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An experimental study of different curing regimes on the mechanical properties and sorptivity of self-compacting mortars with fly ash and silica fume

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HIGHLIGHTS

- Binary and ternary mixes of fly ash and silica fume of self-compacting mortar (SCM).
- Fresh properties of binary and ternary mixes of FA and SF.
- The effect of four different curing regimes on the mechanical properties of SCMs.
- Sorptivity coefficients of SCMs.
- LPWC is effective on the flexural strength of SCMs.

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ABSTRACT

This paper aims to investigate the effect of four different curing regimes namely; tap water curing (WC), wet sack curing (WSC), air curing (AC), and liquid paraffin wax curing (LPWC) and different curing times (3, 7, 28, 56 and 180 days) on the mechanical properties of self-compacting Mortars (SCMs). Binary mixtures of SCMs were prepared by replacing Portland cement with 10%, 20%, and 30% by weight of C class fly ash (FA) and 6%, 10%, 14% by weight of silica fume (SF). In ternary mixes, provided that mineral additive ratio doesn't exceed 30% of cement, 10% of FA with 6%, %10, % 14 of SF and %20 of FA with %6, %10 of SF were produced. The water-to-binder (w/b) ratio ranges from 0.37 to 0.48. A sum of 12 different mixtures with 630 kg/m^3 binder were prepared to observe SCMs behaviour in fresh and hardened conditions. Mini slump flow diameter, viscosity and mini V-funnel flow time tests were performed to assess the fresh properties of SCMs containing FA and SF. Sorptivity tests were performed on cube specimens with the dimensions of 50 × 50 × 50 mm. Compressive and flexural tensile strengths of the hardened mortars were measured at 3, 7, 28, 56 and 180 days at different curing conditions. The best results for compressive strength at the end of 180 d were determined with 10% FA in binary combination at water curing and with %10FA + %6SF in ternary combination at wet sack curing. The best results for flexural strength at the end of 180 d were determined with control samples at LPWC curing and with %10 SF in binary combination at LPWC. SF10 has the lowest sorptivity coefficient with w/b ratio of 0.40.

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1. Introduction

Mineral admixtures replace cement in mortar mixtures and in some concrete types such as lightweight concrete, reactive powder, compacted cylinders and self-compacting concrete to improve the mechanical and durability properties due to pozzolanic and/or self-cementing effects [1]. When mineral admixtures are examined, workability of fresh concrete, strength and durability of hardened concrete are the most interested features. Fly ash and silica fume are the most widely used mineral additives in concrete/mortar. Fly ash has very positive effects on concrete, such as reducing water demand and hydration heat, reducing bleeding and obtaining satisfactory durability [2]. Silica fume is used as a mineral additive in place of cement to produce high performance concrete (HPC). It has been pointed out that silica fume in concrete/mortar is an effective pozzolanic material which results in a more discontinuous and impermeable pore structure than

