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Influence of temperature on yield value of highly flowable micromortars made with sulfonate-based superplasticizers

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Abstract

Self-consolidating concretes (SCC) were proved to be very dependant on concreting temperature and the elapsed time. To enhance the concreting conditions of these flowable concretes, it is important to have a better knowledge of their rheological behavior, depending on the kind of superplasticizer used. The variation of the plastic viscosity and the yield value with the elapsed time and temperature must be accurately quantified. However, the methods of measuring these parameters are expensive and unsuitable with a good forecast of the material behavior due to numerous parameters that interact with each other. A simplest method to study the variation of these rheological parameters, depending on the mixture design, is proposed, using the micromortar, which derivates from the studied SCC. Moreover, to forecast the concrete behavior on the site, a simple thermodynamical approach of the cementitious matrix behavior through the study of the hydration kinetics is described.

Keywords: Temperature; Fresh concrete; High-range water reducers; Rheology; Calorimetry

1. Introduction

Organic admixtures, such as water and high-range water reducers (HRWR), are incorporated in the concrete to enhance its workability. They could either increase the strength by allowing a reduction in the water amount to be used or reduce water and cement contents for a given strength and workability.

An important class of those polymers is the polynaphtalene sulfonate (PNS), which, since 1938, has been known as cement-dispersing agents [1]. The benefit of synthetic polymers, such as PNS and polymelamine sulfonate (PMS), was developed further. But problems also appeared while using them at a high dosage to get either high-performances concrete for strength and durability or self-consolidating concrete (SCC) for workability. This problem is called cement–HRWR incompatibility, due mainly to the action of sulfonate groups within the hydration reaction and cementitious ionic matrix [2].

Although it is important to study cement–HRWR compatibility with sulfate concentration, it is not the only parameter that leads to abnormal behavior, such as delay or fast setting. Temperature also affects the level of incompatibility.

The influence of ambient temperature on the setting of cement is well documented [4]. It was found that high temperature accelerates the setting of cement, regardless of the presence of set retarder. It was also found that the use of silica fumes as a partial replacement of cement decelerates, in general, the setting of the paste; the higher this replacement is, the greater the effect becomes [5].

Temperature also influences rheology through various mechanisms. For mixtures made with PNS HRWR, adsorbed and residual polymer in the aqueous phase varies given the temperature of the fresh paste [6]. Nevertheless, the coupled effect of the HRWR, temperature and the elapsed time on highly flowable micromortars and SCC is not well documented.

The main objective of this study is to investigate the influence of temperature on the yield value τ_o of highly flowable mortar mixtures made with PNS and PMS HRWR. Moreover, studies are also conducted to point out the influence of the elapsed time on τ_o, from the batching up to the end of the dormant period. Furthermore, a simple thermodynamic approach is developed to explain the changes into the interstitial solution that lead to the evolution of τ_o with time and temperature.

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To complete the investigations and explain the thermodynamic changes in the cementitious matrix, conductivity and calorimetry measurements are conducted to evaluate the kinetics of formation of hydrates during the dormant period given the coupled effect of the HRWR and temperature variations.

2. Investigations

2.1. Research significance

The potential benefit of knowing the SCC's behavior depending on the HRWR used and the concreting temperature to enhance concreting conditions is not well documented, especially for a range of time as long as the dormant period. Neither is a thermodynamical approach of what is going on into the cement grout of the SCC.

This work proposes an easier method to study SCC through their micromortars. From the data presented, a thermodynamical approach of the material's behavior is proposed, which aims at highlighting the material's behavior through the explanation of the changes in its microstructure. It aims at doing the right choice of HRWR for each site through a better knowledge of the interactions between the HRWR, the concrete, temperature and time.

2.2. Scope of investigation

Micromortar mixtures investigated in this study derivate from commercially available SCC mixtures. For example, the first SCC, from which a complete series of highly flowable mortar is extracted, was used for the extension of Bethune's Hospital in Northern France. It was important to control the rheology of the SCC with variations in temperature because the site started in wintertime, and concreting was over at the beginning of the summer. Concrete was cast between temperatures of 5 and 30 °C. Moreover, it is also important to control rheology over transportation time because it can last up to 90 min. Consequently, a control of the rheology is essential for the SCC to completely fill the formwork and spread among reinforcing bars.

To be compatible with site conditions, a range of temperature from 10 to 32 °C was either chosen or given by Hydro-Quebec. To be sure that no heat was transferred from the mixer to the samples, temperature was taken after mixing and remixing.

The experimental program consisted of two phases. A total of 11 micromortars were tested.

The first phase concerned the investigation of the effect of temperature on the variations in yield value for a micromortar made from SCC used in light structures, like beams, with a water-to-binder ratio (W/B) of 0.52 (MB series). This high ratio is due to the fact that the specified compressive strength of the original SCC mixture was only 32 MPa because the concrete was used, complying with the French standard for ready-mix concrete NF P 18 305 and the European standard EN 206, in a nonaggressive environment. Consequently, and to be as close as possible to temperature conditions inside the formwork, isothermic calorimetry, which simulates conditions in light structure with a greater effectiveness than semiadiabatic calorimetry, was chosen [7].

Table 1
Summary of experimental program

Series	MB	MC	MD
Calorimetry	Isothermic	1/2 Adiabatic	1/2 Adiabatic
10 or 12 °C	X	X	
15 or 18 °C	X	X	X
20 or 23 °C	X	X	X
25 or 27 °C	X	X	
30 or 32 °C			X
Conductimetry		X	X
Temperature	X	X	X
Rheology with coaxial viscometer	X	X	X
Total of tested mixes	4	4	3

X refers to tested combinations.

The second phase was done on a different mixture design to validate the results found in the first phase. The selected SCC had a W/B of 0.42 and was proportioned with a ternary binder containing both silica fumes and fly ashes in addition to ordinary Portland cement (OPC). No air-entraining agent (AEA) or viscosity modifying admixture (VMA) was used to be as close as possible to the first mixture and to avoid any interaction between the HRWR and VMA polymers [6]. A polynaphtalene sulfonate HRWR was used for the MC series while MD micromortars were made with a polymelamine sulfonate HRWR to compare the effect of HRWR type on the performances of the micromortars. For this phase, semiadiabatic calorimetry [8,9] was chosen, knowing that temperature and heat curves can be correlated with isothermic results [7].

The variations of electrical conductivity with time were monitored to highlight the micromortar behavior through the analysis of the rate of ionic concentration.

As summarized in Table 1, for each five temperature regimes, the following measurements were determined:

– coaxial rheological test to monitor variations in yield value with time of the micromortars,
– either semiadiabatic or isothermic calorimetry, depending on the tested series,
– electrical conductivity,
– temperature rise.

3. Experiments

3.1. Materials and mixture proportioning

This investigation was undertaken on micromortars that constitute of liquid phase and solid particles finer than 315 μ.