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Different curing methods and compounds and effects on the compressive strength characteristic of Roller Compacted Concrete Pavements (RCCP)

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ABSTRACT

This paper discusses the results of a research study conducted to evaluate the effect of curing methods and compounds on compressive strength of Roller Compacted Concrete Pavements (RCCP). Three types of curing compounds namely paraffin wax, chlorinated rubber, and silicate solution, were investigated in this study. Curing by immersion in water was used as the standard method of curing. The curing compounds were applied on the compressed concrete specimens by different methods. The effect of the selected curing regime on the properties of concrete specimens was evaluated by measuring compressive strength. The best performance was shown by concrete specimens cured by immersion in water. Water spraying followed by applying curing compounds and direct application of curing compounds were also investigated. According to the results, using liquid membrane forming curing compounds and silicate base curing compound causes decrease of 11-13% in the compressive strength of RCCP specimens compared to the specimens cured with water and increase of 12-19% compared to the specimens placed in laboratory without curing. Using chlorinated rubber emulsion as a liquid membrane forming curing compound after an initial curing with water, is recommended for curing of RCCP.

1. Introduction

Roller compacted concrete (RCC) is a durable and strong building material that has seen increased utilization in recent years. Roller-compacted concrete for pavement (RCCP) is a relatively stiff mixture of aggregates, cementitious materials, and water that is non-reinforced, generally placed by asphalt-paving equipment and requires external compaction energy by vibratory rollers. Such definition implies that concrete should be of extremely low consistency and workability. The use of RCCP has increased allowing the development of cost-effective pavements for many conventional road and street applications such as highway shoulders, low volume roads, local streets, and industrial parking areas (Harrington. 2010, ACI. 325.10R-95. 2001, The Cement Association of Canada (CAC). 2005). Curing is an extremely important factor in the ultimate strength and durability of RCC. Curing (ACI. 308R-01. 2008, ACI. 116R. 2000) consists of promoting cement hydration by controlling the concrete's moisture and temperature. More specifically, curing consists in keeping the concrete saturated or close to its saturation point. Adequate protection against moisture loss is important, since it affects the proper development of mechanical properties. Lower mechanical properties result in decreased durability and higher permeability. Because RCC has no bleed water, evaporation immediately begins to remove water from the paste, which can lead to shrinkage cracking and shallow micro-cracks, which may result in surface deterioration. Effective curing treatments for RCC prevent evaporation of mix water and must be applied as soon as possible after final compaction. For most projects, a white concrete curing compound conforming to ASTM C309, Specification for Liquid Membrane-Forming Compounds for Curing Concrete, is used. Typically, moisture curing of RCC has not proven to be cost-effective because it requires a large number of water applications for a minimum of seven days. Depending on environmental conditions, water spray trucks have sometimes been unable to provide water at a fast enough rate to avoid some surface drying (ACI. 325.10R-95. 2001, The Cement Association of Canada (CAC). 2005).

Various methods and materials are still studied today to provide curing conditions in concrete production (Makul. et al. 2009, Kim. et al. 2008, Meyer. 1997, Yilmaz and Turken. 2011, Ibrahim et al. 2013, Fattuhi.1986, Yilmaza, Turken. 2012, Nahataa et al. 2014, XUE et al. 2010, Al-Gahtani. 2010, Mohammadi Ahani and Nokken. 2012, Choi et al. 2012, Maslehuddin et al. 2013). In a research the effect of curing methods on the mechanical properties of ordinary Portland cement (OPC) and Silica Fume Cement (SFC) concretes was evaluated by measuring compressive strength, water-absorption and chloride permeability. Four types of curing compounds, namely water-, acrylic-, and bitumen-based and coal tar epoxy, were applied on the concrete specimens. The curing compounds were applied immediately after casting or after an initial period of burlap curing. The strength and durability characteristics of both OPC and SFC concrete specimens cured by applying the selected curing compounds were similar or better than that of concrete specimens cured by covering with wet burlap (Ibrahim. 2013). The use of curing materials has become widespread, lately, both for ease and to provide concrete quality (Fattuhi.1986). In another work the effect of paraffin emulsion based, hydrocarbon resin based, acrylic dispersion based and acrylic resin curing materials on the compressive strength of concrete were experimentally investigated (Yilmaz and Turken. 2011). Research on the effect of curing methods and compounds on strength and durability properties of RCCP has not been reported so far.

In this study, some chemical curing materials were investigated, in terms of their effects on the compressive strength values of RCCP specimens. For this purpose two kinds of liquid membrane forming organic curing compounds and a silicate base inorganic curing compound were applied to the concrete specimens and the compressive strength results were compared with concrete specimens cured by immersion in water and the ones placed in laboratory condition without any curing.

