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THE EFFECTS OF VISUAL STABILITY INDEX ON PROPERTIES OF SELF CONSOLIDATING CONCRETE UNDER ACCELERATED CURING

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Self-consolidating concrete, also known as self-compacting concrete (SCC), is a highly flowable concrete that spreads into place and fills formwork without the need for mechanical vibration. SCC reduces the time and labor cost needed for concrete placement. This study is part of the proposed project by Tennessee Department of Transportation (TDOT) carried out by University of Tennessee at Chattanooga (UTC) to develop four new SCC mixtures (two Class P-SCC (precast) and two Class A-SCC (general use), and insure they meet the minimum strength and durability requirements for TDOT Class P and Class A mixtures. The objectives of the study are to analyze effects of visual stability index (VSI) on both fresh and hardened properties of Class P-SCC concrete under the accelerated curing condition. In addition, the relationship between VSI and fresh segregation of SCC is investigated. A total of 24 concrete mixtures varying in VSI values were produced for the study. Different sizes of coarse aggregates materials were used during the mixing process, as well as different kinds of sands. A number of fresh and hardened properties tests were performed on the concrete mixtures to assess the performance of the mixes. The SURE CURE system is used to accelerate the curing process of the concrete. Finally, the results of this study are analyzed according to the coarse aggregate sizes and evaluated to recommend performance specifications for Class P-SCC for TDOT adoption of SCC standard operating procedures of the precast elements.

Keywords: Fly ash, Slump flow, J-ring, Fresh segregation.

1 INTRODUCTION

The concept of SCC was proposed by Professor Hajime Okamura of Kochi University of Technology, Japan, in 1986 as a solution to the growing concrete durability concerns of the Japanese government. During his research, Okamura found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, he eliminated the main cause for the poor durability performance of their concrete. By 1988, the concept was developed and ready for the first real scale tests (Vachon 2002). Generally, SCC is made with conventional concrete materials with the addition of chemical admixture such as viscosity-modifying admixture (VMAs) to enhance cohesion and control the tendency of segregation resulting from the highly flowable SCC (ACI 2007, Elhassan 2014). Also, the fine aggregate content in SCC is higher than that for conventional concrete in order to provide better lubrication for course aggregates to enhance workability of the mixture (Adekunle 2012). The use of SCC can result in increased productivity in construction, improved jobsite safety, and improved hardened properties. Although SCC can potentially decrease total project costs through minimization of labor, SCC can result in a higher per unit cost compared to conventional concrete due to increased Cementious materials, chemical admixtures, more strict specifications and the need for the advanced technical expertise. The proper selection of materials and mixture proportions is an important factor to ensure that the advantageous properties of SCC can be achieved economically. The effects of individual constituents and changes in mixture proportions are often greater in SCC than in conventional concrete (Koehler 2007).

2 MATERIALS

Materials used in SCC are the same materials used in conventional concrete. Although SCC can be made with a wide range of materials, the proper combination of the materials is crucial for optimizing SCC. Compared to conventional concrete, SCC is more sensitive to changes in material properties (Koehler 2007). Cementious materials, Aggregates and Chemical admixtures were the main components used to produce SCC, in addition of water. SCC mixtures that produce satisfactory results typically have between usually have 650 lb/yd^3 to 840 lb/yd^3 (385 kg/m^3 to 500 kg/m^3) cementious materials content (Mata 2004). Portland cement (ASTM C150) Type I and Class F (ASTM C618) fly ash were the only cementitious materials used in this study. SCC typically contains both types of aggregate fine and coarse aggregate. For Fine aggregate or sand, all normal concreting sands are suitable for SCC. Both manufactured (crushed) and natural (rounded) sands were used in the study. For Coarse Aggregates, all types of aggregates are suitable. The normal maximum size is generally 16-20 mm; however particle sizes up to 40 mm or more have been used in SCC. The aggregate sizes used in this study were ASTM C 33 #67 Stone, #7 Stone, and #89 Stone. All the coarse aggregates had bulk specific gravity of 2.74 and absorption of 0.62 % (EFNARC 2002). Two types of chemical Admixtures used in the study to meet the requirements of ASTM C494, Mid-Range water reducer MasterPolyheed 900 which was used for the conventional concrete and High-Range water reducer (HRWR) ADVA® Cast 575 was used for SCC to maintain a relatively low water cement ratio (w/cm) while increasing fluidity. The deformability of the paste is increased by reducing the viscosity. HRWRA can provide a highly flowable concrete without a significant reduction in cohesiveness and improve the resistance to segregation (ACI 2007, Khayat *et al.* 2004).

3 MIX DESIGN

Two sets of mixtures were developed to assess the effect of VSI on both hardened and fresh properties of Class-P SCC. Each set consist of four Trial mixtures groups. Portland cement was used only as cementitious materials on the first batch, whereas portland cement plus Class-F fly ash is used in the second set. Fly ash was designed to be 20% of the cementitious materials in the second batch. Mixture proportions are provided in Tables 1 and 2.

