DURABILITY OF SELF-CONSOLIDATING CONCRETE IN PRECAST APPLICATIONS

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ABSTRACT

Self-Consolidating Concrete (SCC) has been used in many countries including in the United States. Production of SCC has been made possible due to the availability of newer admixtures based on polycarboxylate technology. The desire slump flow from 20 to 30 inches can be easily produced on a daily basis with this advanced admixture technology.

The use of pozzolanic materials, such as fly ash, slag, calcined shale, and limestone powder helps the SCC to flow better. The pozzolanic reaction in SCC, as well as in Conventional Slump Concrete (CSC), provides more durable concrete to permeability and chemical attacks.

Self-Consolidating Concrete, like any other conventional slump concrete, requires proper air entrainment when subjected to freeze-thaw conditions. The combination of polycarboxylate admixture for flow and air-entraining admixture is the key to durable concrete subjected to freeze-thaw.

This paper emphasizes he durability aspects in precast applications. Sets of data are presented including permeability, drying shrinkage, scaling resistance, hardened air-void analysis, and freeze-thaw durability.

Keywords: Self-Consolidating Concrete, SCC, Durability, Precast, Strength, permeability, drying shrinkage, scaling resistance, air-void analysis, freeze-thaw

INTRODUCTION

Self-Consolidating Concrete (SCC) was introduced in Japan in the late 1980's[1,2]. The use of SCC spread quickly to Europe and other continents. In the United States, SCC is still a relatively new technology that is well suited for precast applications. This technology allows significant improvements compared to conventional slump concrete, in terms of workability or slump flow ability. No vibration is necessary, and better quality concrete can be produced on a daily basis. These benefits impact designers and clients, contractors, and precasters. Some of the benefits for designers and clients are more innovative designs, more complex shapes, faster construction, improved durability, and better appearance. While for contractors, the benefits are reduced formwork, placement, finishing costs, less manpower, improved safety, and shorter construction program. For the precasters, the benefits are more savings on formwork and manpower, rapid placing, and improved safety.

Typical SCC applications in precast industries are double tees, wall panels, jail cells, utility vaults, as well as architectural precast.

In general, the SCC mixtures require more fine particles in order to have a good flow and avoid segregation and bleeding. Normal CSC may need about 38% of fine particles, while SCC mixture needs about 8% more fine particles. This additional fine particle could be achieved from replacing cement by weight with ground granulated blast-furnace slag or pozzolans, such as fly ash, slag or pulverized calcined shale (PCS) since the specific gravity of these materials are lower than that of cement (3.15).

RAW MATERIALS AND FRESH SCC PROPERTIES

In this study, Rotondo Precast in Fredericksburg, VA used Type III cement and pozzolans, with total cementitious materials content of 750 lbs. Table1 shows the raw materials used for this study.

Table 1: Raw materials* used for the study.

Cement	Type III	750	lb/cu.yd.
Sand	Natural sand		
Stone	¾ in. max		
Slag**		30%	Cement Replacement
Pulverized Calcined Shale **		30%	Cement Replacement
Water / cementitious materials ratio		0.37	
Admixtures	HRWRA***	as needed	
	Air-entraining	as needed	

*Mix proportions are proprietary of Rotondo Precast, Fredericksburg VA
** Slag OR Pulverized Calcined Shale (PCS) was used as cement replacement
*** High Range Water Reducing Admixture (ViscoCrete 6100) is polycarboxylate polymer based on ViscoCrete ®Technology from Sika Corporation, Lyndhurst NJ

Table 2 shows different mixes for each combination of cementitious materials. The slump flow tends to improve slightly when pozzolan was used. The significant improvement was in the T_{50}, where cement/PCS mixture was used. However, the accuracy of the T_{50} results was unclear whether it can be used as an indicator of lower yield stress and viscosity or not. The air content in all the mixes was relatively stable indicating that the high-range water-reducing admixture used did not impact air-entrainment.

Table 2: Fresh concrete properties

	Slump Flow (in.)	T_{50} (Sec)	Unit Weight (lb/cu.ft)	Air Content (%)
Straight cement (III)	23.8	2.5	141.0	6.2
	25.0	2.2	142.0	6.0
Cement/Slag (70/30)	24.8	2.6	144.0	5.3
	25.0	2.9	145.6	4.4
	24.0	3.6	146.0	6.6
	25.5	2.2	140.0	6.3
	27.3	2.2	141.0	5.0
Cement/PCS (70/30)	24.0	5.6		5.1
	25.0	5.2		7.0
	26.0	4.8		5.2

STRENGTH DEVELOPMENT

The strength development of the three different mixes is plotted in Fig.1. As expected, the early age strength of the straight cement was slightly higher compared to mixtures with pozzolan. However, the 28-day strength was very similar.

