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THE EFFECT OF GROUND GRANULATED BLAST FURNACE SLAG AND SILICA FUME ON THE DURABILITY OF HIGH PERFORMANCE CONCRETE IN BRIDGE DECKS

Abdulaziz Alaskar
PhD Candidate and Lecturer, University of Toronto, Canada
King Saud University, Saudi Arabia

Douglas Hooton
Professor, University of Toronto, Canada

ABSTRACT

High-performance concrete typically has a low water to cementing materials ratio (w/cm), high binder content and may contain high levels of supplementary cementitious materials. The effects of ground granulated blast furnace slag (GGBFS) and silica fume (SF) on the durability of HPC were investigated. In this study, HPC mixtures at 0.33 w/cm were made with two sources of blended cements containing 8% SF mixed with 25 and 50% GGBFS replacements by mass of cement. The compressive strength, drying shrinkage, thermal deformation and transport properties were tested. The preliminary test results have shown that increased fineness of the blended cement enhances the transport and mechanical properties), but results in increased early age thermal deformation, drying shrinkage, leading to increased cracking potential.

Keywords: slag, silica fume, drying shrinkage, RCPT, strength

1. INTRODUCTION

High-performance concrete (HPC) has been widely used for the last couple of decades due to its superior performance (low transport properties and high compressive strength), offering substantial enhancement of durability of concrete construction. HPC has economic benefits, significantly reducing the maintenance costs and enhancing service life (Neville and Aitcin 1998). Researchers (Hooton, 2000; Rodriguez & Hooton 2003) have emphasized that slag replacements improve the transport preoperties and lower heat of hydration of HPC. The effect of level of cement, ground granulated blast furnace slag and silica fume on the durability of HPC were investigated. The compressive strength (ASTM C39, 2010), rapid chloride permeability test (RCPT) (ASTM Standard C1202, 2010), and drying shrinkage (MTO LS-435 R23, 2006) were tested. HPC is defined as a concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices (ACI 318-2014). The Ontario Ministry of Transportation (MTO) has specified HPC with 28-day limits of 50MPa compressive strength and RCPT of 1000 coulombs. But in a survey of 15 HPC bridge decks, the MTO found a high risk of increased early age cracking (MTO 2012), and as a result, use of HPC has fallen out of favour. It should be mentioned that in 2015, the MTO lowered the 28-day HPC strength requirement to 40 MPa.

2. RESEARCH MOTIVATIONS AND OBJECTIVES

Due to the typically high cementing materials content in HPC, it tends to be more vulnerable to developing high temperature gradients between the concrete temperature and ambient temperature. Susceptibility to thermal cracking in concrete depends on the heat evolved during cement hydration. Therefore, the influence of chemical and physical properties of GU8SF cement and GGBFS on the thermal characteristics of HPC needs to be well understood. This study is a part of ongoing PhD research on developing strategies to mitigate early-age transverse cracking in HPC bridge decks.

3. EXPERIMENTAL PROGRAM

The experimental program consists of various tests to assess durability, mechanical properties, and shrinkage properties. The cementing binder included CSA A3000 blended portland cement interground with 8% silica fume (Type GU-SF8) and ground granulated blast furnace slag (GGBFS). HPC was made with two sources of blended cements (A and C) containing 8% SF used together with 25 and 50% by mass replacement levels of GGBFS. The blended cement and slag were mixed at a water/binder ratio of 0.33. Table 1 shows the chemical and physical properties for the blended cements and slag. The total binder content was selected based on an MTO 50 MPa mix design obtained from one of the concrete ready mix suppliers. Table 2 shows mixture proportions of the HPC concretes. The superplasticizer and water reducer admixtures were used to maintain slump at 150±10 mm and to provide efficient dispersion.

