Properties of high early-strength Type V cement concrete for rapid repair

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Abstract. This study examines the suitability of ASTM Type V cement concrete for rapid repair applications. To this end, experimental results on transport and durability properties of high early-strength concretes using ASTM Type V cement were compared with those of a more traditional cement used for rapid repair, i.e. Type III cement. A cement content of 445 kg/m^3 (750 lb/yd^3) was maintained for all studied concretes. The experimental program included compressive strength, absorption, rapid chloride migration, corrosion resistance, and mass loss due to freezing and thawing regimes. The results of this study revealed that use of Type III and V cements were both effective for concrete rapid repair applications. The opening time to reach the minimum compressive strength of 21 MPa (3000 psi) was found dissimilar. Type III cement concrete showed better strength properties at early ages due to its high fineness. However, as curing age was extended to 24 hours and 28 days, Type V cement concrete produced higher strength results. Moreover, Type III cement concretes failed to display better performance in transport properties, corrosion, and frost resistance when compared to that of the studied Type V cement concretes.

1 Introduction

The infrastructure annual report published by the American Society of Civil Engineers (ASCE) depicted that the infrastructure of the United States received an overall D$^+$ grade where A stands for best and F is for the worst [1]. More than two trillion dollars have been needed to repair American infrastructure alone [2]. As a result, extensive research has been conducted on repair and retrofitting of existing structures [9-11]. For structures like buildings, it is easy to repair without making a colossal effort. However, for a reinforced concrete bridge or concrete highway repair, the scenario is quite different. Before repairing a deteriorated bridge or a highway pavement, significant planning and considerable time are required to make the transportation infrastructures serviceable. Recent studies have found that traffic congestion dominates the life-cycle social costs due to construction-related congestion, operation interruption, wasted time and fuel cost, vehicle damage as a result of poor road conditions, safety concerns, and environmental impact during maintenance and repair operations [3].

In this context, in recent years, several propriety cementitious materials and admixtures have been developed for rapid repair of concrete structures [4]-[6]. However, for all practical purposes, most of them do not deliver as promised. Additionally, these newly-developed materials are far more expensive than the parent material used for construction. To this end, viable alternatives are needed for rapid repair works. ASTM Type III cement has high fineness and high C_3S content that helps in early age strength development, making it to be a viable solution for rapid repair [7]. However, the concerns over its wide-spread availability and long-term strength and durability have given an impulse to consider other ASTM cement types for rapid repair [8].

2 Experimental Procedure

2.1 Materials

The fine and coarse aggregates used in this study were obtained from a local quarry in Nevada. The physical properties of the coarse and fine aggregates are presented in Table 1. ASTM C136 and ASTM C33 were used to determine size distribution of the aggregates. ASTM Type III and Type V cements were used in this study. Polycarboxylate high-range-water-reducing (HRWR), and air-entraining (AE) admixtures were used to maintain the desired fresh properties of concrete.

2.2 Mixture constituents and proportions

A total of four mixture proportions were selected to evaluate the mechanical and transport properties of concrete. The selected mixture proportions are given in Table 2. The total cement content was kept constant. To accelerate the hardening process, a higher amount of accelerating admixture was used. Among the four studied mixes, two of them contained air-entraining

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Table 1. Aggregate properties.

Aggregate type	Bulk specific gravity (OD)	Bulk specific gravity (SSD)	Absorption (%)
Fine aggregate	2.76	2.78	0.81
Coarse aggregate	2.73	2.76	0.82

Table 2. Mixture proportions

Mixture id	w/cm	C* (kg/m^3)	FA* (kg/m^3)	CA* (kg/m^3)	HRWR* (kg/m^3)	Acc* (kg/m^3)	Air entrainer (kg/m^3)
Type III	0.35	445	848	1037	1.65	8.90	-
Type III-AE	0.35	445	848	1037	1.37	8.90	2.30
Type V	0.275	445	890	1088	2.91	8.90	-
Type V-AE	0.275	445	890	1088	2.80	8.90	2.50
*Note : *AE = Air Entrained ; C = Total Cement ; FA= Fine Aggregate ; CA= Coarse Aggregate ; Acc= Accelerator*							

admixtures (AE). A constant workability of 125±25 mm (5±1 in.) was maintained for all studied concretes.