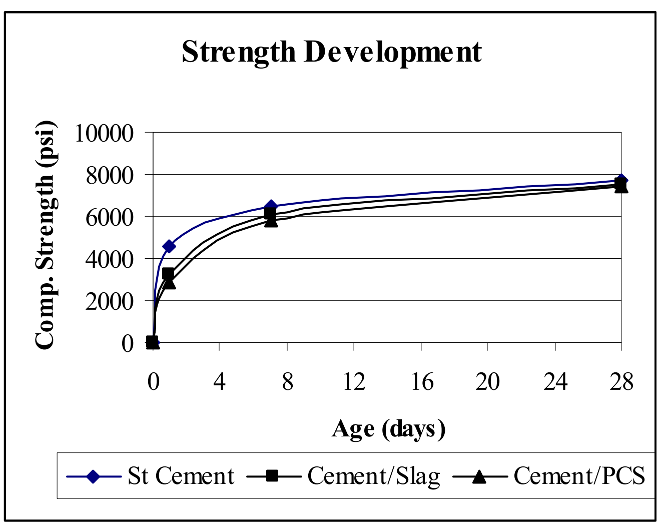

Fig. 1. Strength development of mixtures

HARDENED SCC PROPERTIES

A. PERMEABILITY (ASTM C 1202)

The ASTM C 1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration" is considered as an indication of chloride ion penetration into concrete. There are pro and contra to this test method. However, this is the available test method accepted by some, if not most, Department of Transportation. The result in Fig.2 shows that slag as well as calcined shale helps reducing the electrical charge passed through concrete. The chloride ion penetrability of straight cement mixture (samples #1 and #2) is categorized as "Moderate" (2000 to 4000, Table 1 Ref. 3). The mixtures with slag (samples #3 to #7) or calcined shale (samples #8 to #10) show improvement from Moderate to "Low" (1000 to 2000) or "Very Low" (100 to 1000).

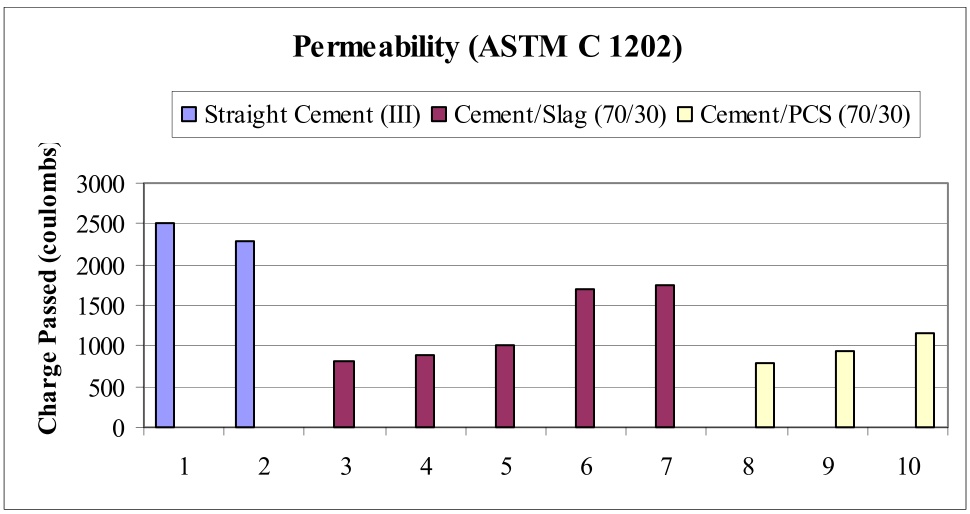

Fig.2. The electrical charge (coulomb) of the samples with different mixture proportions.

B. DRYING SHRINKAGE

Fig.3. shows the drying shrinkage results of different mixture proportions. The straight cement samples (#1 and #2) tested @14 days had the highest drying shrinkage values. The mixture with slag and calcined shale had lower drying shrinkage tested @28 days.