2. Material & Methods

The material properties of the concrete mixture used in this research are given in the following. The cement used was cement type II in accordance with Iranian Standards whose physical and chemical characteristics are given in Tables 1 and 2.

Table1. Physical properties of cement

sample	Bending strength (MPa)			Compressive strength (MPa)			Residue (%wt)	Setting time(min)		Blaine (cm^2/g)
	3 day	7 day	28 day	3 day	7 day	28 day	90 mic	Ini.	Fin.	
Cement type II	4.2	5.5	7.0	22	33	46	2.00	140	190	3000

Table 2.Chemical composition of cement

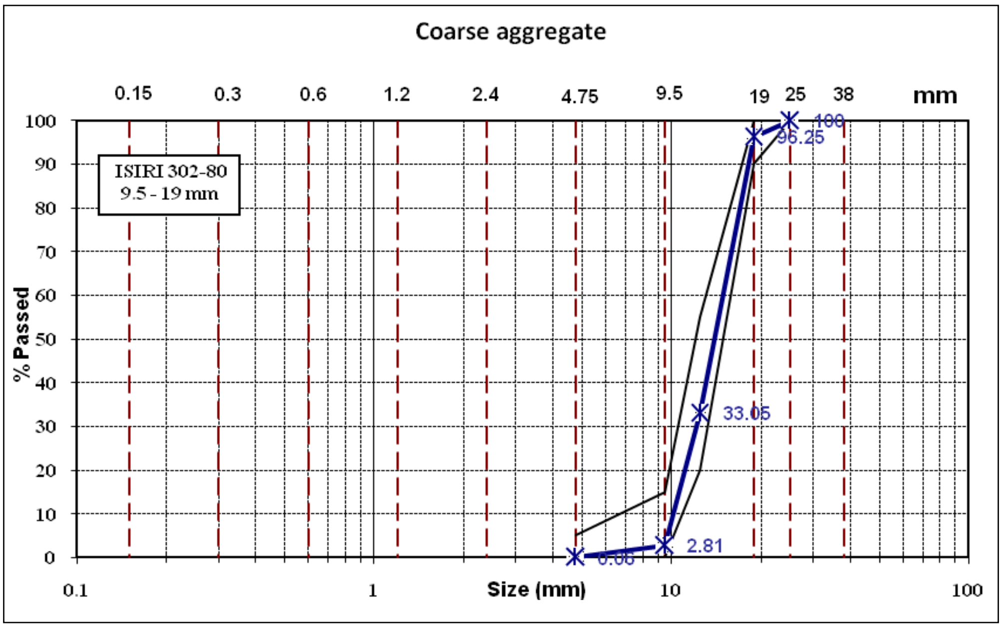
Chemical analysis (%)	Portland cement
Cao	65.02
SiO2	20.90
Al2O3	5.00
Fe2O3	4.30
So3	1.80
Mgo	1.02
K2O	0.60
Na2O	0.32
Cl	0.013
Loss on ignition	0.93

The water used for mixing the concrete mixtures was potable and appropriate to the Iranian Standards. The Aggregate used in this study was of 0.15–4.75 and 4.75–19 mm grain size which is widely used in RCC mixes (Table 3).

