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Sorptivity of self-compacting concrete containing fly ash and silica fume

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HIGHLIGHTS

- Sorptivity decreased with partial replacement of cement by FA and SF in SCC.
- An increased 28-day compressive strength of SCC was obtained by a combined use of FA and SF while it generally decreased with only FA replacement.
- No obvious correlation achieved between sorptivity and compressive strength.

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ABSTRACT

This paper presents the surface water absorption of self-compacting concrete (SCC) containing fly ash and silica fume using sorptivity test. Ordinary Portland cement was partially replaced by various combinations of fly ash and silica fume. Test results show that the presence of fly ash and silica fume significantly reduce the surface water absorption of self-compacting concrete at a water-binder ratio of 0.38. When only fly ash is used to partially replace Ordinary Portland cement, a more noticeable reduction in sorptivity is found when the fly ash content is greater than 20%. The effect of combined use of fly ash and silica fume on reducing the water absorption and sorptivity is much more significant than using fly ash only. Moreover, it is noted that increasing the proportion of fly ash and silica fume leads to an enhanced reduction in water absorption. The addition of fly ash and silica fume, in general, increases the 28-day cube strength. However, there is no correlation between the compressive strength and the sorptivity in SCC achieved.

1. Introduction

It is necessary for reinforced concrete (RC) structures to undertake maintenance over its design and service life. However, the frequency of maintenance works can be minimized using a durable concrete material. In RC structures, corrosion subsequently leads to deterioration in structural capacity, serviceability and even the appearance of the structure. It is apparent that air and water play an important role in triggering the corrosion process. If the ingress of these two components can be hindered, the occurrence of corrosion would be prevented. One of the methods to measure the ingress of water into concrete is by sorptivity test. This test is used to determine the properties of the near surface concrete which can control the transport of water into the concrete and to the reinforcement. The water absorption or sorptivity of concrete can be regarded as a measure of the capillary forces as exerted by the pore structure causing the liquids to be drawn into the concrete [1]. However, the sorptivity test is only applied to the surface of the concrete, not much information about the bulk properties of concrete can be derived. It has been reported that the sorptivity of concrete was affected by its surface condition. Besides, the initial moisture content of concrete also altered the additional absorption of water [2]. Tasdemir [3] conducted a series of sorptivity tests on Ordinary Portland Cement (OPC) concrete with sand instead of cement being partially replaced by mineral admixtures including fly ash (FA), limestone, sandstone and silica fume (SF) and the test results revealed the sorptivity coefficient decreased as the compressive strength of concrete increased and the sorptivity coefficient was almost constant for water-cured concretes. Abdul Razak et al. [4] investigated the initial surface absorption, water absorption and sorptivity of concrete containing metakaolin (MK) and SF, each 10%. The results showed that the presence of MK and SF greatly reduced the initial surface absorption, water absorption and sorptivity of concrete as compared to OPC concrete. Experimental results of Guneyisi et al. [5] indicated that the effect

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of MK and SF on mechanical, permeability and shrinkage properties of concrete with water binder ratio of 0.25 and 0.35 was significant. The 28-day compressive strength for MK and SF concretes were higher than the control concretes and the sorptivity coefficients decreased with the introduction of MK and SF. An inverse proportionality between sorptivity values and mechanical properties was highlighted, i.e. concrete with the lowest sorptivities had the highest compressive strengths, especially for those having 15% MK or SF. Chen et al. [6] investigated limestone fines as cement paste replacement and the limestone significantly enhanced the strength of concrete.

In the recent decade, self-compacting concrete (SCC) has been characterized as a promising construction material. This is attributed to the fact that SCC is able to be placed and compacted under its own weight with no vibration needed which is extremely important especially in areas with highly congested reinforcement. With the use of SCC, it is believed that the chance of having corrosion in RC structures is lowered and the possibility of poor workmanship which may lead to honeycombing and segregation can be eliminated [7]. As a result, SCC has to be cohesive at the same time no segregation or bleeding of fresh concrete is anticipated. To achieve such effect, a SCC mix is usually consisted of superplasticizer (SP) and viscosity modifying agent (VMA), along with high content of fines. Regarding the substitute of fine content, FA which enhances the workability and reduces the cracking due to lower heat of hydration has been introduced in SCC so that the dosage of SP can be reduced while maintaining the required slump flow. Apart from FA, SF could enhance the bond between paste and aggregate through its pozzolanic reaction appears to be a good substitute in fine content. In a recent research, SCC incorporating MK [8] was also investigated.