2.3 Mixing, sampling, curing, and testing

A pan-style counter-current mixer with a capacity of 0.0283 m^3 (1 ft^3) and a constant speed of 60 RPM was used. Upon molding, specimens were densified for a period of approximately 7 seconds, longer as workability decreased, using a vibrating table operating at 6200 Hertz. Two different curing types; namely 24 hours curing and 28 days moist curing were utilized. Cylindrical specimens with dimensions of 102 mm (D) x 203 mm (L) (4in. x 8 in.) were used to evaluate compressive strengths of the studied concretes in accordance with ASTM C39. Three transport and durability properties were evaluated. These properties were: Absorption, Rapid Migration (RMT), and Accelerated corrosion Tests. The absorption properties of the studied high early-age strength concretes were evaluated in accordance with ASTM C642 using cylindrical specimens with a diameter of 102 mm (4 in.) and a height of 51 mm (2 in.). These properties included absorption after immersion, absorption after immersion and boiling, and volume of permeable pore space (Voids). Rapid Migration Tests (RMT) of the studied high early-age strength concretes studied were conducted in accordance with NT Build 492 (Figure 1a). The corrosion tests were conducted using 102 mm (4 in.) x 152 mm (6 in.) cylindrical specimens in accordance with FM S-522 (Figure 1b). To evaluate the durability properties of the studied high early-age strength concretes, the mass losses due to freeze/thaw with de-icing salt tests were conducted in accordance to ASTM C672.

3 Results and Discussion

3.1 Compressive strength

The required time to achieve 21 MPa compressive strength (The opening time) using Type III and Type V cement concrete is given in Figure 2. It is observed that, the opening time for Type III cement concrete was lower as compared to that of Type V cement concrete. This is due to the higher fineness and presence of a high amount of C_3S in Type III cement. Also, air-entraining admixture acted as a retarder to the concrete and increased the opening time for both Type III and type V cement concretes. The effect of curing age and cement type on the compressive strength is shown in Figure 3 Concrete with air-entrainment showed lower compressive strength compared to the non- air-entrained concrete. This is mainly due to presence of higher porosity in air-entrained concrete compared to the non air-entrained concretes. In contrast to the early age strength performance of type III cement concrete, its 24 hour and 28 day cured strengths fell below those Type V cement concrete.

(a) (b)

Figure 1. Test setup to evaluate the transport properties of concrete (a) Rapid migration test, (b) Accelerated corrosion test.

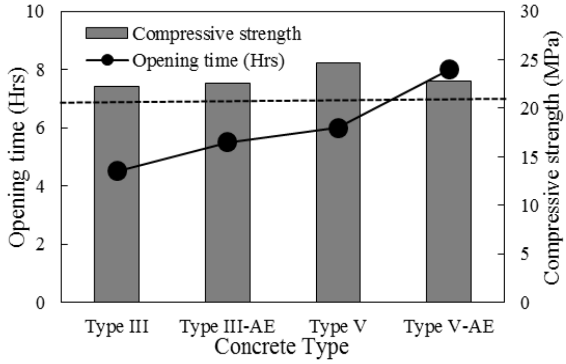

Fig. 2. Opening time-compressive strength of concretes made with Type III and Type V cement with and without air-entrainment (AE).

3.2 Absorption capacity

Absorption and permeable void percentage of concrete at different test ages is presented in Table 3. The absorption and void percentage found to be high when air-entraining admixture was added to the mixtures. Curing played an important role in reducing the absorption and percentage of permeable voids in the concrete. With 28 days curing, the percentage voids reduced significantly for both studied Type III and Type V cement concretes. The absorption and volume of voids of Type V cement concretes were considerably lower than those of Type III cement concretes.

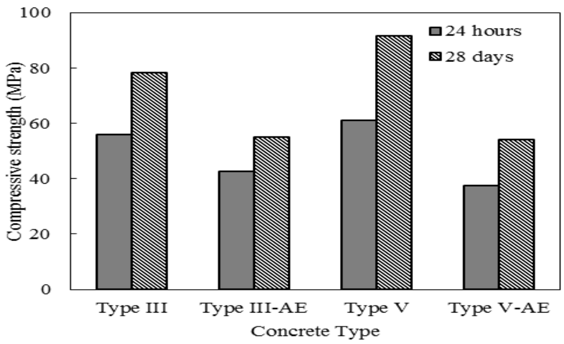

Fig. 3. Compressive strength of concretes made with Type III and Type V cement with and without air-entrainment (AE).

