MATEC Web of Conferences **361**, 03001 (2022) https://doi.org/10.1051/matecconf/202236103001
Concrete Solutions 2022

De-icing salt resistance of high early-strength concrete for rapid repairs

Nader Ghafoori[1], *Matthew O.* Maler[1], *Meysam* Najimi[1], *Ariful* Hasnat[1*]

[1]Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas 4505 S Maryland Pkwy Street, Las Vegas, USA

Abstract. This paper examines the freezing and thawing resistance of high early-strength concrete (HESC) developed for rapid repair of pavements and bridge decks. The cement types chosen for this study included ASTM Type III, ASTM Type V, and Calcium Sulfoaluminate (CSA). A cement content of 386 kg/m^3 was maintained for all studied concretes. Specimens were tested after 24 hours and 28 days of curing in order to evaluate compressive and flexural strengths. In addition, the opening time was determined based on the required time to achieve the minimum compressive strength of 20.7 MPa. The freezing and thawing (F–T) resistance of the test samples were evaluated in accordance with the F–T duration of 96 hours per cycle for a total of 25 cycles. Test results revealed that at the opening time and after 24 hours curing, CSA cement concrete displayed the highest compressive and flexural strengths, but lowest resistance to freezing and thawing with de-icing salt. The 28-day cured Type V cement concrete produced the highest strength and de-icing salt resistance, while CSA cement concrete produced the contrary.

1 Introduction

In the construction industry, high early-strength concrete (HESC) was traditionally regarded as a concrete that achieves a required strength in matter of days rather than weeks [1-3]. With the recent advancement of cement technologies and chemical admixtures, this time has been reduced down to a matter of hours [4]. The required minimum opening time (time to open to traffic) compressive strength is determined on a case-by-case basis depending on the project. For example, in construction applications for structures and dwellings, the minimum compressive strength requirement is 17.2 MPa (IBC 2012), while in road and bridge construction the minimum requirement is typically 20.7 MPa [5]. Apart from achieving high early age strength, concrete should be durable enough to sustain against aggressive environmental conditions, such as snow and ice. According to the US Federal Highway Administration (FHWA), in the United States, more than 70% of roadways are affected during winter.

ASTM divides ordinary Portland cement (OPC) into five types (Type I to Type V). These types are categorized by their four main components, in addition to their particle size. Among these five types of cement, Type III, which is designed for high early-age strength, has both a high C_3S content and a high Blaine fineness. Another specialized type of proprietary cement named Calcium Sulfoaluminate (CSA) cement is commonly used in bridge or road repair works due to its very high fineness, rapid setting, and early strength development. However, the performance of these HESCs remains questionable is some cases. In most of the North American and European countries snow and ice poses severe problems to concrete pavements and bridges [6-8]. The information on de-icing salt resistance of rapid concrete repairs using traditional and specialized cements is still limited. Moffat et al. [4] partially replaced the Portland cement with CSA cement and observed an increased mass loss after 50 rapid F-T cycles as compared to the HESCs containing only Portland cement. Porras et al. [9] concluded that an increase in Type III cement reduced the dynamic modulus after 36 freeze-thaw cycles. With the growing deterioration of transportation infrastructure, it becomes imperative to understand the properties of different repair materials. In this study, the effect of cement type and curing duration on the bulk and de-icing salt resistance of different HESCs were investigated.

2 Experimental works

2.1. Materials

In the production of the HES concretes, ASTM Type V Portland cement, ASTM Type III cement, and Calcium Sulfoaluminate (CSA) cement were used as cementitious materials. The chemical compositions of these cements are provided in Table 1. The locally available fine and coarse aggregates used in this study complied with the size requirements of ASTM C136 and ASTM C33, respectively. The size gradation of the coarse aggregate is presented in Table 2. Polycarboxylate based high-range-water-reducer (HRWR), accelerating admixture, and air-entrainer (AE), all from the same manufacturer, were used to maintain the desired fresh and early-strength properties of the studied HESCs.

* Corresponding author: hasnat@unlv.nevada.edu

Table 1. Cement composition and blaine fineness.