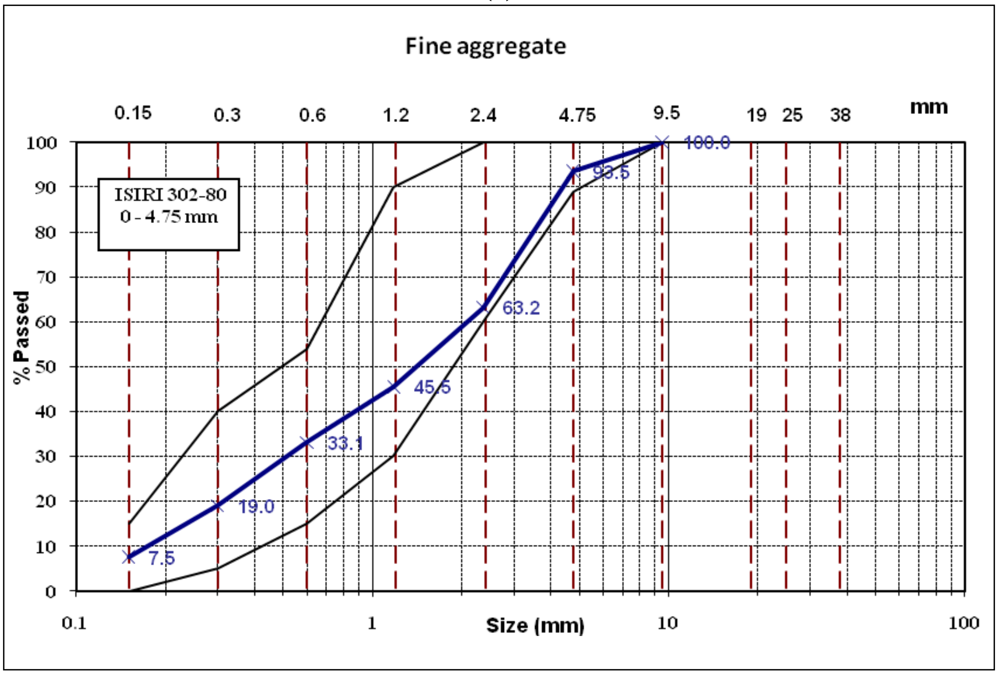
Table 3.Grain size of aggregates

Sieve (mm)	% Passed	
	Aggregate type	
	Fine aggregate	Corse aggregate
25		100
19		96.25
12.5		33.05
9.5	100	2.81
4.75	93.53	0.06
2.36	63.2	
1.18	45.5	
0.6	33.06	
0.3	18.98	
0.15	7.54	

The aggregate grade was designed as existing between the curves defined in Iranian Standards (diagrams of figure 1a & b).



(a)



(b)

Figure 1. Grading curves of aggregates, (a) coarse aggregate, (b) fine aggregate

The concrete specimens were prepared for 28-day compressive strength study (according to EN 12390-3) using three 15 × 15 × 15 cm^3 cubic molds for each of different types of concrete mixtures and curing procedures. The concrete mixtures were proportioned on a weight basis. Table 4 shows the amounts of components of concrete mixtures.

Table 4. Components of concrete mixtures

Concrete mixtures components	Amounts of components (Kg)	Specific gravity	Fineness modulus	Water/cement ratio	Water absorption (%)
Coarse aggregate	698.558	2.56		0.37	2
Fine aggregate	1310.721	2.6	3.38		3.02
water	104.500				-
Cement	275.000				-

Compaction of RCCP specimens was performed using a vibrating hammer according to ASTM C1435-99 (Figure 2).

Figure 2. Molding and compaction of concrete specimens

After molding and compaction of the specimens, curing processes were performed by various methods. Curing application 1, the top surfaces of the specimens were covered with chemical curing materials immediately after molding. The vertical surfaces and the bottom surface of the specimen were cured with chemical curing materials after removal of the concrete specimens from the molds. During application 2, the top surfaces of the specimens were covered with water immediately after molding. Water spraying was continued until removal of the concrete specimens from the molds. Then all surfaces of the specimens were cured with chemical curing materials.
Curing application 3; the specimens were immersed in water after removal from the molds until the compressive strength test according to EN 12390-2. In order to investigate the effect of curing operations, some specimens were kept without curing. Figure 3 shows the specimens cured with different materials. Table 5 shows the characteristics of the curing compounds applied to the concrete specimens. All the curing compounds were applied on the surfaces by spraying. The concrete specimens were encoded, as in Table 6, according to the curing methods and the curing materials applied to them.

Figure 3. RCC specimens cured with different materials

Table 5. Curing compounds

Paraffin emulsion in water (Membrane-Forming)	PW
chlorinated rubber (Membrane-Forming)	CR
Silicate based	S
water	W

Table 6. Specimen identification

concrete specimen	Curing application	Curing compound
PW-1	1	PW
PW-2	2	PW
CR-1	1	CR
CR-2	2	CR
S-1	1	S
W	3	W
WC	Without curing	-

4. Results and Discussion

The 28-day compressive strength of the roller-compacted concrete specimens cured by the application of different curing processes on fresh concrete is summarized in Table 7 and the diagram of figure 4. The amount reported for compressive strength is the average of three specimens.
Maximum compressive strength was noted in the concrete specimens cured by immerging in water, which was 32% compared to the specimens without curing. Curing with chemical compounds caused a decrease of 10-15% in compressive strength compared to water curing. The minimum strength was noted in the concrete specimens that were placed in laboratory condition without any curing, which was 24% less than the specimens cured with water.
Application of curing materials on the concrete specimens caused an increase of 12- 19% in 28-day compressive strengths, in comparison to those of concrete specimens with no curing. Paraffin-based

(PW) and rubber-based (CR) curing compounds were membrane forming and conform to ASTM C 309 requirements.