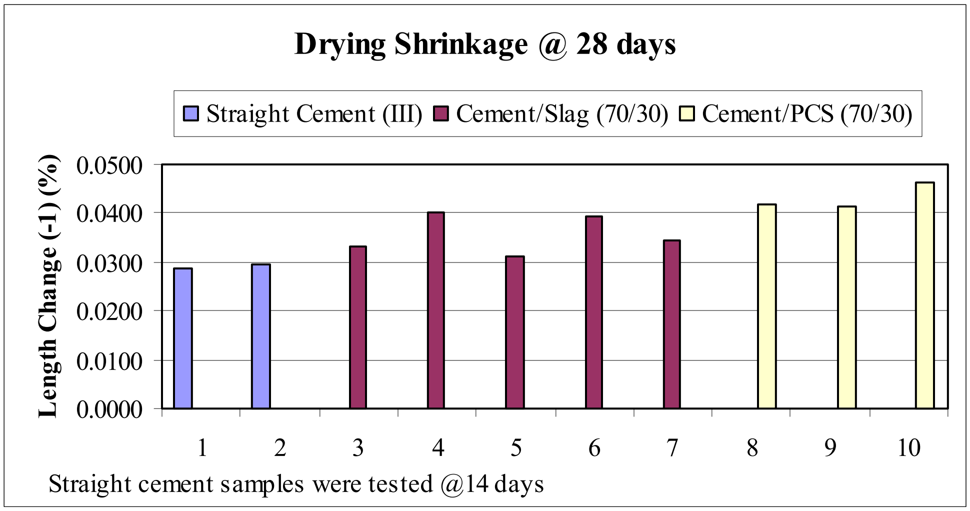

Fig.3. Drying shrinkage of samples with different mixture proportions.

C. SCALING RESISTANCE (ASTM C-672)

The scaling test was conducted as required by Maryland State Highway Administration. The samples were stripped @20 to 24 hours after casting and cured in moist room for 14-day @73°F $\pm$ 3°F.and let them dry for additional 14 days. No surface treatment was done for all these samples. Deicing solution used was 4 grams anhydrous calcium chloride diluted into 100 ml. of water. Approximately ¼ to ½ inch of solution was maintained on the top of the surface of concrete. Results of the mixtures of containing slag and PCS are shown in the Table 3 with no indication of scaling on all samples.

Table 3: Scaling Resistance of mixtures with slag and calcined shale.

Cycles	Time (days)	Cement/Slag Rating	Cement/PCS Rating
0	0	0	0
5	7	0	0
10	14	0	0
15	21	0	0
25	35	0	0
50	70	0	0

Note: Rating 0 = no scaling, while rating 5 = severe scaling.

D. HARDENED AIR PROPERTIES (ASTM C-457)

The hardened air properties are important parameters in achieving durable concrete due to freeze-thaw. The good air-void system should have proper air entrainment and spacing factors as measured based on ASTM C-457. The hardened concrete was sliced and polished to get smooth surface and observed under microscope.

The results of the mixture with PCS were presented in Table 4. The air content in hardened concrete was slightly lower than that of companion sample of fresh concrete. The specific surface area for sample A was above the higher limits, while sample B was within the limit. The void frequency was greater than 8 as recommended.

Table 4: Hardened air properties of concrete with PCS

	A	B	Recommended values
Air Content,%	4.18	6.37	
Specific surface area, in^2/in^3	1,151	892	600-1100
Spacing factor, in.	0.0050	0.0053	0.004 - 0.008
Void Frequency	12.03	14.22	>8
Cement Paste Content, %	33.54	33.30	
Paste - Air Ratio	8.03	5.22	
Traverse Length, in.	95.7	98.1	
Traverse Area, $in.^2$	19.4	19.6	
Number of stops	1,914	1,961	
Maximum aggreagate size, in.	3/4	3/4	

E. FREEZE-THAW DURABILITY FACTOR (ASTM C-666)

Freeze-thaw test was conducted for straight cement and cement/PCS mixtures for 300 cycles using procedure A of ASTM C-666, “Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing”. Both samples have 96% durability factor, and low weight loss (0 and 0.8%) as shown in Table 5. VTRC limit for durability factor is 60%, and weight loss is 7.0%. Both samples had excellent resistance to freeze-thaw due to proper combination of superplasticizer and air-entraining admixtures.

Table5: Freeze-thaw Resistance of straight cement and cement/PCS mixtures.

Mixture	Durability factor (%)	Weight loss (%)
Straight cement	96	0
Cement/PCS	96	0.8
VTRC limits	60 (min)	7.0 (max)

CONCLUSIONS

- Self-Consolidating Concrete, as well as Conventional Slump Concrete, requires proper mixture proportion to become a durable concrete.
- The use of pozzolanic materials, such as slag or pulverized calcined shale will help concrete to be more durable when subjected to chloride ion and length change (drying shrinkage).
- The use of proper superplasticizing admixture (in this case polycarboxylate polymer) in combination with proper air-entraining admixture is the absolute key to durable concrete due to freeze-thaw and scaling.
- Hardened air properties could be used as an indication whether concrete will survive the freeze-thaw or not. Proper air-void system will ensure that concrete will survive in the harsh environment due to freeze-thaw cycles.

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