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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

Objective: This paper evaluates the effect of curing methods and compounds on the compressive strength of Roller Compacted Concrete Pavements (RCCP), aiming to identify practical field-applicable strategies that balance strength retention with construction constraints.

Methods: Three curing compounds—paraffin wax, chlorinated rubber, and silicate solution—were investigated, with water immersion used as the standard reference. Application techniques included direct compound application and water spraying prior to compound application. Performance was assessed by measuring the compressive strength of treated specimens.

Results: Water-immersed specimens showed the highest compressive strength. Compared to this standard, liquid membrane-forming compounds and the silicate-based compound reduced compressive strength by 11–13%, yet they increased strength by 12–19% relative to uncured laboratory specimens.

Conclusion: Based on the findings, applying chlorinated rubber emulsion as a liquid membrane-forming compound after an initial water curing period is recommended for RCCP. This approach offers a viable compromise between field practicality and adequate compressive performance.

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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.	3000
Cement type II	4.2	5.5	7.0	22	33	46	2.00	140	190	

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).

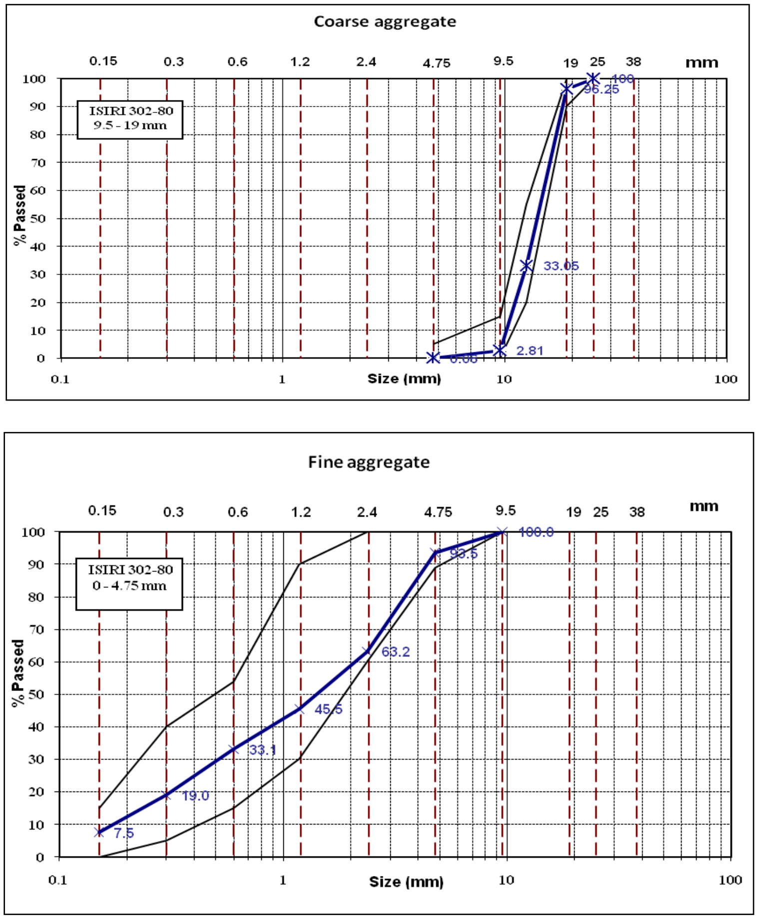

Figure 1. Grading curves of aggregates, (a) coarse aggregate, (b) fine aggregate

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	-

3. Results

The 28-day compressive strength of the roller-compacted concrete specimens cured using different curing methods is presented in Table 7 and Figure 4. The reported values represent the average compressive strength of three specimens.

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	-

obtained for the water-cured specimens (W), reaching 55 MPa, whereas the lowest value was recorded for the specimens without curing (WC), with a compressive strength of 41.7 MPa.

The membrane-forming curing compounds produced compressive strengths ranging from 46.7 to 49.5 MPa. Compared with water curing, these values were 10-15% lower, while they were 12-19% higher than those of the uncured specimens. Among the curing compounds, CR-2 exhibited the highest compressive strength (49.5 MPa), followed by S-1 (49.2 MPa) and PW-2 (49.0 MPa). In addition, specimens subjected to curing application 2 consistently achieved higher compressive strengths than those treated using curing application 1.