The concrete mix proportions are shown in Table 2. Cylindrical specimens were used for tests including compressive strength and RCPT. The compressive strength was tested on cylinders of 100 mm in diameter and 200 mm in height. For RCPT, four 50 mm thick samples were cut from two cylinders on the day of testing, and prepared in according to (ASTM Standard C1202, 2010). Prismatic specimens (75x75x285 mm) were used to determine the drying shrinkage at 1, 7, 14, 21 and 28 days according to (MTO LS-435 R23, 2006).

Table 1. Blended cement and slag properties

	Cement Type GU8SF		GGBFS
Binder ID	A	C	I
Chemical Analysis (%)			
LOI	2	2.33	0.21
SiO_2	25.1	26.67	39.62
Al_2O_3	4.4	4.72	7.63
Fe_2O_3	2.7	2.23	0.53
CaO	57.3	56.71	39.51
MgO	2.6	2.23	10.8
SO_3	3.7	4.07	2.68
K_2O	-	-	0.39
TiO_2	-	-	0.36
Total Alkali (Na_2O_{eq})	0.91	0.91	0.27
Physical analysis			
Blaine fineness (m^2/kg)	582	787	587

Table 2. Concrete mixtures

Mixture ID	Ternary Binder %	GU8SF (kg/m^3)	GGBFS (kg/m^3)	Water (kg/m^3)	Fine agg. (Max 4.75mm)(kg/m^3)	Coarse agg. (Max. 19mm) (kg/m^3)	Fresh Density (kg/m^3)
A-I-25S	GU8SF (A)+25%GGBFS	349	116	153	624	1065	2366
A-I-50S	GU8SF (A)+50% GGBFS	233	233	153	621	1067	2345
C-I-25S	GU8SF (C)+25% GGBFS	349	116	153	622	1068	2372
C-I-50S	GU8SF (C)+50% GGBFS	233	233	153	620	1066	2355

*Note: A-I-25S; A (means blended cement of source A, and I is slag ID, 25S is the slag replacement)
* All aggregate quantities shown are in SSD condition.

Thermal deformations were measured in a semiadiabatic condition; the test set up for obtaining the thermal deformation and temperature profile is shown in Figure 1. An insulated 150 x 300 mm cylinder mold was surrounded with 50mm thick rigid polystyrene insulation and filled with concrete just after mixing. The room temperature was controlled at 25 ± 2 °C. The internal strain and the temperature of the specimens were obtained every 15 seconds by data acquisition.

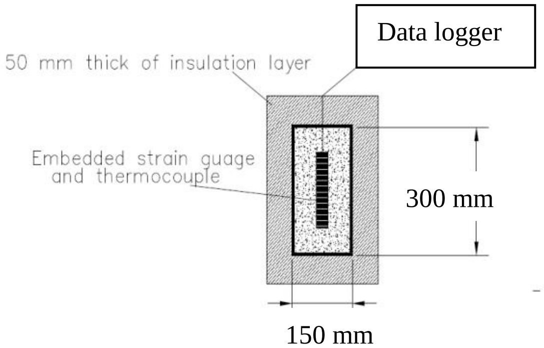
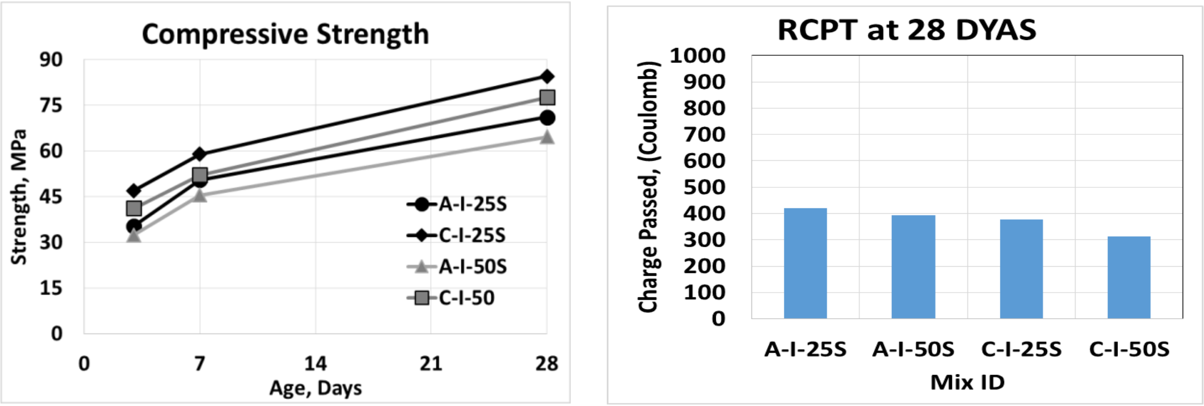