Potential Compounds	ASTM Type V	ASTM Type III	CSA (Rapid set)*
C_3S (%)	58	50	Proprietary information
C_2S (%)	16	24	
C_3A (%)	4	11	
C_4AF (%)	12	4	
Blaine Fineness (m^2/kg)	420	496	>500

* C_3S and C_3A are in the form C_4A_3S

Table 2. Size gradation of coarse aggregate.

ASTM sieve size	ASTM #67	ASTM #7	Recombined distribution (%)
25.4 mm	-	-	-
19 mm	Used	-	5
12.7 mm	Used	Discard	35
9.5 mm	Used	Used	30
#4	Used	Used	30
#8	-	Discard	-

2.2. Mixture design

A total of three HESCs were prepared to determine the compressive and flexural strengths, and de-icing salt resistance expressed in mass loss. The mixture constituents and unit contents of the studied HESCs are presented in Table 3. The amount of cement was kept constant at 386 kg/m^3. The workability of the studied concrete was kept constant at 125±25 mm. To accelerate the hardening process, a higher amount of accelerating admixture was used for Type III and Type V cement concretes. A small amount of retarding admixture was also used in the CSA cement concrete. All studied concretes contained air-entraining admixtures (AE).

Table 3. Mixture proportions

ID	W*	C*	FA*	CA*	WRA*	Acc*	AE*
	kg/m^3						
Type V	121	386	933	1141	3.2	7.7	2.1
Type III	149	386	898	1097	1.9	7.7	1.9
CSA	144	386	865	1057	2.2	1.2#	0.1

*Note : *AE = Air Entrained ; W=Water; C = Total Cement ; FA= Fine Aggregate ; CA= Coarse Aggregate ; Acc= Accelerator; #Retarder.*

2.3. Casting, curing, and testing

A uniform mixing procedure, as presented in Figure 1, was used to prepare the test specimens. After placing concrete into the molds, specimens were densified for a period of approximately 7 seconds using a vibrating table. Both 24-hour and 28-day moist curing were utilized for all test samples. Cylindrical specimens with dimensions of 102 mm in diameter and 203 mm height were used to evaluate compressive strengths of the studied concretes at different ages in accordance with ASTM C39 [10]. Resistance to freezing and thawing with de-icing salt of the studied HESCs was evaluated in accordance with ASTM C672 [11] using cylindrical specimens having dimensions of 76.2 mm diameter and 152.4 mm height. Four samples per curing type were made to determine the average mass loss per freezing and thawing cycle. To start a four-day testing cycle, the samples were soaked in a 3% saltwater solution for 48 hours prior to placing into a freezer for 48 hours. The first 24 hours of soaking took place on a shelf in the laboratory. The second day of soaking took place in the pre-cooler which was set to 0° ± 1° C. After the samples had been in the pre-cooler for 24 hours, they were moved into the freezer with the cooling rate set to reach -14.4° ± 1° C at an elapsed time of 24 hours. At the end of the freezing cycle, samples were removed and placed inside the laboratory at room temperature (21° ± 2° C) for 24 hours of the thawing cycle.

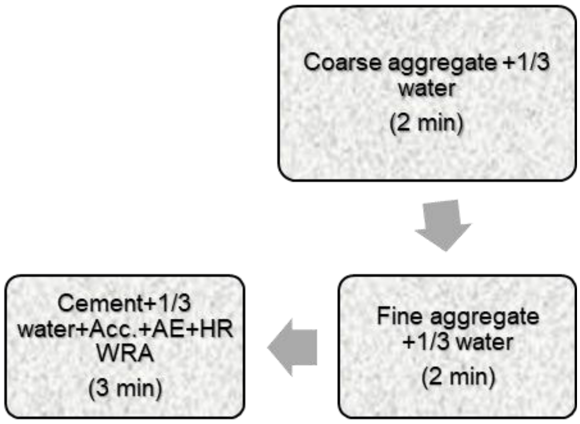

Fig. 1. HESCs' mixing sequence.