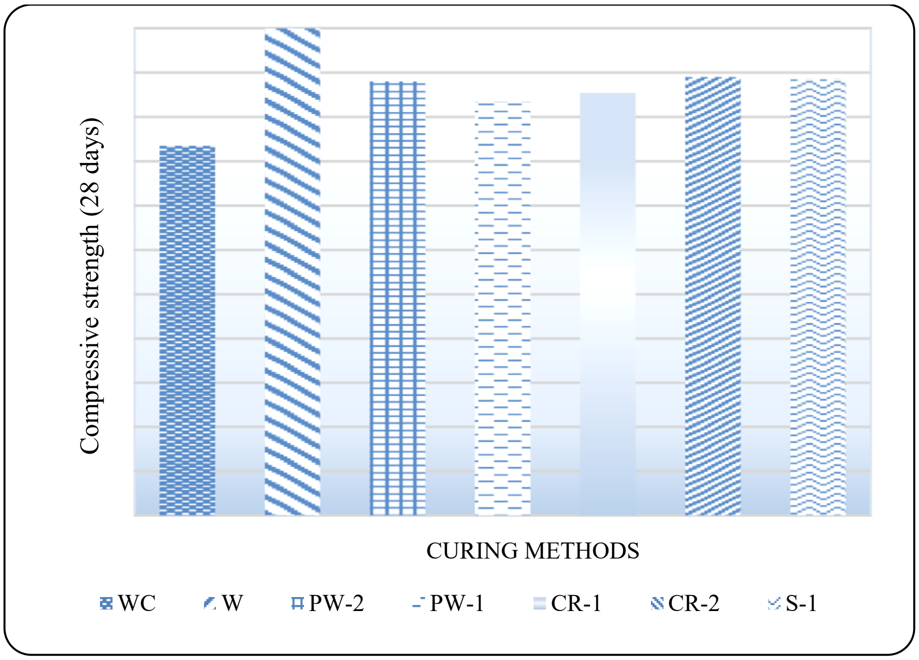

Figure 4. Compressive strength test results of RCC specimens cured by different methods

The trend illustrated in Figure 4 is consistent with the numerical values presented in Table 7.

4. Discussion

The superior performance of water curing can be attributed to its ability to continuously supply moisture required for cement hydration. Maintaining adequate moisture throughout the curing period promotes more complete hydration, resulting in a denser cementitious matrix and consequently higher compressive strength. This finding confirms the effectiveness of conventional water curing in improving the mechanical properties of roller-compacted concrete.

The membrane-forming curing compounds also enhanced the compressive strength compared with the uncured specimens. Their effectiveness is associated with the formation of a thin and continuous film on the concrete surface, which limits moisture evaporation and preserves the internal water required for hydration. Both the paraffin-based (PW) and rubber-based (CR) curing compounds satisfy the requirements of ASTM C309 for membrane-forming curing compounds.

The results further indicate that curing application 2 was more effective than curing application 1. Applying the membrane-forming compound after initially wetting the concrete surface appears to improve moisture retention during the early stages of hydration, leading to greater strength development. This observation is consistent with the recommendations of ACI 308R-01 (2008), which suggest that membrane-forming curing compounds are more effective when used after an initial period of water curing.

Among the membrane-forming compounds, the rubber-based material showed slightly better performance than the paraffin-based compound. This may indicate a greater ability of the rubber-based compound to reduce moisture loss and maintain favourable curing conditions, although additional microstructural investigations would be required to confirm the underlying mechanism.

Unlike membrane-forming compounds, silicate-based curing materials act through chemical reactions with the concrete rather than by creating a surface membrane. Consequently, they do not conform to the intent of ASTM C309 for curing fresh concrete. Nevertheless, the compressive strengths obtained with the silicate-based material were comparable to those achieved using membrane-forming compounds under curing application 2, suggesting that silicate-based treatments can provide similar mechanical performance despite their different mode of action.

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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