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The influence of variation in cement characteristics on workability and strength of SCC with fly ash and slag additions

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HIGHLIGHTS

- The interaction of mineral and chemical admixture with different cements for self-compacting concrete was assessed.
- The sensitivity of self-compacting concrete properties on cement characteristics was shown.
- A procedure to determine the self-compacting concrete sensitivity was suggested.

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ABSTRACT

The effects of fly ash and slag on fresh and hardened properties of self-compacting concrete (SCC) were investigated using four CEM I 52.5 N cements produced at different factories according to ASTM C150, two polycarboxylate-acid based superplasticisers, two class F fly ashes and one slag. The differences in the cement characteristics were enough to affect the SCC flow properties. The compatibility of cement and admixtures depended mostly on the concentration of C_3A, C_2S/C_3S ratio, the specific surface area of the cement and the type of superplasticiser used. A protocol to assess the sensitivity of a SCC mix design to a type of cement is proposed.

1. Introduction

The construction industry has significantly evolved over the past decades. Structures made of different materials, with complex shapes and heavily reinforced, have been incorporated in designs around the world. Self-compacting concrete (SCC) was developed in the early 80's in Japan and has ever since become widely used in the concrete industry due to the advantages that it offers [1,2]. SCC is a special type of concrete that possesses the ability to fill complex shapes and flow through congested reinforcement and narrow sections by its own weight without necessitating internal or external vibration. It is able to consolidate and can remain stable i.e. free of any objectionable segregation and bleeding [3].

Various chemical admixtures including superplasticisers as well as supplementary cementitious materials such as fly ash and slag and fillers such as limestone are used in order to improve both the flowability and stability properties of SCC and to produce a greener material [4,5].

Okamura and Ouchi [6] and Siddique [7] acknowledged that, the development in superplasticiser technology has greatly contributed to the promotion of SCC. These chemical admixtures are used to improve properties of SCC including workability, water permeability, resistance to carbonation and chloride attack and both the initial and final strength [8,9].

Saleh Ahari et al. [10] demonstrated that supplementary cementitious materials do not only enhance the mechanical or durability properties of SCC, but can also improve the rheological properties by tailoring especially the plastic viscosity in accordance with the desired performance.

According to Ahmad et al. [11] the difference between the conventional concrete and SCC is that, the latter requires a high amount of SP for the targeted flow ability, and a high powder content for the lubrication of coarse and fine aggregates. Consequently, the workability is improved and the stability of the mixture against any form of segregation is ensured.

The improvement of mechanical and rheological properties and the reduction of the cost associated with the high volume of Portland cement used in the producing SCC, is achieved by replacing cement with supplementary cementitious materials [12]. The recent investigation of Jalal et al. [13] has shown that an increase of fly ash content improves the rheological properties of self-compacting concrete. Likewise, Güneyisi et al. [14] found that the incorporation of fly ash enhanced the fresh characteristics of SCC.

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Zhao et al. [15] investigated the properties of SCC in the presence and absence of FA and slag. They discovered that the presence of these mineral admixtures increased the initial slump flow and prolonged the setting time of cements, whereas the replacement of cement by FA or slag lowered the mechanical properties of the samples. The study of Sethy et al. [16] focused on replacing cement by a volume of slag up to 90%. They observed that the plastic viscosity of the mixture decreased with the increase of the percentage of slag. They also noticed that the compressive strength of SCC decreased with the increase in slag replacement. High and low compressive strengths were respectively obtained at 30% and 90% of slag replacement.

Other researchers have scrutinized the utilization of these admixtures in binary, tertiary or quaternary mixes and some results pertaining to the improvements of SCC properties have been reported in [10,11,17–19].

The incompatibility problems between the chemicals and cements used for a given concrete have been extensively studied by Jang [20] and Agarwal et al. [21].

Burgos-Montes et al. [22] reported that the addition of mineral admixtures such as fly ash and slag may affect the interaction of superplasticiser and cement used for a particular SCC design. Toledano-Prados et al. [23] investigated the effect of polycarboxylate based SP on large amount of fly ash cements, and found that both fluidity and compressive strength of concrete were increased. The dosage of 0.15% SP used resulted in the best SCC.

Vikan et al. [24] and Zingg et al. [25] discussed many factors that might be at the core of these incompatibilities including cement chemical and physical characteristics such as C_3A content, alkali equivalent, sulphate content and specific surface.

