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Effects of pre-soaked super absorbent polymers on fresh and hardened properties of self-consolidating lightweight concrete

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HIGHLIGHTS

- The use of SAP improves the static stability and passing ability of SCLWC mixtures.
- The incorporation of SAP in SCLWC resulted in reducing the compressive strength.
- The increase in silica fume content in the mixture compensates for the strength reduction observed with the SAP.
- The fine SAP proved to be more effective in reducing the total shrinkage of SCLWC.

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ABSTRACT

In this research, the influence of pre-soaked super absorbent polymers (SAPs) on the properties of Self-Consolidating Lightweight Concrete (SCLWC) was evaluated. SAP with two different fineness of 1–4 mm and 0.3–1 mm was incorporated in SCLWC mixtures at a constant percentage of 1.5%, by mass of binder. SCLWC mixtures were evaluated in terms of slump flow, T50, V-funnel, J-ring, compressive strength, water absorption, electrical resistivity, and total shrinkage. The test results indicated that SAP improve passing ability and decreases the static stability of fresh SCLWC mixtures. Furthermore, the use of SAP reduced the compressive strength of SCLWC mixtures at 7 and 28 days ages and induced a negative effect on the electrical resistivity and water absorption of SCLWC. However, the use of SAP resulted in up to 50% reduction in total shrinkage of SCLWC, compared to the reference mixture made without SAP.

1. Introduction

Current orientation of concrete technology is towards development and application of high performance concretes rather than conventional concretes [1]. Two examples of special concretes that have been successfully used in construction include self-consolidating concrete (SCC) and lightweight concrete (LWC). SCC is a highly flowable, non-segregating concrete that can fill the formwork, and properly encapsulate the steel reinforcement without any mechanical consolidation [2]. The use of LWC has gained great attention in concrete industry due to economic, architectural, and structural benefits [3,4]. LWC is proportioned with porous lightweight aggregates. Combining these advantages with those of SCC can result in self-consolidating lightweight concrete (SCLWC) with low unit weight, high flowability, and good stability. Successful development of SCLWC will provide advantages in various applications. Indeed, due to its relatively low unit weight, SCLWC induces low formwork pressure in many applications, including insulating concrete forms (ICF) panels [5]. For such ICF panels, the use of SCLWC is suitable to reduce the lateral pressure and avoid their distortion. Furthermore, LWC is reported to possess great internal curing potential induced by pre-wetted lightweight aggregates, which is advantageous in mitigating shrinkage [6–8].

Due to significant differences between the density of lightweight aggregates and cementitious matrix, there is a high segregation risk in SCLWC mixtures [9,10]. In SCLWC, the lightweight aggregates are likely to float because of buoyancy phenomenon. In order to prevent segregation, the viscosity of the cementitious matrix can be increased by adding either a viscosity modifying admixture (VMA) or increasing the solid fraction of cementitious particles [11–14]. In addition to increase solid fraction, the use of superabsorbent polymers (SAPs) can serve as an internal curing

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of SCLWC. Unlike air entertaining agents, SAPs supply water-filled air voids in the matrix, which remain stable during consolidation and transportation, regardless of mixture's workability [15]. SAPs are cross-linked hydrophilic networks that can swell in contact with water, while osmotic pressure is the important moving force for swelling [16]. Therefore, SAPs absorb liquid from their vicinity and retain it without being dissolved [17]. Consequently, SAP increases the amount of internal water sources for internal curing and reduce shrinkage [17,18].

The incorporation of SAP in concrete can affect its fresh and hardened properties. For example, the use of 0.4% SAP, by mass of cement, resulted in substantial increase in slump flow and decrease in V-funnel flow time (up to 30 s) of 0.29 W/C SCC [17]. The improvement in fluidity is due to the extra water which was not completely absorbed by SAP particles [17]. In the case of concrete with high w/c (>0.45), the use of 0.6% SAP, by mass of cement, resulted in little effect on degree of hydration, but a reduction in compressive strength due to an increased volume of voids. However, in the case of mixtures with low w/c (<0.45), even the moderate amount of SAP addition corresponding to 0.4%, by mass of cement led to compressive strength reduction [19]. Snoeck et al. [20] reported that the use of 1–2% SAP in mortar could decrease the water permeability of cracked specimens due to their swelling ability. Also, it was reported that chloride migration of concrete mixtures proportioned with w/c of 0.35, 0.40, and 0.50, and containing SAP decreased [21]. Mechtcherine et al. [22] reported that the addition of 0.6% SAP, by mass of cement in concrete can increase its total porosity by approximately 2% by total volume, compared to a mixture with 0.3% SAP. Delay in strength development was also observed when incorporating 0.2–0.6% SAP in blended cement mortars containing silica fume (SF), blast furnace slag (BFS), and fly ash (FA) [23]. The addition of pre-soaked SAP in high strength concrete improves its early-age dimensional stability and resulted in less strength reduction compared to mixes with dry addition of SAP powder [6,24]. They also reported that pre-soaked SAPs have less impact on workability of concrete. Brudern and Mechtcherine [25] investigated the use of SAP in strain-hardening cement-based composites and they observed a decrease in total shrinkage during the first few weeks after concrete production.

