) in a very similar way.
- Possibility of replacing the VMA by the silica fume and vice versa.

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ABSTRACT

The apparition of a wide generation of mineral powders industrially mastered (like silica fume and limestone filler) and organic products (particularly the superplasticizers and viscosity modifying agent) increases significantly the range of concrete rheological performance.

This experimental study is built around the characterization of the effect of viscosity modifying agent (VMA) and silica fume on the rheological and mechanical properties of self compacting concrete. The aim is to find the percentage of silica fume and of VMA that allow to obtain the same mechanical and rheological characteristics. The used rheological tests are the slump flow, V-funnel, L-Box, sieve segregation test, and measurement of the yield stress and viscosity. The mechanical tests are the compressive strength, flexural strength and modulus of elasticity.

In this study, we show the role of the VMA and silica fume for the stability and robustness of the concrete. Our experimental results show that, depending on the availability of materials, we can replace the viscosity modifying agent by silica fume and vice versa.

1. Introduction

The concrete is a material undergoing a complete revolution. Since its inception, major progress has been made, particularly in the improvement of the concrete strength. Recently, other properties are considered essential, such as durability and workability. Examples of this development can be seen in [1–12]. Through this development, it is possible to obtain some predefined properties by adapting a certain composition of mixture.

Despite the interesting aspects that it presents, especially at fresh state, the self-compacting concrete (SCC) does not have the necessary and sufficient perspective to be accepted by all clients and project supervisors, and therefore reducing their dissemination. This concern about the use of SCC is caused by many problems encountered during the concrete formulating (for example, bleeding and segregation).

Several approaches have been used to develop the SCC. The objective of superplasticizers addition in the SCC is to increase the fluidity of concrete and to release, without affecting the mechanical strength, the water trapped between the grains. However, in some cases, the appearance of segregation that degrades the concrete quality can be observed. Hence, the use of VMA which allows, by making the mixture more stable and cohesive, to limit or eliminate the segregation is required. The VMA polymer chains are connected one to the other by the Van der Waals interaction effect up to the blocking of the free water movement. This mechanism leads to an increase in the mixture plastic viscosity.

Another approach is to significantly increase the amount of cement. However, this leads to a significant increase in the cost

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of material and also to problems of shrinkage due to the temperature rise during the cement hydration. It is therefore necessary to substitute a part of the cement with mineral additives (e.g. limestone filler and silica filler) in order to ensure a sustainable development of concrete. Silica fume reacts with the lime during the hydration of cement and promotes the formation of calcium silicate hydrates (C–S–H). This phase links the various components together allows to create a dense and compact cementitious matrix. The fineness and pozzolanic properties of the matrix give to the silica fume a high reactivity with the calcium hydroxide ($Ca(OH)_2$) produced during the hydration of cement which provides a very high compressive strength.

Concretes made with silica fume have a different rheology from currents concretes. They are thixotropic. At rest, they have a viscous and compact behavior. However, they become fluid once a pressure is applied on them. The viscosity increases with the concentration of silica fume. This feature provides an advantage by reducing the risk of the segregation appearance.

In order to replace VMA by silica fume and vice versa, the objective of this study is to examine the effects of VMA and silica fume on the rheological and mechanical properties of concretes. The rheological tests are carried out on SCC in the aim of finding the percentage of fume silica and VMA which gives the same viscosity value. Next, the effects on compressive strength, flexural strength and modulus of elasticity are studied in the aim of finding the percentage of fume silica and VMA which gives the same mechanical characteristics.

2. Experimental program

The experimental study was conducted in two parts. In the first part, rheological tests (slump flow, L-Box, V-funnel and sieve segregation) and the measurement of yield stress and plastic viscosity (by a rheometer) have been performed on various mixtures of SCC; in the second part, the mechanical characteristics of the specimens prepared from SCC mixtures were determined after 1,7 and 28 days of curing.

2.1. Materials

Ordinary Portland cement CEM I 52.5 R according to European Standard EN 197-1 was used as binder. The used viscosity modifying agent (VMA) is SIKA STABILIZER 400, marketed by Sika France. VMA was applied in combination with a polycarboxylate type superplasticizer (SP). The used SP is SIKA VISCOCRETE TEMPO 20, according to European Standard NF EN 934-2 and manufactured by Sika France. All dosages of liquid admixtures are referring to the aqueous solutions and not to the solid fraction. In this study, Silica fume (SF) Sikacrete HD, manufactured by Sika France, and Limestone Filler (LF), marketed by Carmeuse, were used as a partial replacement for cement. The chemical composition and physical properties of Portland cement and mineral admixtures are given in Table 1.

Local crushed sand, with a maximum size of 2 mm, (fineness modulus was 2.3, specific gravity of 2.65, water absorptions of 0.81% and sand equivalent was 72,5) and gravel, with a maximum size of 10 mm (specific gravity of 2.65, water absorptions of 1.4% and Los Angeles coefficient of 22) were used.