The main purpose of this study was to investigate the effect of replacing local ordinary Portland cements by utilizing fly ash and slag on self-compacting concrete in the presence of different commercial polycarboxylate based SPs and also to assess their sensitivity to the production of SCC. The baseline mixes used were limestone blended CEM I 52.5 N cements.

2. Experimental study

2.1. Materials

The following materials were used in the research.

2.1.1. Cement

In this investigation, four ordinary Portland cements of CEM I 52.5 N were obtained from PPC cement Ltd at their different factories across the country. The cements are produced according to ASTM C150. The physical and chemical composition analysis determined by XRF are presented in Table 1 while the phase compositions of cements were characterised by XRD and are given in Table 2.

2.1.2. Mineral admixtures

Two different class F fly ashes and one slag were used as supplementary cementitious materials for cement replacement at variant concentration. Limestone was used at optimum dosage in the control mix as a viscosity modifier. The chemical composition and physical characteristics of these mineral admixtures are given respectively in Tables 3 and 4.

2.1.3. Superplasticisers

Two types of polycarboxylate acid based superplasticisers with long slump retention were used and labelled as SP1 and SP2. SP1 is a modified vinyl polymer-based while SP2 is a modified phosphonate based. Table 5 gives the characteristics of these SPs.

2.1.4. Aggregate

The river sand from Malmesbury with maximum size of 4.75 mm and natural crushed stone with maximum size of 13 mm were used as fine and coarse aggregates. The apparent specific gravity was 2.74 for the coarse and 2.56 for fine aggregates. The absorption capacity of fine aggregate was estimated at 1.1% while that of coarse aggregate at 1.2%. The well-shaped cubicle coarse aggregate was sourced from a local ready-mix supplier with a PSD envelope that falls within the [26] specification. Fig. 1 gives the particle size distributions of the aggregates.

2.2. Mix proportions

In this study a total of 1248 mixes were designed including one control mix for all cements. The latter was designed in accordance with the European Guideline for SCC. SP and limestone concentration were adjusted to meet the SCC properties as stipulated in [27]. The effect of fly ash and slag on the SCC properties were then evaluated by comparing the behaviour obtained after cement replacement at different concentrations of FA 10%, 20%, 30% and 40%) and Slag 30%, 40%, 50%, 60% and 70%) to the control mix properties [10,28].

The control mix for each cement had respectively 418 kg/m^3, 952 kg/m^3 of coarse and fine aggregates, 418 kg/m^3 of cement with 35 or 25% wt of limestone and an optimum SP dosage as described in Table 6.

Consequently, all SCC mixes were prepared with a fixed binder [cement with (no) FA or slag] content of 418 kg/m^3. The water-binder (w/b) ratio was fixed at 0.45. This was done to reduce variables.

Table 6 gives the mix proportions for each cement (C) extended by the different mineral admixtures at various concentrations.

2.3. Sample preparation and testing method

Concrete sample preparation, including mixing procedures and SP addition into the mixture are very important due to their effect on fresh and hardened properties of SCC [29]. These should be very effective and consistent throughout the experiments in order to obtain a homogeneous concrete sample as well as to ensure the reproducibility of results.

Using a drum mixer, the cement and mineral admixtures were dry mixed with the aggregates for 1 min. Thereafter, the mixing water with dissolved SP was added and mixed for another 5 min. A portion of this freshly mixed SCC was used directly to perform a number of tests including: slump flow, T_{500} and segregation ratio tests to determine the fresh properties of SCC. Another portion was cast in cubes of 100 mm × 100 mm × 100 mm and cured at a constant temperature of 23 °C for 24 days. After curing, samples were transferred and stored in a temperature controlled room at 20 ± 2 °C with relative humidity of 95% until the compressive strength was tested at 28 days.

2.3.1. Fresh properties

All tests were performed according to the recommendations in the European Guidelines for SCC, EFNARC, (2005) [27] standard.

2.3.1.1. Flowability. The spread flow and the flow time (T_{500}) were evaluated simultaneously. The spread flow value of the fresh SCC was determined by considering the mean diameter (of two diameters taken in two perpendicular directions) of the concrete on a 900 mm × 900 mm base plate. This was done after the standard slump cone was vertically lifted in one uniform movement. The time taken for concrete to reach the 500 mm diameter engraved on the plate was recorded and is referred to as the T_{500} value of the SCC.