Figure 1. Test set-up for thermal deformation

4. TEST RESULTS

Compressive strength results are shown in Figure 2a. Strengths were tested at the ages of 3, 7, 28 days. Three cylinders were tested at each age and the average of the three was plotted. The development of compressive strength of all four HPC mixtures met the MTO requirement of 50 MPa by 28 days. It was observed that the compressive strengths of mixtures made with the lower fineness Cement A (A-I-25S and A-I-50S) were lower ranging between 15-33% than that of the higher fineness Cement C at all ages. The mixtures containing 50% slag replacement had 9-14% lower compressive strengths at the age of 3 days in comparison to those with 25% slag replacement. The 25% slag replacement met or exceeded that of the MTO 50 MPa requirement at age of 7 days. The 50% slag replacement at an age of 7 days, showed a delayed strength development, but the compressive strength of A-I-50S was 45MPa and C-I-50S reach 52MPa. At 28 days, all the 50% slag mixtures had 29-55% higher strengths in comparison to the MTO 50 MPa requirement.

The RCPT was performed to ensure the HPC mixtures met the MTO durability requirements. Four, 50-mm thick specimens were saw cut from two 100×200 mm cylinders and tested at an age of 28 days. Every specimen was vacuum saturated one day prior to testing. Specimens and water were placed under vacuum independently for three hours, and the specimens were then submerged in the de-aired water and the vacuum maintained for another hour. Results from the rapid chloride penetration test are shown in Figure 2b. The RCPT results are in the category of very low. The MTO specifies a maximum rapid chloride permeability of 1,000 coulombs (Very Low) or less at 28 to 32 days of age for HPC, and the four HPC mixtures reached RCPT results well below this limit at the age of 28 days. Since concrete used for bridge decks also has to meet either exposure class C-1 or C-XL (CSA Standard A23.1, 2014), the 56-day CSA chloride ion penetrability requirements are also considered.



a) b)

Figure 2: (a) Compressive strength development; (b) RCPT at age of 28 days

Figure 3 shows linear drying shrinkage versus time of drying until an age of 28 days. There was slight difference difference in shrinkage of the four mixtures during the first 1 day of drying (following 7 days of wet curing). It was observed that all four mixtures (A-I-25S, A-I-50S, C-I-25S, and C-I-50S) met the requirement of low-shrinkage concrete as defined by CSA 23.1 (2014), which is less than 0.040% shrinkage after age of 28 days of drying. At 28 days of drying, the most shrinkage was observed for mixtures made with Cement C; it can be attributed to the higher Blaine fineness of the cement. As well, with both cements, the mixtures with 50% slag had lower 28-day shrinkage than those with 25% slag.