Table 1. TDOT Class A mixtures with Portland cement.

Mixture No	1	2	3	4	5	6	7	8	9	10	11	12
VSI	1	2	Conv.	1	2	Conv.	1	2	Conv.	1	2	Conv.
Cement	678	678	678	678	678	678	678	678	678	678	678	678
Class F-Ash	0	0	0	0	0	0	0	0	0	0	0	0
# 67 stone	1551	1551	1735	1550	1550	1735	0	0	0	0	0	0
# 7 stone	0	0	0	0	0	0	1551	1551	1735	0	0	0
# 89 stone	0	0	0	0	0	0	0	0	0	1551	1551	1735
Natural sand	1470	1470	1295	0	0	0	1470	1470	1295	1470	1470	1295
Man. sand	0	0	0	1550	1550	1364	0	0	0	0	0	0
Water	304	304	304	304	304	304	304	304	304	304	304	304
H/MRWR (oz./cwt)	7	9	4	7	9	4	7	9	4	7	9	4
w/cm ratio	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sand ratio by volume	0.5	0.5	0.44	0.5	0.5	0.44	0.5	0.5	0.44	0.5	0.5	0.44

Table 2. TDOT class A mixtures with 20% cement replacement of class F fly ash.

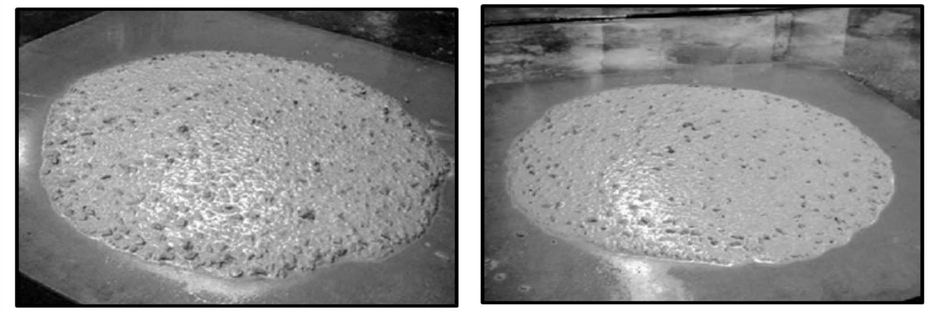
Mixture No	13	14	15	16	17	18	19	20	21	22	23	24
VSI	1	2	Conv.	1	2	Conv.	1	2	Conv.	1	2	Conv.
Cement	543	543	543	547	547	547	543	543	543	543	543	543
Class F-Ash	135	135	135	131	131	131	135	135	135	135	135	135
# 67 stone	1536	1536	1720	1536	1536	1720	0	0	0	0	0	0
# 7 stone	0	0	0	0	0	0	1536	1536	1720	0	0	0
# 89 stone	0	0	0	0	0	0	0	0	0	1536	1536	1720
Natural sand	1455	1455	1280	0	0	0	1455	1455	1280	1455	1455	1280
Man. sand	0	0	0	1535	1535	1350	0	0	0	0	0	0
Water	304	304	304	304	304	304	304	304	304	304	304	304
H/MRWR (oz./cwt)	7	9	4	7	9	4	7	9	4	7	9	4
w/cm ratio	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Sand ratio by volume	0.5	0.5	0.44	0.5	0.5	0.44	0.5	0.5	0.44	0.5	0.5	0.44

4 ACCELERATED CURING

Accelerated curing is a way to achieve high early age strength. This practice is most common in the precast industry, where there is a need for concrete elements to be casted and transported as quickly as possible to the site. The idea behind the accelerated curing is by increasing the concrete temperature, the rate of hydration increases and a larger portion of the later-age properties of the concrete can be attained during the short curing period compared with standard temperature curing. The concrete specimens were cured under the accelerated curing for 18 hours. The rate of temperature increments was set to be less than 50 °F per hour to avoid cracking, starting from 80°F up to 155°F in a time of 18 hours.

Table 3. Testing protocol.

Fresh Concrete Testing	
Slump Flow and Visual Stability Index (ASTM C1611)	1 per batch
Consolidating ability by J-Ring (ASTM C1621)	1 per batch
Static Segregation by Column Test (ASTM C1610)	1 per batch
Unit Weight and Gravimetric Air Content (ASTM C138)	1 per batch
Air Content by Pressure Method (ASTM C231)	1 per batch
Hardened Concrete Testing	
Compressive Strength 1 (ASTM C 39)	2-6x12 inch cylinders per test time
Static Modulus of Elasticity1 (ASTM C 469)	The 2-6x12 compressive strength cylinders will also be used for modulus per test time
Splitting Tensile Strength 1(ASTM C 496)	2-6x12 inch cylinders per test time



VSI = 1 – No evidence of segregation and slight bleeding observed as a sheen on the concrete mass

VSI = 2 – A slight mortar halo # 0.5 in.(# 10 mm) and/or aggregatepile in the of the concrete mass

Figure 1. Visual stability index criteria.

