Quality Control Parameters for on-site evaluation of pumped Self-Compacting Concrete

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ABSTRACT

An experimental study comprising laboratory and real scale tests was carried out to evaluate the usefulness of several pumping, early age and hardened parameters for pumped Self-Compacting Concrete (SCC) quality control. Two pumped SCC, with fly ash and limestone filler, were tested. Pumpability was controlled online by real-time measuring of pumping pressure and discharge rate. Temperature, capillary pressure, dimensional stability and P-wave ultrasonic pulse transmission (UPV) were measured simultaneously to monitor microstructure evolution at early age (EA). UPV (P- and S-waves) were also used as non-destructive testing method for hardened quality control. Pumping reduced compressive strength between 12 and 16% and changed air permeability, although did not modify porosity accessible to water. These Quality Control Parameters (QCP) showed their ability to detect the changes on material’s pumping, EA and hardened performance. Accordingly, they can be used to establish acceptance limits and to identify potential issues arising from undesired changes in material’s properties.

1. Introduction

As many advanced cement-based materials, Self-Compacting Concretes (SCC) are meant to improve cast-in-place performance and speed-up on-site working, considering material’s performance (self-compactability in this case) rather than material’s composition. To achieve a low yield stress in the fresh state without segregation, SCC are designed increasing the amount of paste [1]. Subsequently, SCC is characterized by the use of large amounts of fine particles in its composition. Many different types of mineral additions, reactive and non-reactive or combination of both, can be used [2–4]. Among the mineral additions limestone filler [2,5] and fly ash [6] are the most commonly used and cheapest.

Due to SCC large flow-ability without segregation, pumping is the most used cast-in-place technique [1,7,8]. However, pumped SCC is prone to undergo some specific problems, as shear-thickening in the fresh state [9–12], shrinkage and cracking at early age (EA) [13] and changes in its physical and mechanical properties in the hardened state [14].

In the fresh state, the shear thickening or rheopectic behavior implies that SCC does not show a linear pressure loss–discharge curve as traditional concrete [15,16] which can limit its use...
From a practical point of view, the rheopetic behavior produce an increase of the pressure required to obtain a certain discharge rate [18], which would imply lower pumpability and would require more powerful and expensive equipment. Hence, neither the traditional evaluation tools nor those based on the Bingham model can be considered for SCC mixes [11,12].

Fresh SCC state properties depend on composition and real-scale mixing and cast-in-place techniques [4,19]. Concrete pumpability is affected by a number of factors, including the mix design, aggregate gradations, aggregate moisture content, air content and admixtures [17,20–24]. Besides, pumping produces also changes on the air distribution of the fresh SCC [10]. Thus, on-site quality control tools and methods for monitoring the pumping process are still needed for SCC pumping [15,18].

Further than fresh properties, SCC also present other differences of performance that can jeopardize SCC hardened properties, due to its larger sensitivity to the cast-in-place techniques [10,11], curing conditions [4,13] and temperature at EA [25]. Water to cement ratio [26] and the type and amount of mineral addition have been also described to affect EA and hardened properties [13,14]. Therefore, SCC performance must be evaluated considering the EA and hardened properties jointly with the fresh state parameters.

The main events that occur at EA are related to the reaction speed, the microstructure formation and the development of mechanical properties [13,27]. All of them are affected by both the SCC composition and the on-site factors, as curing conditions, production facilities and cast-in-place techniques [1,11,12]. SCC is prone to suffer larger evaporation and early age shrinkage under adverse curing conditions that can lead to larger cracking risk and can reduce long term properties and durability [13,14].

Although SCC composition and fresh performance differs from conventional concrete, its hardened mechanical properties have been described in the literature to be similar to conventional concrete [28]. Nevertheless, it has been observed that SCC performance can change under real on-site conditions which results in different hardened properties [11,14].

Most of SCC fresh, early age and hardened properties can be easily characterized by parameters measured in the laboratory [13–15,28]. However, it is not easy to simulate in the laboratory the real on-site conditions during the cast-in-place procedure and the curing conditions that produce substantial changes on the material’s performance. Consequently, laboratory results are not representative of the real scale material and can be only used as reference values rather than control parameters.

That is why a set of Quality Control Parameters (QCP) which allows real-time on-site measurement is necessary to identify the changes on pumped SCC performance produced by real scale conditions [11,12,15,18]. These set of measuring techniques should be flexible, portable, easy to use and robust. They must be useful for identifying on site changes in fresh, EA and hardened properties. Besides, they must be useful for establishing process interrelations with the same accuracy as when using on laboratory.

In this paper, two types of SCC, with Fly ash (FA) and with Limestone filler (LF), were tested in the laboratory and in on-site real scale applications. Several parameters were measured continuously or at stated intervals during pumping, at early age and on hardened state. The general approach to the definition of the properties, potential issues and QCP are described in Fig. 1. The aim of the study was to evaluate the usefulness as QCP of several pumping, early age and hardened parameters measured by non-destructive methods.

2. Materials and methods

2.1. Materials and SCC composition

Two cements, CEM I 52.5 SR and CEM I 42.5R, designated according to UNE-EN 196 standard, were used to achieve the target compressive strength. To reach the large amount of fine particles required for SCC, two types of mineral addition were utilized: a class F fly ash, designated according to ASTM C 618 standard, and a limestone filler with an average particle size of 20 μm. Two types of SCC compositions, with Fly Ash (FA) and Limestone Filler (LF) were studied. FA mixtures incorporated crushed aggregates and an air entraining admixture (HRWRA or Superplasticiser), Viscocrete® supplied by SIKA Spain, was used to improve SCC fluidity.

The components and mix compositions used for the laboratory characterization (LAB) and the Full scale tests (FS) are summarized in Table 1. The water to binder ratio (w/b) of these four compositions were adjusted to achieve a minimum spread diameter of 600 mm using the slump flow test of Self-Consolidating Concrete according to ASTM C1611 [29].

2.2. Experimental real scale test-bench set-up and sampling

Each composition (FA and LF) was evaluated both in laboratory conditions (LAB) and in full scale pumping tests (FS). The real scale tests of FA SCC (60 m³) were performed in summer conditions and outdoor temperature ranged 25-38 °C, while LF SCC (30 m³) was tested in winter conditions and the outdoor temperature interval oscillated between 8 and 16 °C. Laboratory conditions remained almost constant at 22 ± 2 °C and 50 ± 5% RH.

A SCC pumping test-bench was designed to evaluate Pumpability of a real scale SCC application, as shown in Fig. 2. A standard stationary pump (PM1408D) was connected to a pumping circuit formed by a horizontal section of 10 m length and 125 mm diameter followed by a 3 m long rubber hose. The pump was instrumented with pressure sensors and displacement transducers to monitor the pumping parameters [18]. All sensors were connected to a data logger and a computer, supplying real-time data.

During the full scale test, samples were taken before and after pumping. Accordingly with this set-up, three types of samples were monitored from each composition: Laboratory (FA_LAB and LF_LAB), Full Scale Un-pumped (FA_FS_U and LF_FS_U) and Full Scale Pumped (FA_FS_P and LF_FS_P).

Fig. 1. General approach of the research: Performance properties, potential issues and Quality Control Parameters (QCP) selected during pumping in the fresh state, at early ages and after hardening.
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