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The effect of cement type on long-term transport properties of self-compacting concretes

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HIGHLIGHTS

- SCC may not be obtained with some of the cements of high pozzolan content.
- CEM II/B-M showed the best performance with respect to permeability properties except RCPT.
- The pore solution chemistry is more important for RCPT than permeability properties.

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ABSTRACT

In this study, four types of pozzolanic cements—CEM II/A-P, CEM II/B-M, CEM II/B-P and CEM IV/B-M, together with CEM I, were used to produce self-compacting concretes. However, it was not possible to obtain self-compacting properties with CEM II/B-P and CEM IV/B-M. The fresh concrete properties and the hardened concrete properties—sorptivity, water penetration under pressure, carbonation and rapid chloride penetration—were determined on the concretes stored in air for 3 years. Drying shrinkage was monitored for up to 4 months, and compressive strengths were measured at the age of 28 days after a standard water curing.

1. Introduction

It is well established that self-compacting concretes can be prepared with a powerful superplasticizer (largely polycarboxylate-based), a high content of fine material (finer than 100 μm) with or without a viscosity-modifying admixture and a decreased water/binder (w/b) or water/powder (w/p) ratio. Widely used fine materials include inert fillers such as limestone powder and pozzolans such as fly ash (FA), blast furnace slag (SL), silica fume (SF) and natural pozzolan (NP). NPs include volcanic ash, pumice, natural zeolite and perlite. It is possible to incorporate fine materials into the concrete as an additive during the preparation of concrete at the plant or incorporate them into the clinker as an addition at the cement factory.

In SCCs, increasing the fine material content increases the paste volume, which, together with the interfacial transition zone (ITZ), affects the durability performance under freezing–thawing action, alkali-silica reactions, sulfate attack, corrosion, shrinkage, etc. Furthermore, these properties are affected by the quality as well as the quantity of the paste volume. In particular, the addition of pozzolanic materials into the cement paste, together with reducing the water/cement (w/c) ratio, improves the impermeability properties of SCCs. Pozzolanic materials exhibit two effects. First, pozzolans, especially fine pozzolans, may cause a filler effect [1] by providing more space for hydration products and for the formation of nucleation sites [2]. Second, a pozzolanic effect occurs by which silicon dioxide in the pozzolans reacts with the lime generated during the hydration reaction of silicates in cement to form products similar to C–S–H. Although they may not completely fill large pores, the pozzolanic reaction products can disrupt the continuity of thin channels [3].

From investigating the influence of cement type on chloride migration coefficients, it was found that limestone filler-based

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Table 1
Chemical and pozzolanic compositions and physical properties of cements.

	CEM I 42.5 R	CEM II/A-P 32.5 N	CEM II/B-M (P-V) 42.5 R	CEM II/B-P 32.5 N	CEM IV/B-M (P-V) 32.5 N
Pozzolan contents	–	15% NP	10% NP, 15% FA	35% NP	25% NP, 15% FA, 5% LF
Chemical composition (%)					
SiO_2	20.16	28.24	30.13	35.81	34.96
Al_2O_3	5.12	6.61	8.77	8.57	9.80
Fe_2O_3	2.92	3.04	4.11	3.29	4.52
CaO	63.87	55.14	49.34	43.89	40.01
MgO	1.81	1.69	1.72	1.63	1.92
SO_3	3.03	1.43	1.38	1.37	0.87
K_2O	0.65	0.84	1.17	1.19	1.25
Na_2O	0.23	0.58	0.56	1.21	0.69
LOI	2.12	1.73	2.56	2.29	4.04
Insoluble	0.58	10.70	7.57	24.97	18.35
Physical properties					
Specific gravity	3.14	2.99	2,92	2.76	2.75
Fineness blaine (m^2/kg)	312	295	355	328	398

cement (CEM II/A-LL 42.5 N) was not as effective as slag cement (CEM III/A 32.5 N) in reducing the chloride penetration in concrete [4]. Similarly, lower permeability and sorptivity were obtained from SCCs prepared with fly ash and CEM III/A 42.5 LA (slag cement) than from SCCs prepared with limestone filler and CEM I 42.5; this difference was attributed to the finer pore structure of the former concretes [5].

In considering the carbonation of concrete, the permeability and $Ca(OH)_2$ content are important factors. The addition of pozzolans improves the impermeability properties and reduces the amount of carbonatable materials. SCCs prepared with Portland cement (CEM I 42.5 or 52.5) showed lower CO_2 penetration depths than those prepared with slag cement (CEM III A 42.5 LA) because of the high amount of lime released from the former [6]. It was also reported that the carbonation rate was lower in SCCs prepared with limestone filler than in vibrated concrete (VC) because the former had lower porosity and finer pore structure [7]. Siddique found that the carbonation depth increased slightly with higher fly ash content because fly ash reduced both the permeability and the alkalinity of concrete [8].