2.2. Mixture proportions

A total of 13 concrete mixtures were designed having water/binder (W/B) ratio equal to 0.37 and total materials content of 520 kg/m^3 (Cement = 350 kg/m^3 and LF = 170 kg/m^3). The control mixture included cement and limestone filler as the binder. The remaining mixtures incorporated ternary (CEM + LF + SF) cementitious blends in which a proportion of Portland cement was replaced with the mineral admixtures. The replacement levels for SF are 5%, 10%, 15%, 20%, 25% and 30%. The percentages of VMA replacements are 0.05%, 0.10%, 0.15%, 0.20%, 0.25% and 0.30% by weight of binder. For all concretes, superplasticizer content is kept constant at 0.45% by mass of binder. Concrete mixture proportions are summarized in Table 2 where the mixtures are designated according to the type and the amount of additions included.

2.3. Mixing and preparation of test specimens

To supply the same homogeneity and uniformity, the time of mixing process was kept constant in all mixtures. It starts by mixing, during 1 min, all of the aggregates (gravel and sand) and binder using a standard mixer of 40 L. Then, the mixing water was added and mixed for an additional minute. Thereafter, the SP was added and the concrete was mixed for an additional 3 min. In the case of mixtures with the VMA, this viscosity agent was added and the concrete was mixed for an additional 2 min.

After the mixing process was completed, tests were carried out on fresh concrete to evaluate the slump flow diameter, V-funnel flow time, filling capacity by L-Box test, resistance to segregation by sieve segregation test, yield stress and viscosity.

The 16 × 32 cm cylindrical samples were used to determine the compressive strengths after 1, 7 and 28 days of hardening. Moreover, these specimens at the age of 28 days were prepared for the evaluation of the flexural strength, the dry unit weight and the modulus of elasticity.

2.4. Test methods

The slump flow test for SCC is described by AFGC (French Association of Civil Engineering) and standard EFNARC [13,14]. In this test, a truncated cone mould was placed on a smooth plate, filled with concrete, and lifted upwards. The subsequent diameter of the concrete was measured in two perpendicular dimensions and the average was reported as the final diameter. The V-funnel flow test is also described by [13,14]. In this test, the funnel was filled completely with concrete and the bottom outlet is opened, allowing the concrete to flow out. The flow time (t), in seconds, in the V-funnel is the time calculated between the opening of the bottom outlet and when the light becomes visible from the bottom. The L-Box is used to assess the passing ability of the concrete in confined spaces and to check that placement of the concrete is not blocked by any obstructions. The box is placed on a horizontal base and the inside surface is moistened. The vertical part of the box is entirely filled with concrete. After any excess has been struck off, the concrete is left to stand for 1 min. When the concrete stops flowing, heights H1 and H2 are measured and the result is given as the passing ability PA = H2/H1 [13,14]. The aim of sieve segregation test is to determine the stability of a SCC mixture by placing a sample into a 5 mm sieve and then calculating the percentage which passes trough during a standard period of time [13,14]. Figs. 1–4 demonstrate the slump flow, V funnel flow, L-Box and sieve segregation tests, respectively.

Table 1
Chemical and physical proprieties of the used materials.

	CEM	LF	SF	SP	VMA
C_3S (%)	67	–	–	–	–
C_2S (%)	12	–	–	–	–
C_4AF (%)	9	–	–	–	–
C_3A (%)	9	–	–	–	–
SiO_2 (%)	20.5	–	85	–	–
Fe_2O_3 (%)	2.6	0.04	–	–	–
Al_2O_3 (%)	5.0	<0.4	–	–	–
CaO (%)	65.0	–	1.0	–	–
MgO (%)	1.1	–	–	–	–
SO_3 (%)	3.6	–	2.0	–	–
Loss on ignition (%)	1.2	43.10	4.0	–	–
NaO_2 eq. (%)	0.43	–	1.0	<1.5	<0.2
cl-	0.01	–	<0.1	<0.1	<0.1
Density	3.15	2.70	2.24	1.06	1.02
Blaine (cm^2/g)	4750	5550	2200	–	–
pH	–	–	–	6	8
Dry extract (%)	–	–	–	30	–

Table 2
Concrete mixture proportions.

Mixture codes	W/B (%)	SF (%)*	VMA (%)**	Binder (kg/m^3)	SP (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)
Control	0.37	0	0	520	7.8	890	900
SF5	0.37	5	0	520	7.8	890	900
SF10	0.37	10	0	520	7.8	890	900
SF15	0.37	15	0	520	7.8	890	900
SF20	0.37	20	0	520	7.8	890	900
SF25	0.37	25	0	520	7.8	890	900
SF30	0.37	30	0	520	7.8	890	900
VMA0.05	0.37	0	0.05	520	7.8	890	900
VMA0.10	0.37	0	0.10	520	7.8	890	900
VMA0.15	0.37	0	0.15	520	7.8	890	900
VMA0.20	0.37	0	0.20	520	7.8	890	900
VMA0.25	0.37	0	0.25	520	7.8	890	900
VMA0.30	0.37	0	0.30	520	7.8	890	900

* (%): Percentage by weight of cement.
** (%): Percentage by weight of binder.