Khatib [9] studied SCCs containing FA by 0–80% cement replacement at a water-binder ratio of 0.36. According to the test results, a systematic increase in water absorption with increasing FA content was found for SCCs with 1, 28 and 56 days of curing. However there was a decrease in compressive strength with increased FA content. An inverse relationship between strength and water absorption was therefore suggested. Kanellopoulos et al. [10] also observed similar variations between the compressive strength and sorptivity. The same variation between compressive strength and sorptivity was noted. Dinakar et al. [11] conducted durability tests which include water absorption test, on SCCs with FA percentage from 0% to 85%. Higher water absorption in FA SCCs than normal concretes at the same strengths was concluded. Wongkeo et al. [12] examined the compressive strength and water absorption of SCC with a high volume of FA and SF. According to their experimental results, water absorption of SCC containing FA was greater than control concrete, however this decreased with increasing SF content. In terms of compressive strength, SCC showed decreased strength with increasing FA content, even lower than the control concrete. Addition of SF in the SCC mix gave higher strengths. Mohamed [13] studied the compressive strength of three different SCC mixes consisted of FA, SF and a combination of FA and SF. A water-cement (W/C) ratio of 0.42 and the cement contents of 450 kg/m^3 and 550 kg/m^3 were adopted in the SCC mixes. The experimental results on 450 cylinders revealed an optimum compressive strength for SCC with 15% cement replacement by SF and SCC with 30% cement replacement by FA. The 28-day compressive strength for SCC with 15% SF was higher than those with 30% FA. The results also indicated that 10% of SF and 10% of FA was the best percentage combination in the adopted SCC mixes. In addition, water cured specimens generally gave higher compressive strength.

Hassin et al. [8] conducted tests on twelve SCC mixtures with different proportions of metakaolin (MK) and SF in which the water-binder ratio of 0.4, binder content of 450 kg/m^3, a maximum of 11% SF by cement replacement and varied amount of high range water reducer were used to meet the required slump flow of 650 mm. Based on the results of some mechanical and durability tests, they concluded that the 28-day compressive strength of SCC increased with both MK and SF contents. An optimum percentage of SCC containing SF was found to be at 8%. Different permeation properties of SCC were also studied by Zhu and Bartos [14]. Experimental tests on SCC at strengths between 40 MPa and 60 MPa with the addition of powder (limestone, pulverized fuel ash) as filler were carried out and the results revealed that the water absorption of SCC was significantly lower than that of normally vibrated concrete.

2. Research significance

A more extensive use of SCC in the construction industry can only be achieved when more durability data regarding SCC containing different ingredients is available. Sorptivity as one of the main durability considerations requires more study. As the study on sorptivity of SCC in the literature is relatively limited, this paper attempts to present some sorptivity test data on SCC containing different volumes of FA and SF by partial replacement of OPC. Since the data were obtained from standard sorptivity test, future research results can be compared directly with the current data. In addition to sorptivity, the compressive strength of SCC under the effect of cement replacement by FA and SF is also investigated. It is of particular importance for practising concrete and construction professional to understand the correlation between sorptivity and compressive strength of SCC.

3. Experimental program

3.1. Materials

In this study, OPC was used as a main binder while FA and SF was employed as mineral admixtures. The OPC used is complied with BS12:1991 [15]. The type of FA used in the study is Class F in accordance with the ASTM C 618-99 [16] and the SF is complied with ASTM C 1240-99 [17]. Typical particle size of FA is below 20 μm while SF has an average diameter of about 0.1 μm. River sand and crushed granite with a maximum size of 10 mm were used as fine and coarse aggregate respectively. They are all complied with BS882:1992 [18]. A carboxylate polymer based clear liquid SP and a liquid polymer-based VMA complying with BS 5075: Part 3:1985 [19] was introduced as chemical admixtures.

3.2. Mix proportioning

Two series (F and FS) of concrete mixes were prepared. The detailed mix proportions are presented in Table 1.

The F-series aims to compare the sorptivity of SCC containing different amounts of FA. The replacement levels (by weight) of OPC by FA were 0% (control), 12.9%, 20%, 30%, 40% and 50%. The FS-series attempts to investigate the combined effect of FA and SF on the SCC's sorptivity. Class F FA is normally used at a dosage of 15–25% by mass of cementitious materials, thus the amount of FA was maintained at 25% of OPC while the SF levels were 0%, 5%, 10% and 15%. Therefore the total OPC replacement levels by FA and SF were 25%, 30%, 35% and 40%. The water-binder (W/B) ratio was 0.38 (binders here included OPC, FA and SF) and a water content of 235.6 kg/m^3 was adopted. The fine and coarse aggregate contents were 780 kg/m^3 and 720 kg/m^3 respectively for all SCC mixes. In each SCC mix, two specimens were cast for subsequent tests.

In order to satisfy the requirements of SCC, SP and VMA were added. It is noteworthy that all SCC mixes in this study were produced using single type of SP and VMA although the effect of types of SP and VMA on the properties of SCC has been reported elsewhere [20–21]. The proportions of SP and VMA were determined according to the test results of slump flow, U-box [22] and segregation [23]. Essentially, the following requirements were to be fulfilled.

- a minimum flow diameter of 650 mm
- a height difference of less than 30 mm in the U-box test
- a segregation index of less than 20%