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Quantitative measurements of curing methods for concrete bridge decks

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HIGHLIGHTS

- Resistance of microstructure to limewater and chloride penetration is investigated.
- Drying rate is higher in lithium cured spans of bridge decks than in wet cured ones.
- Lithium cured samples have higher chloride concentration than wet cured samples.

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ABSTRACT

This paper gives a quantitative comparison of how different curing methods impact the rate of drying and subsequent penetration of lime water and chloride penetration of concrete. Laboratory work is used to investigate a bridge deck concrete mixture cured by two different curing compounds, wet curing of different lengths, and then no curing. The results confirm that wet curing methods reduce the ingress of external chemicals more effectively. The wet curing for even one day provided significant improvement over both curing compounds and no curing. To confirm the findings in the field eight bridge decks were investigated that were cured with a curing compound and wet curing. The field investigation confirms the findings of the laboratory testing and emphasizes the importance of wet curing for long term durability of concrete. This paper provides important quantitative data that can be used to compare these methods and help with making decisions about different curing practices and the impact on the service life of concrete.

1. Introduction

After casting concrete it is typically necessary to maintain sufficient moisture content on the surface to sustain hydration [1]. This process is called curing [2]. Maintaining the moisture in concrete promotes reaction of the binder to develop a torturous and strong microstructure [1–3]. A torturous microstructure will reduce the drying rate and the ingress of fluids and external ions. This means that curing can improve the long-term durability of concrete [4–6].

Wet curing continuously supplies moisture to the surface of the concrete [1,2]. However, there are challenges in curing concrete elements that dry from one side, such as pavements [2,7,8]. For example, concrete pavement in a dry environment can suffer from large differential drying shrinkage after the termination of wet curing which can lead to dimensional instability, called curling [9–13].

Some have suggested that a possible alternative could be to use curing compounds instead of wet curing. While wet curing must be removed from the surface to allow traffic on the structure, curing compounds can stay in place until they are worn off the concrete surface [14,15]. Curing compounds have their own challenges. For example, the amount of curing compound needed depends on the ambient conditions, surface texture, and product being used [16]. Therefore, it has been suggested to apply them in two layers to ensure a uniform coverage [17–20].

Two recently developed curing compounds are investigated in this paper. The first is based on Poly(alpha-methylstyrene) or PAMS, which has been reported to be very effective in reducing the moisture loss and drying shrinkage induced curling [16,21]. This work also investigates a lithium silicate curing compound that has been reported to cure concrete and reduce the cracking in bridge decks [22]. The lithium silicates are reported to react with calcium hydroxide to generate calcium silicate hydrates and cause a densification near the surface [23,24]. Some researchers reported a potential benefit in using lithium-based curing for airport

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pavements [25–27]. It should be pointed that there is a lack of knowledge in the literature about the performance of different curing practices. This work aims to quantitatively compare the different performance in drying, subsequent moisture uptake, and then chloride penetration of concrete cured with different curing methods in laboratory testing. Therefore, the moisture loss, moisture gain on rewetting, and chloride penetration for concrete cured with curing compounds, no curing, and wet curing of different durations will be compared. To verify the findings, chloride profiles from eight bridge decks cured with a lithium silicate curing compound and wet curing are compared.

2. Experimental methods

2.1. Materials, mixture proportion, and procedures

The cement used for laboratory concrete samples was type I, according to ASTM C150 [28], and its chemical analysis is shown in the Table 1. Samples were made with dolomitic limestone aggregate and natural river sand used commercially in concrete. An ASTM C618 [29] class C fly ash with chemical analysis shown in Table 1 was also used.