Table 3. Absorption and permeable voids of concrete at different curing ages.

Mixture ID	Curing age	Absorption after immersion (%)	Absorption after immersion and boiling (%)	Volume of permeable voids (%)
Type III	24 hours	4.56	4.69	11.20
	28 days	2.01	2.14	5.19
Type III-AE	24 hours	4.65	5.00	11.26
	28 days	2.76	3.05	6.89
Type V	24 hours	2.18	2.66	7.17
	28 days	0.89	1.32	3.33
Type V-AE	24 hours	3.42	4.02	8.98
	28 days	1.84	2.12	4.73

3.3 Rapid chloride migration test (RMT)

The chloride penetration depth through a rapid chloride migration test (RMT) is presented in Figure 4. The studied 24 hour cured Type III cement concrete performed slightly better than the companion Type V cement concrete for both non air-entrained and air-entrained mixtures. However, after 28 days curing, the chloride penetration for Type V cement concrete was less than that of the Type III cement concrete.

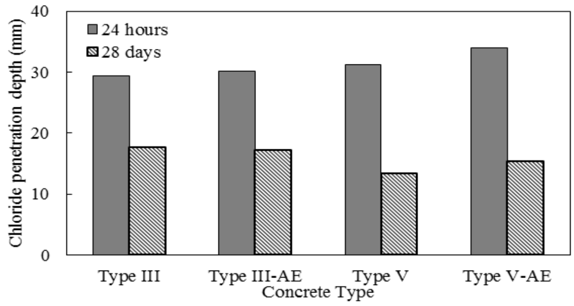

Fig. 4. Effect of curing age on chloride penetration depth for Type III and Type V cement.

3.4 Corrosion resistance

Resistance to corrosion was measured by the average time for the specimen to fail. Figure 5 presents the average failure time for Type III and Type V cement concretes at different curing ages. No variation was observed in average failure time for 24 hour cured concretes. Once curing time was extended to 28 days, the studied Type V cement concrete outperformed Type III cement concrete.

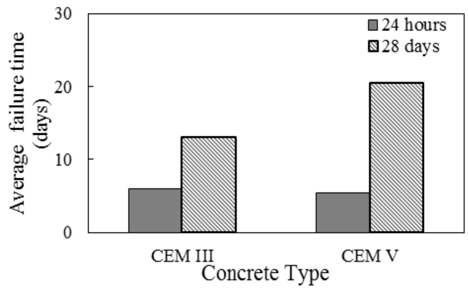

Fig. 5. Effect of curing age on failure time of Type III and Type V cement concrete.

3.5 Mass loss due to freezing and thawing

The percentage mass loss due to freezing and thawing is given in Figure 6. The studied Type III cement concretes displayed nearly 50% more mass loss than Type V cement concrete for the 28 days cured samples. In the case of 24 hours curing, the effect of cement type was not substantial.

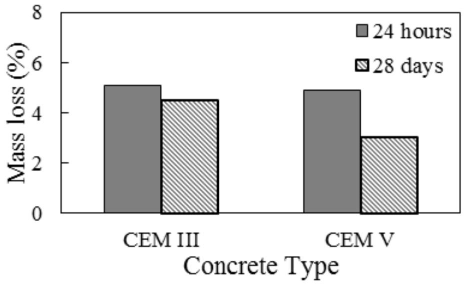

Fig. 6. Ultimate mass loss of concrete subjected to 25 freezing and thawing cycles.

4 Conclusions

Based on the results of the investigation, the main conclusions are as follows:

- Within a short period of time, all studied concrete attained the minimum compressive strength of 21 MPa which is required for rapid repair. On average, for non air-entrained concretes, Type III cement concrete met the opening strength requirement about 90 minutes before the Type V cement concrete did. For air-entrained Type V cement concrete, it took nearly 150 minutes more to reach 21 MPa than that of companion Type III cement concrete with air-entrainment.
- Age of curing had a significant effect on both compressive strength and transport properties of the studied concretes. As the curing age was extended to 24 hours and 28 days, Type V cement concrete showed higher strength and better resistance in varying degrees against chloride permeation, corrosion, and freezing and thawing.

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