5 FRESH AND HARDENED PROPERTIES TESTS

Twelve Batches of each mixture was undergone standard fresh and hardened property testing as outlined in Table 3. The variety of fresh consistencies coupled with segregation and strength results provided data to determine the acceptance/rejection threshold that TDOT will ultimately adopt.

6 VISUAL STABILITY INDEX

The Visual Stability Index (VSI) is a method for determining the segregation stability of the mixture, and to evaluate the relative stability of batches of the same SCC mixture. The VSI is determined through visually rating apparent stability of the slump flow patty based on specific visual properties of the spread. The SCC mixture is considered stable and suitable for the intended use when the VSI rating is 0 or 1, and a VSI rating of 2 or 3 gives an indication of segregation potential (ACI 2007). The VSI required for the mixtures in this study were VSI of 1 and 2. The desirable VSI values were achieved by varying the amount of HRWR used during mixing. Values of VSI of 1 and 2 were recorded according to (ASTM C1611/C1611M) as shown in Figure 1.

Table 4. The results of fresh properties tests.

Mix	VSI	Slump (in)	J-ring (in)	HRWR (oz./cwt)	Air (%)	Unit weight (lb./ft3)	Col. Seg. (%)
1	1	19	17	2.99	3.60%	142.9727	9.2%
2	2	25	21	3.89	4.70%	141.3549	23.3%
3	Conv.	5.25		0.00	3.40%	0	
4	1	22.5	17.5	3.44	5.30%	144.186	15.0%
5	2	24.75	19.75	6.58	1.50%	148.0283	7.7%
6	Conv.	3.25		6.21	3.90%	0	
7	1	23	18.75	4.49	3.10%	143.3771	12.3%
8	2	25.5	24	6.88	1.80%	145.3994	18.2%
9	Conv.	3		10.36	3.60%	0	
10	1	20.5	16	4.19	6.20%	139.1304	10.1%
11	2	22.5	18.25	5.09	5.60%	139.9393	8.3%
12	Conv.	3.5		4.14	3.00%	0	
13	1	23	18.75	7.18	5.60%	143.1749	1.3%
14	2	26.5	25	8.68	4.30%	145.3994	20.9%
15	Conv.	5		0.00	2.20%	0	
16	1	23	18	9.28	3.20%	143.3771	20.3%
17	2	25	21.75	11.37	3.20%	144.9949	9.7%
18	Conv.	4.25		6.21	3.10%	0	
19	1	20	18.25	3.39	4.40%	147.0172	8.0%
20	2	28.25	28	3.59	2.40%	143.5794	16.4%
21	Conv.	4		0.00	3.20%	0	
22	1	19	17	1.80	6.10%	140.546	10.1%
23	2	25	24.5	4.49	7.10%	139.1304	14.8%
24	Conv.	2		4.97	3.60%	0	

7 RESULTS

The results of the fresh properties test are presented in Table 4. The results of the hardened properties tests are shown in Table 5. The representations of the results are shown as a comparison between VSI 1 and VSI 2 for both fresh and hardened properties.

8 CONCLUSION

- In general, the #7 and #89 stone mixtures have better fresh properties than #67 stone mixtures. And have good hardened properties when combined with OPC only.
- The test results indicated that Class F fly ash mixtures have poor hardened properties (compressive strength less than 4000 psi), this could be attributed to the slow reaction process of the fly ash.
- The coarse aggregate #7and #89 mixtures are more convenient for making Class-P SCC mixtures when cement was used as the sole cementious materials.

Table 5. The results of hardened properties tests.

		18-hrs			**28 days**		
Mix	**VSI**	**Comp. (psi)**	**Tensile. (psi)**	**E. (ksi)**	**Comp. (psi)**	**Tensile. (psi)**	**E. (ksi)**
1	1	3540	360	4850	5580	460	5222
2	2	3830	255	5740	6310	351	4940
3	Conv.	3250	276	4972	5700	310	6063
4	1	4380	272	5093	6310	452	4827
5	2	5140	390	5618	7080	477	4757
6	Conv.	4405	338	4981	7015	457	8046
7	1	5005	254	4163	7280	386	6467
8	2	5185	289	4850	7750	398	6548
9	Conv.	4455	391	5174	7185	406	6467
10	1	4615	359	6871	6610	428	4975
11	2	4710	356	4293	7105	370	6007
12	Conv.	4250	341	4238	6230	298	5337
13	1	4825	304	4320	7360	536	5206
14	2	4640	322	7996	6225	457	5340
15	Conv.	2835	232	3537	6860	441	6013
16	1	3270	270	3442	5505	414	5128
17	2	3875	358	3125	6780	447	5908
18	Conv.	3335	261	4005	5860	435	5293
19	1	2520	190	3395	5205	385	4357
20	2	1845	205	3601	5010	341	4258
21	Conv.	3145	214	4378	5950	464	4980
22	1	2460	294	3631	4950	340	3858
23	2	2710	186	3229	5165	313	4341
24	Conv.	3565	259	4514	6490	345	5047

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