These curing compounds form a thin, continuous film on the concrete surface that greatly reduces the amount of internal water that can pass through as vapor. Compressive strength test results show that curing the concrete specimens by applying liquid membrane-forming compounds after covering the surface with water (curing application 2) has caused a greater increase in 28-day strength compared to direct application of these compounds (curing application 1). Thus, the application of membrane-forming curing compounds seems to be appropriate for intermediate curing after an initial curing of the surface with water (ACI 308R-01. 2008). Results also show that curing with rubber-based compounds had more effects on strength increase to paraffin-based compounds. Solutions of sodium, potassium, or lithium silicate are chemically reactive in concrete rather than membrane-forming; therefore, they do not meet the intent of the ASTM C 309 specification. While their use may offer some desirable benefits when applied after curing, they should not be applied on fresh concrete. The results of compressive strength of the specimens cured by silicate solution-based material were, approximately, identical with those cured with liquid membrane-forming compounds through curing application 2.

Table 7. Compressive strength test results

concrete specimen	Compressive strength (MPa)	Strength decrease compared to W (%)	Strength increase compared to WC (%)
PW-1	46.7	15	12
PW-2	49	11	17
CR-1	47.7	13	14
CR-2	49.5	10	19
S-1	49.2	10	18
W	55	-	32
WC	41.7	24	-

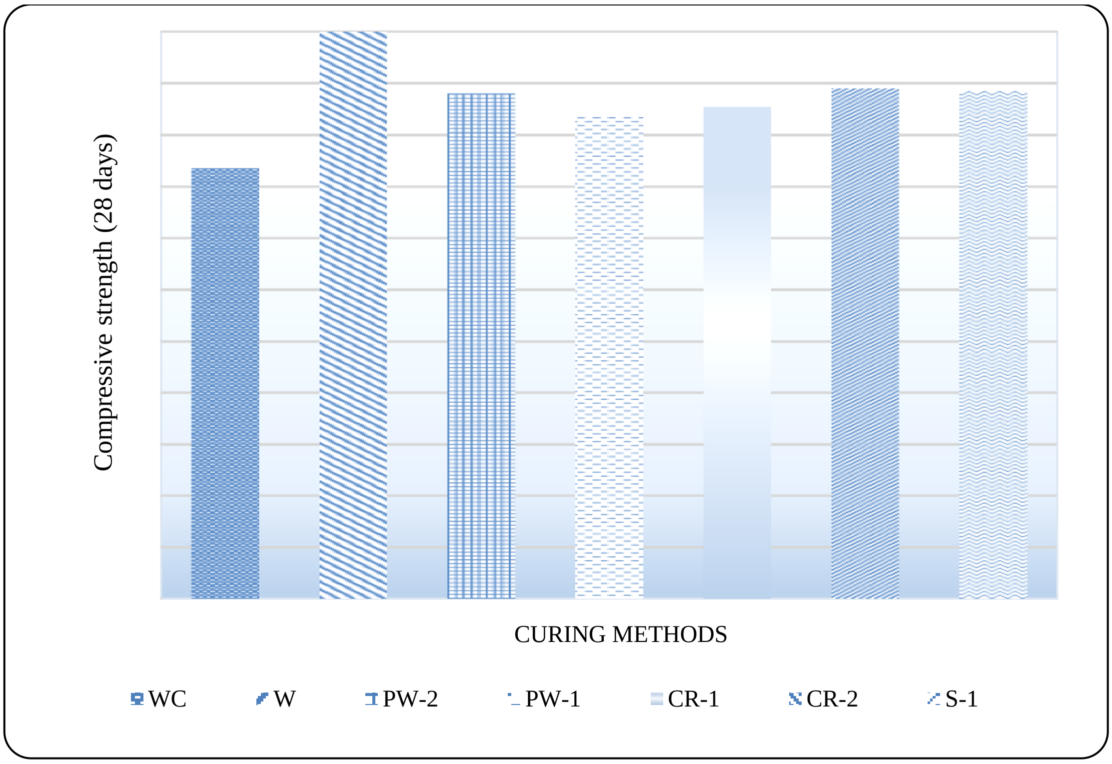


Figure 4. Compressive strength test results of RCC specimens cured by different methods

5. Conclusions

In conclusion, each curing method used in this study presented various results, differing from each other, for RCCP specimens. Curing by emerging the specimens in water had the most significant effect on the compressive strength of concrete specimens but this method is not applicable to making roller-compacted concrete pavements in the field because of economic issues. Also, curing by silicate-based materials creates limitations because of their reactivity with concrete mixtures. Applying the membrane-forming compounds directly on the surface of specimens did not show a noticeable effect on increasing the compressive strength. However, curing by using water spraying followed by applying liquid membrane-forming compounds caused a considerable increase in the strength of concrete specimens. Therefore, this method seems to show appropriate results to be used as a curing method for making RCCP.

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