3 Results and discussion

3.1. Compressive strength

The influence of cement type and curing duration on compressive strength of the studied HESCs is presented in Table 4. As can be seen, All HESCs achieved the minimum compressive strength of 20.7 MPa at opening. The HESC containing CSA depicted the highest compressive strength at the opening time as compared to the Type V and Type III cement concretes. Highly fine particles and presence of calcium sulfate facilitated the concrete containing CSA to develop a very high early-strength in a short period of time as compared to the other two mixtures. However, as the duration of curing increased to 24 hours, the strength gap amongst the three HESCs was narrowed from 33% to 4%. In fact, the 28-day compressive strength of the concrete containing Type V cement became the highest amongst the three studied HESCs. Figure 2 presents the normalized strength development of the three studied HESCs. CSA cement concrete gained 44 and 82% of its 28-day strength at opening time and 24 hours, respectively. Type V and Type III cement concretes also performed well, gaining 70% compressive strength of the 28-day strength after 24 hours.

The flexural strengths of the studied HESCs are presented in Table 5. As can be seen, after 24-hour curing, Type V and CSA cement containing HESCs displayed 11% higher flexural strength as compared to that of the Type III cement concrete. However, after 28 days of curing, the HESC made using CSA cement displayed 21% lower flexural strength as compared to that of the Type V cement concrete. Averagely, 28-day cured HES concrete showed 31% higher flexural strength as compared to those of the 24-hour cured samples.

Table 4. Compressive strength of the studied HESC.

ID	OT (Hr)	Open. (MPa)	Diff. (%)	24-hour (MPa)	Diff. (%)	28-day (MPa)	Diff. (%)
Type V	6.5	24.6	-	57.9	-	83.2	-
Type III	5	23.6	-4.1	58.6	1.1	81.5	-2.1
CSA	1	32.7	32.9	60.5	4.4	73.9	-11

Note : OT=Opening time ; Open=Opening time strength; Diff.=Percent difference

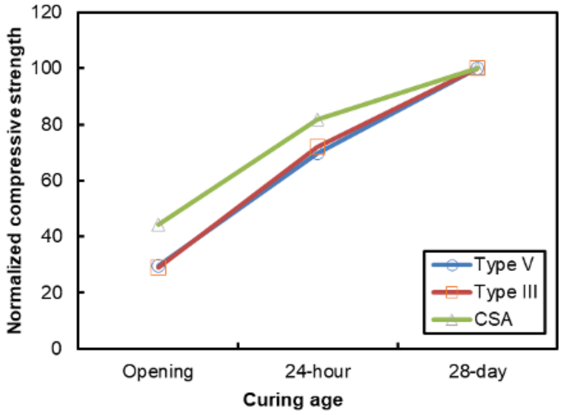

Fig. 2. Effect of curing age on normalized compressive strength of HESCs.

Table 5. Flexural strength of the studied HESCs.

ID	24-hour	Difference (%)	28-day	Difference (%)
Type V	7.4	-	10.3	-
Type III	6.6	-10.8	9.5	-7.8
CSA	7.4	0.0	8.1	-21.4

3.2. Mass loss

The de-icing salt resistance of the studied HESCs at different freezing and thawing cycles is presented in Figures 3 and 4, respectively, for the 24-hour and 28-day cured samples. Overall, it was observed that the frost resistances of 28-day cured concretes were superior to those of 24-hour cured concretes. The ultimate mass loss of the 28-day cured concretes was averagely 37% lower than those of the 24-hr cured concretes. The HESC containing CSA cement displayed the highest mass loss for both 24-hour and 28-day cured specimens. After 25 F-T cycles, the 24-hour cured CSA cement concrete lost one third of its mass, whereas Type V and Type III cement concretes lost only 3 and 5% of their mass, respectively. Once curing age was extended to 28 days, CSA cement concrete continued to display a higher mass loss as compared to the mass loss obtained for the other two studied HESCs.

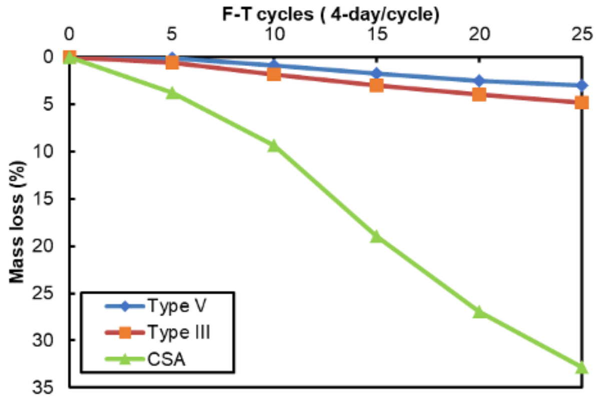

Fig. 3. Mass loss 24-hour cured HESCs.