On the other hand, some differences in the shrinkage properties of SCC and VC can be expected because of the large difference in their paste volumes, especially when SCC is prepared with the increase-in-powder method. It is well known that the shrinkage of concrete is inversely proportional with the aggregate volume [9]. Similarly, Loser and Leemann [10] found that shrinkage is strongly related to paste volume for both SCC and VC. They also found no difference in shrinkage between SCCs prepared with either CEM I or CEM II/A-LL. However, the addition of limestone filler that was finer than cement reduced the shrinkage because of the formation of a denser microstructure.

In this study, five different cement types—CEM I 42.5, CEM II/A-P 32.5, CEM II/B-P 32.5, CEM II/B-M 32.5 and CEM IV/B-M 42.5—were used in the production of SCCs. The properties of fresh and hardened SCCs were compared. To measure the permeability properties, tests of sorptivity, water permeability under pressure, carbonation depth and rapid chloride penetration were conducted on specimens stored in air for 3 years. In addition, the drying shrinkages of the specimens were monitored for up to 4 months.

2. Experimental study

2.1. Materials

2.1.1. Cement

In accordance with EN 197-1, normal Portland cement (CEM I 42.5 R) and four pozzolan cements (Portland composite cements CEM II/A-P 32.5, CEM II/B-P 32.5 and CEM II/B-M 32.5; and Portland pozzolanic cement CEM IV/B-M 42.5), obtained from different sources, were used in the production of concretes. Their pozzolanic and chemical compositions and physical properties are given in Table 1.

2.1.2. Aggregates

Natural sand (specific gravity: 2.56) and crushed stone sand (specific gravity: 2.61) were used as fine aggregate, and two crushed stones, designated as Crushed Stone 1 (specific gravity: 2.69) and Crushed Stone 2 (specific gravity: 2.69), were used as coarse aggregate. The maximum size of aggregate was 22 mm, and the volume proportions of aggregates were as follows: 33% natural sand (0–4 mm), 14% crushed stone sand (0–8 mm), 25% Crushed Stone 1 (4–16 mm) and 28% Crushed Stone 2 (8–22 mm).

2.1.3. Admixture

A polycarboxylate-ether-based superplasticizer (SP) was used in the concretes. For all mixtures, the dosage of SP was 2.5% of cement content.

2.2. Concrete mixtures

Concretes were prepared at a constant cement dosage of 550 kg/m^3 and at a fixed SP dosage of 2.5 wt.% of cement. w/c ratios of 0.31, 0.30 and 0.31 for the CEM I, CEM II/A-P 32.5 and CEM II/B-M 42.5 cement-concretes, respectively, were obtained. However, for the remaining two cements, the target slump-flow was not reached even with increased w/c ratios. The mixing proportions of the concretes are shown in Table 2. The concretes were mixed in a pan mixer that had a capacity of 40 liters according to the following mixing sequence. First, all aggregates were mixed with ½ of the mixing water for 2 min. The cement was then added with the rest of the water and mixed for an additional 2 min. After the addition of the superplasticizer, the mixing continued up to a total time of 6 min.

2.3. Testing procedures

2.3.1. Fresh concrete tests

Slump-flow and the time to reach the 500-mm diameter circle (t_{500}) were determined (in accordance with EN 12350-8) on fresh concrete samples immediately after mixing and at every 30 min up to 90 min.

2.3.2. Hardened concrete tests

Compressive strength tests were conducted on 150 × 150 × 150 mm^3 cubic specimens at an age of 28 days after the standard curing. Three specimens were tested for each mixture. Permeability tests were conducted on concrete specimens stored at 65 ± 5% R. H. and 23 ± 2 °C, at the age of 3 years. As required by the sorptivity test, the specimens were oven dried and side surface sealed. The capillary water intake was monitored for up to 64 min on 100 × 100 × 100 mm^3 cubic specimens in accordance with EN 772-11. In accordance with EN 12390-8 but modified with respect to DIN 1048 [11], tests of water penetration under pressure were conducted on oven-dried 100 × 100 × 100 mm^3 cubic specimens under the following conditions: 1 bar of pressure for the initial 48 h, 3 bar for the next 24 h and, subsequently, 7 bar for another 24 h. The water penetration depth was measured at the surfaces of split specimens. A rapid chloride penetration test (RCPT) was conducted on 50-mm-thick specimens in accordance with ASTM 1202. The carbonation properties of concretes were measured by using phenolphthalein as indicator at freshly cut concrete surfaces. The number of replicates is two for each property tested.

Shrinkage measurements started two days after the casting and were monitored up to 120 days on 100 × 100 × 500 mm^3 prismatic specimens. The specimens were stored in the laboratory at 65 ± 5% R. H. and **22 ± 3 °C**. The average result from two specimens was reported.