Research studies on SAP are mainly focusing on its application in high-strength concrete [7,26–29]. However, its effect on the properties of SCLWC needs comprehensive investigation to elucidate how SAP incorporation can affect fresh and hardened properties of concrete. The main objective of this study is to evaluate the influence of pre-soaked SAP used as a partial replacement of aggregates on properties of SCLWC. SAP with two fineness levels of 1–4 mm and 0.3–1 mm was incorporated at a constant percentage. Various SCLWC mixtures were proportioned using two different water-to-binder ratios (w/b). The investigated mixtures incorporated different contents of SF as a supplementary cementitious material. Slump flow, T50, V-funnel, J-ring, compressive strength, water absorption, electrical resistivity, and total shrinkage tests were carried out as a comprehensive experimental evaluation of the investigated SCLWC mixtures.

2. Experimental program

2.1. Materials

A commercially available ASTM Type II Portland cement with a specific gravity of 3.16 and Blaine fineness of 337 m^2/kg was used. Silica fume (SF) was also used as a supplementary cementitious material. It has a specific gravity of 2.2 and a specific surface area of 20,000 m^2/kg. The chemical compositions of the cementitious materials is presented in Table 1. A polycarboxylate-based superplasticizer (SP) was used to improve the workability of fresh concrete. The specific gravity, solids content, and pH value for the SP were 1.14, 30%, and 6.2, respectively.

Table 1
Chemical composition of cementitious materials.

Chemical properties	Cement (%)	Silica fume (%)
CaO	63.80	–
SiO_2	21.2	93.16
Al_2O_3	3.70	1.13
Fe_2O_3	3.64	0.72
MgO	1.70	1.60
SO_3	2.48	0.05
K_2O	0.67	–
Na_2O	0.90	–
Ignition loss	5.18	1.58
Remaining insoluble (RI)	0.58	–
Alkaline equivalents (AE)	1.34	–

A natural sand with specific gravity, fineness modulus, and water absorption of 2.51, 2.79, and 2.6%, respectively, was used. A lightweight expanded clay aggregate (LECA) with a maximum size of 12.5 mm, specific gravity of 1.45, and water absorption of 14% was used as coarse aggregate.

The sieve analysis results for both LECA and river sand are summarized in Table 2. The aggregates grading curves are within the limit specified by the ASTM C136-06 [30] and ASTM C33-13 [31] standard.

The SAP polymer type was a commercially available gel polymerized Polyacrylate. It was sieved into two fractions: 0.3–1 mm and 1–4 mm, which are addressed as fine SAP and coarse SAP, respectively. For both SAP types, cation exchange capacity of 4.6 meq/g is obtained. On the other hand, the specific gravity and pH values of 1.1 and 8.1, respectively, were measured. It is important to mention that SAP was pre-saturated prior its use in concrete. The water absorption of SAP was determined using the tea bag method proposed by Schröfl et al. [32]. It is well established that the absorption capacity of SAP decreases in presence of higher ionic strength solution. In this study, the absorption capacity of SAP is evaluated using tap water and saturated limewater solutions. The obtained results revealed that the absorption capacity of coarse SAP (1–4 mm) in tap water and saturated limewater is 180 and 22 g/g of polymer, respectively. In the case of fine SAP (0.3–1 mm), these values are 150 and 20 g/g of polymer, respectively. Based on the assumption that both concrete and saturated limewater solution will have similar ionic strength (pH around 13), the absorption value obtained in the saturated limewater are adopted to pre-saturate SAPs before their use in concrete [24].

2.2. Mixture proportions, mixing sequence, and sample preparation

The SCLWC mixtures were designed with two different water-to-binder ratios (w/b) of 0.36 and 0.39. SAP types (i.e. coarse and fine SAP) were used at a constant percentage of 1.5%, by mass of binder. The amount of water absorbed by SAP during its pre-saturation period is not considered as free water (i.e. it does not affect w/b ratio). Two different silica fume dosages corresponding to 7.5% and 15%, by mass of binder, were also investigated. For all the investigated mixtures, total binder content and aggregate grading were kept constant. The aggregates were used in their saturated surface dry (SSD) condition. The SCLWC mixture design was determined by trial and error until achieving filling ability, segregation resistance and flowability of fresh concrete. The mixture proportions are summarized in Table 3.

The mixing sequence consists in introducing the aggregates and cementitious materials into the mixer. After 60 s of mixing, water and SP were added and the mixture was mixed for another 5 min. Thereafter, the pre-saturated SAP was added to the mixture and the mixing was continued for two additional minutes. The mixing speed was kept constant during all the mixing steps. The mixture was allowed to rest for two minutes, and then the mixing was presumed for three minutes. Immediately after mixing, slump flow, T50 and V-funnel tests were carried out. After assessing the fresh properties of concrete, various specimens were sampled. This consist in 100 mm cubic, 200 mm cubic, and $280 \times 75 \times 75$ mm prisms molds to evaluate compressive, shrinkage and durability properties of the mixtures. All the specimens were cast in molds without any consolidation and cured at 23 ± 2 °C and 50% relative humidity.

2.3. Testing methods

The slump flow values test was carried out according to ASTM C1611-09 [33]. This test is used to assess the filling ability of concrete. According to the ASTM C1611-09, the slump cone is filled in one layer without any consolidation. After lift-

Table 2
Sieve analysis of LECA and river sand.

LECA	Sieve (mm)	12.5	8	5.75	4	2	1
	Passing (%)	100	76	47	22	4	2
River sand	Sieve (mm)	9.5	4.75	2.36	1.18	0.6	0.3
	Passing (%)	100	100	80.3	63.3	27.5	8.9