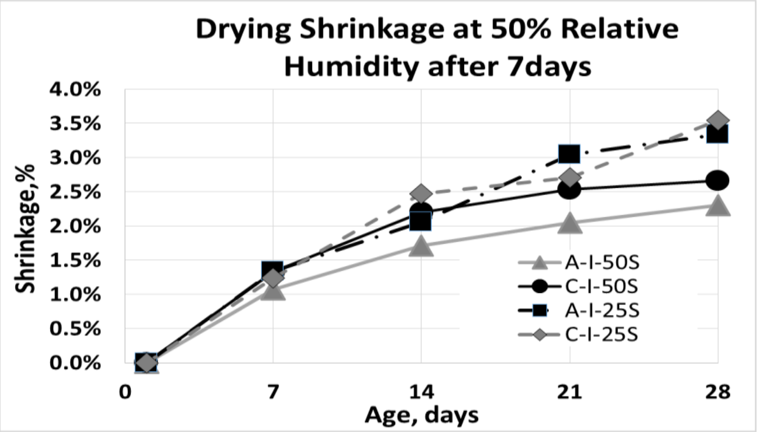


Figure 3: Drying Shrinkage of four HPC mixtures

Thermal deformation in conjunction with temperature profile versus time (up to 72 hours) are displayed in Figure 4 for two HPC mixtures (A-I-25S and A-I-50S). Thermal deformation started to take place almost immediately. The strain increased in conjunction with temperature rise due to the generated heat of hydration during the cement and water reaction at early stages. The thermal shrinkage of insulated and uninsulated specimens was almost identical from 4 to 12 hours of age (see Figure 4). The rate of deformation changed in conjunction with the temperature evolution between 6 and 12 hours, followed by a significant increase beyond 12 hours for A-I-25S. The measured ultimate thermal deformation at an age of 18-20 hours was reduced by up to 30% with 50% slag replacement. The peak temperature was 45 °C with 50% slag replacement compared to 60 °C with 25% slag replacement.

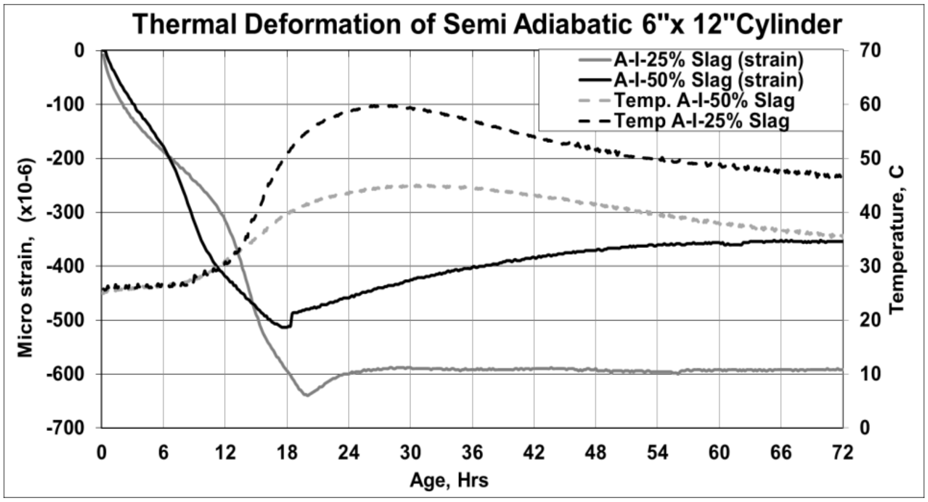


Figure 4: Measured strain and semi-adiabatic temperature rise of HPC concretes

5. DISCUSSION AND CONLUSIONS

The key benefit of using HPC for bridge deck applications is that it has enhanced resistance to chloride penetration (RCPT is low/or very low). Due to its low w/cm, use of high binder contents including silica fume, and other supplementary cementitious materials, HPC is essentially more vulnerable to the various types of early-age volume change, including autogenous shrinkage, and thermal shrinkage. The experimental results show that increasing the level of slag replacement and decreasing the fineness of the silica fume blended cement used, significantly improved both the strength and the drying shrinkage. The ternary HPC mixtures with 50% slag replacement exhibited lower drying shrinkage compared for the low slag replacement level. The RCPT results of HPC mixtures with 50% slag replacement met MTO standards with less than 1000 coulombs at 28-days of age. The thermal deformation increased as the concrete temperature increased; 50% slag replacement reduced the ultimate thermal deformation by up to 30%.

ACKNOWLEDGMENT

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