All of the aggregate, both coarse and fine, were brought into the temperature controlled mixing facility at least a day before and their batch weights were corrected based on the moisture content of the aggregates. The aggregates were charged into the mixer along with approximately two-thirds of the mixing water. The combination was mixed for three minutes. Next any clumped fine aggregate was removed from the walls of the mixer. Then the cement and fly ash were loaded into the mixer, followed by the remaining mixing water. The mixer was turned on for three minutes. Once this mixing period was complete, the mixture was left to "rest" for the following two minutes while the buildup of material along the walls was removed. Next the mixer was allowed to run for three minutes and the water reducer was added as well. The mixture proportion used is presented in Table 2 for a cubic meter. The mixtures had a water to binder ratio (w/b) of 0.40 and 20% of the mass of cement was replaced by the class C fly ash. The slump, unit weight and the air content were measured according to ASTM C143 [30], ASTM C138 [31], and ASTM C231 [32] respectively. The results are presented in Table 2.

2.2. Sample Preparation, Casting, and curing

Three samples were used for each curing method. Each sample was cast in plastic containers with area of about 10.2 cm × 10.2 cm and a height of about 7.6 cm. Samples were filled with concrete in two layers and were rodded 25 times with a 9.5 mm rod at each layer and then the side was tapped to consolidate the concrete. The samples were finished with a wood float. After finishing the specimens were either wet cured, covered with a curing compound, or not cured. Details are provided in the following respective sections.

Table 2
The mixture proportions (kg/m^3) and fresh concrete properties (assuming SSD condition).

Cement	Fly ash	Coarse aggregate	Fine aggregate	Water
290.1	72.4	1110	733.3	145.4
Water reducer			9.7 (mL/kg)	
Unit weight (kg/m^3)		Slump (cm)		Air (%)
2234.6		10.2		2.5

2.2.1. Wet curing and no curing

Samples were covered in wet burlap and a plastic tarp for 3, 7, and 14 days inside an environmental chamber room at 23 °C and 40% relative humidity. The burlap was wetted every day to ensure that it remained saturated until the curing was terminated. The sample that was not cured was placed directly in the environmental chamber.

2.2.2. Curing compounds

In addition to the wet cured samples, specimens were also cured with two curing compounds. A cart was constructed that held the application nozzle at a controlled height as shown in Fig. 1. The cart was moved across the sample at a constant velocity by placing marks on the track at set distances. A metronome was used to help the cart operator move at the desired velocity. For this testing the velocity of the cart was kept constant and the application rate was adjusted by changing the height of the spray nozzle. A pump pressure of 40 psi was used to produce a spray angle of 80° and a flow of 1.36 kg/min through a commercially available curing compound flat nozzle. To check the uniformity of the coverage, tests were done using steel plates of known areas placed at the same height as the specimen. These plates were weighed before and after applying curing compounds. By using the area of the plate and the weight of the curing compound the coverage was calculated. This equipment and procedure has been used successfully in other publications [21].

The suggested application rate by the manufacturer was 4.9 m^2/L with a double layer of application. Therefore, a double layer of curing compound was applied in two equal layers with the application of each layer to be equal or close to 9.8 m^2/L. The second layer was applied after a few minutes after the first one at the same rate and in the same direction. The results are shown in Table 3.

Table 1
Oxide analyses reported on the mill sheets.

Chemical test results (%) of the cement						
SiO_2	Al_2O_3	MgO	Fe_2O_3	CaO	SO_3	
20.77	4.57	2.37	2.62	62.27	3.18	
Na_2O	K_2O	TiO_2	P_2O_5	SrO	BaO	
0.19	0.32	0.34	0.14	0.22	0.07	
Phase concentrations (%) of the cement						
C_3S		C_2S		C_3A	C_4AF	
52.13		20.22		7.68	7.97	
Chemical test results (%) of the fly ash						
K_2O	BaO	MgO	SrO	CaO	SO_3	Na_2O
0.58	0.72	5.55	0.39	23.12	1.27	1.78
SiO_2	Al_2O_3	MnO_2	P_2O_5	Fe_2O_3	TiO_2	
38.71	18.82	0.02	1.46	5.88	1.35	