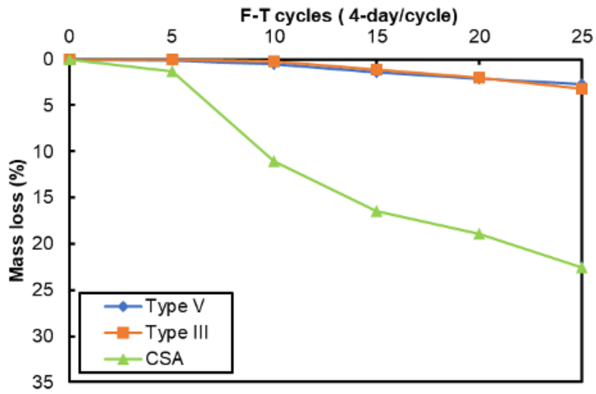

Fig. 4. Mass loss 28-day cured HESCs.

4 Conclusions

Based on the results of this study, the following conclusions are made:

- All studied high early-strength concretes achieved the required minimum compressive strength of 20.7 MPa at the opening times of 1, 5, and 6.5 hours for the HESCs containing CSA, Type III, and Type V cements, respectively.
- HESC containing CSA cement displayed higher strength at the opening time and 24 hours, whereas Type V and Type III cement concretes showed higher strength once the curing age was extended to 28 days.
- HESC containing CSA cement displayed poor de-icing salt resistance, making it unsuitable for rapid repair applications in the cold regions. Both Type V and Type III cement concretes performed well against the 25 repeated F-T cycles, keeping their mass losses below 5%.

Acknowledgements

This study was made possible by the financial contributions of The US Federal Highway Administration through UTC Solaris Consortium. Thanks are also extended to a number of producers and manufacturers for providing materials used in this investigation.

References

1. Li, M., & Li, V. C. (2011). High-Early-Strength Engineered Cementitious Composites for Fast, Durable Concrete Repair-Material Properties. *ACI Materials Journal,* 108(1), 3-12.
2. Naik, T. R., & Ramme, B. W. (1990). High Early Strength Fly Ash Concrete for Precast/Prestressed Products. *PCI Journal*, 35(6), 72-78.
3. Soroushian, P., & Ravanbakhsh, S. (1999). High-Early-Strength-Concrete: Mix Proportioning with Processed Cellulose Fibers for Durability. *Materials Journal*, 96(5), 593-600.
4. Moffatt, E. G., & Thomas, M. D. (2018). Durability of Rapid-Strength Concrete Produced with Ettringite-Based Binders. *ACI Materials Journal*, 115(1), 105-115.
5. Maler, Matthew O. (2017). High Early-Age Strength Concrete for Rapid Repair. MSc Diss. University of Nevada, Las Vegas.
6. Yu, W., Yi, X., Guo, M., & Chen, L. (2014). State of The Art and Practice Of Pavement Anti-Icing And De-Icing Techniques. Sci. Cold Arid Reg, 6(1), 14-21.
7. Habibzadeh-Bigdarvish, O., Yu, X., Lei, G., Li, T., & Puppala, A. J. (2019). Life-Cycle Cost-Benefit Analysis of Bridge Deck De-Icing using Geothermal Heat Pump System: A Case Study of North Texas. Sustainable Cities and Society, 47, 101492.
8. Mehta, P. K., & Burrows, R. W. (2001). Building Durable Structures in the 21st Century. *Concrete International,* 23(3), 57-63.
9. Porras, Y., Jones, C., & Schmiedeke, N. (2020). Freezing and Thawing Durability of High Early Strength Portland Cement Concrete. *Journal of Materials in Civil Engineering,* 32(5), 04020077.
10. ASTM C39 / C39M-20, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, *ASTM International*, West Conshohocken, PA, 2020, www.astm.org
11. ASTM C672-03, Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals, *ASTM International*, West Conshohocken, PA, 2020, www.astm.org