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the plain cement paste. The addition of silica fume increases the rate of cement hydration at early age due to the release of OH^- ions and alkalis into pore fluids [1,3,4]. Furthermore, the benefits of using mineral admixtures in concrete are protecting nature and providing economy. Using ternary mixes containing fly ash and silica fume in concrete/mortar is combined the advantage of silica fume such as reduced bleeding and relatively fast rate of pozzolanic reaction with the benefits of fly ash such as increased workability and improved long term durability [5]. Self-compacting concrete (SCC) which offers benefits in workability, reduces labour costs and high strength compared to conventional concrete has recently emerged as a new concrete technology and its use has increased rapidly over the last three decades and reflected in the number of published works. Self-compacting mortar (SCM) exhibits similar mechanical and durability properties to SCC and can be used to examine the performance mechanisms of the SCC [6]. Mortar forms the basis of the workability properties of self-compacting concrete (SCC) and these properties can be evaluated with self-compacting mortars (SCMs). In fact, evaluating the properties of the SCMs is an integral part of the SCC design [7,8]. Super plasticizing chemical additives, powder material and/or viscosity regulators which reduce water at high levels in SCC/SCM production are used [9–11]. While the use of superplasticizer maintains fluidity, it ensures the stability of the fine-content mixture and thus obtains resistance against bleeding and separation. The use of fly ash and silica fume, blast furnace slag in SCC reduces the dosage of the superplasticizer required to achieve a similar slump flow compared to concrete mixtures made only with Portland cement [10,12]. Curing is one of the most important parameters to help improve the water holding capacity of concrete, which in turn helps improved microstructure of concrete [13–15]. Curing involves maintaining sufficient moisture content to the last stage of the placement of the concrete; At this point, the concrete develops satisfactory properties by promoting optimum cement hydration immediately after being placed. Properly cured concrete has improved durability and surface hardness and less permeability. Preventing loss of moisture is also important in terms of resistance development, but also to prevent plastic shrinkage, reduces permeability and increase resistance to abrasion. Good and complete curing is not always possible for a variety of reasons, such as human defects, vertical elements, and water-tightness. In such cases, the self-compacting concrete is very adaptable and helps alleviate this problem. The basic concept of self-curing concrete is to remove water from the water vaporization of the concrete and thus to improve the water holding capacity when compared to normal curing. Many hydrophilic materials, including polymeric glycols and paraffin wax, can act as self-curing compounds [15,16]. This study explores the role of liquid paraffin wax as a self-curing agent and compares it to the effect of different curing regimens simulating traditional curing methods [17]. Not much study on self-curing exists in the literature, Madduru et al. [18] studied the effect of self-curing chemicals in self-compacting mortars. The authors concluded that the use of self-curing agents in self-compacting mortars in optimum dosages benefited self-compacting mortars in achieving better strength and durability performance. In the research reported by Bingol and Tohumcu [14], the effect of different curing regimes which are air curing, water curing and steam curing on the compressive strength properties of SCC with different ratios of SF and FA replacements was studied. They pointed out that the highest compressive strength values were obtained from standard cured samples (cured in water for 28 days). The increase in water curing time caused an increase in compressive strength. Air curing caused the compression strength to decrease and the lowest strength values were obtained for all groups from air-cured specimens. Wongkeo et al. [19] investigated that the compressive strength of binary and ternary blended cement mortars containing fly ash and silica fume under autoclaved curing. They showed that the compressive strength of the FA blended cement mortar tends to decrease due to increased FA replacement and has a lower compressive strength than the PC control. However, the compressive strength of the binary blended cement mortar was improved by SF and the compressive strength was higher than the PC control. Poon et al. [20] did research on the influence of different curing conditions on the pore structure and related properties of fly-ash cement pastes and mortars. They found that F class fly ash improves the interfacial zone between the pastes and the aggregates. Another study of Wongkeo et al. [21] was on the influence of high-calcium fly ash and silica fume as a binary and ternary blended cement on compressive strength and chloride resistance of self-compacting concrete (SCC). The study revealed that binary blended cement containing high level fly ash generally reduced the compressive strength of all SCC at all test ages (3, 7, 28 and 90 days). However, ternary blended cement with fly ash and silica fume gains higher compressive strength after 7 days compared to binary blended fly ash cement at the same replacement level. Leung et.al [22] studied sorptivity of SCC containing F class fly ash and silica fume. The research showed that fly ash and silica fume significantly decreased the sorptivity of SCC at a water-binder ratio of 0.38. Siddique [23] indicated that sorptivity of SCC mixes increased with the increase in bottom ash content.

In this study, standards issued by EFNARC were utilized [18]. According to EFNARC; workability of self-compacting concrete can be provided with filling capability, suitable viscosity determined by the flow rate, the ability to pass through the narrow section and the separation resistance [24,25]. Limiting amount of coarse aggregate is common method to achieve the high fluidity of SCC/SCM. The main objective of this paper is to examine the effects of different curing conditions including tap water curing (WC), wet sack curing (WSC), air curing (AC), and Liquid Paraffin Wax curing (LPWC) and different curing times (3, 7, 28, 56 and 180 days) on the mechanical properties of self-compacting Mortars (SCMs). For this purpose, Binary and ternary mixtures of SCMs were prepared and produced by replacing Portland cement with different replacement contents of C class fly ash (FA) silica fume (SF). A sum of 12 different mixtures with 630 kg/m^3 binder were prepared to observe SCMs behaviour in fresh and hardened conditions. The water-to-binder (w/b) ratio ranges from 0.37 to 0.48. Hardened properties were evaluated by 3, 7, 28, 56 and 180 days of compressive strength and flexural tensile strength tests. Mini slump flow diameter, viscosity and mini V-funnel flow time tests were performed to assess the fresh properties of SCMs containing FA and SF. In addition, capillary water absorption (sorptivity) characteristics of SCM samples cured at 28 days were also evaluated.

2. Experimental program

The main purpose of the work is to investigate the mechanical properties and sorptivity of self-compacting mortars (SCMs) by using binary and ternary combinations of fly ash and silica fume under four different curing conditions at the age of 3, 7, 28, 56 and 180 days. For this purpose, $40 \times 40 \times 160$ mm specimens (Fig. 1) were cast with various fly ash and silica fume contents for compressive and flexural testing of SCMs.

The mini slump flow and mini V-funnel flow tests recommended by EFNARC were carried out to assess the characteristics of rheological properties of SCM. In addition, viscosities of fresh mortars were also measured. The tensile strength in bending and compressive strength tests were conducted on SCMs exposed to different curing conditions. Furthermore, Sorptivity coefficients were determined on 50 mm cube samples cured in water for 28 days

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