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Impact of curing technique on roller-compacted concrete pavement production

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ABSTRACT

Roller-compacted concrete pavement (RC-C-P) is an economical and fast structure that has a relatively dry consistency (zero-slump), but requires more curing care and consideration than conventional concrete pavements. The objective of the research was to investigate the influence of various curing kinds and impact on the mechanical characteristics off RC-C-P. Three various curing techniques can be investigated, compared to lab-normal curing. The liquid membrane-forming compound (Sika Antisol WB) is by spraying to the surface of samples after 2-hour casting and then spraying the sides of the sample following mold extraction. Water is sprayed twice a day (8:30 a.m. and 2:30 p.m.) for three-days and also the damp burlap curing continues three-days. The best curing technique can be recommended is liquid membrane-forming compound technique, since the improvement of compressive strength results up to (12.80, 11.26 and 11.96)% at 7, 28 and 90 days, respectively, compared to lab-normal curing results. While the compressive strength results reduced by (2.37, 3.64 and 4.29)% at 7, 28 and 90 days, respectively, using the damp burlap curing technique compared to lab-normal curing results, it should be taken into consideration that it is still within ACI recommendation (not less than 28 MPa). Finally, the spray-water curing technique needs to be carefully employed in mix design, due to the reduction up to (9, 8.94 and 7.67)% at 7, 28 and 90 days, respectively, for compressive strength test, compared to lab-normal curing results. The results of tensile and flexural strength for RC-C-P with different curing using similar trends with compressive strength results for all curing techniques.

Keywords: roller compacted-pavement-concrete, curing technique, liquid membrane-forming compound, damp burlap curing.

INTRODUCTION

Roller compacted-concrete-pavement (RC-C-P) is a solid and concrete should be zero in slump that is frequently utilized for pavements due to its quick building and economical nature (ACI 325, 2001). RC-C-P is frequently used in pavements, hydraulic structures, and materials for infrastructure (Fang et al., 1999; Atis, 2005; Chi and Huang, 2014). Although the materials used in RC-C-P exhibit the characteristics that are comparable to those of traditional concrete, the gradation of RC-C-P is comparable to that of hot mix-asphalt pavement. The volume of fine-aggregate (F-A) in the RC-C-P combination is large, while the volume of water, coarse-aggregate (C-A), and binder is low (Lam et al., 2018). Additionally, the RC-C-P mixture is determined and generated in a manner distinct from conventional-concrete-pavement (C-C-P) regarding placement strategy and design specifications (Harrington et al., 2010). RC-C-P is permitted as a pavement material, since it does not need dowel bars or steel reinforcement. This reduces the total cost of building the pavement. When compared to C-C-P, the RC-C-P can save up to 60% on costs (Pittman, 1994; Vahedifard et al., 2010). The primary factors influencing the characteristics of ordinary-portland-cement-concrete (O-P-C), such as density and (w/c) ratio is also taken into consideration while designing RC-C-P. Nonetheless, the compaction characteristics of RC-C-P are basic factors in determining the appropriate load carrying capacity (Yerramala et al., 2014). In order to retain hydration, it is usually important to keep a suitable moisture content on the surface after concrete casting (Kosmatka et al., 2011). Curing is the term for this method (ACI 308R, 2001). It is essential that concrete be sufficiently cured if its resistance and strength potential is to be fulfilled in its entirety. If concrete is subjected to hot, dry conditions right after casting and has extra cementitious elements, such as fly ash or silica fume or slag, curing becomes more important (Ramezanianpour and Malhotra, 1995). Maintaining ideal both moisture content and temperature levels that support cement hydration and the formation of the concrete microstructure requires careful curing measures. Because of its fast production rate, large, flat, open functioning space, and extremely low mixing water content, RC-C-P construction needs additional care (Wang et al., 2006; Nanni, 1988). Concrete pavements can be cured using a variety of techniques and materials, such as fluid membrane, sheets of plastic, blankets that provide insulation, damp burlap and water-spray. Damp burlap or blankets that provide insulation are thought to be the best curing materials for keeping moisture and heat, but they need a lot of work and time to apply. In a more cost-effective and maintenance-free manner, the liquid membrane can offer comparable insulation (Mather, 1990). Studies on the curing effects of RC-C-P and other types of concrete have been conducted by researchers. With varying replacement proportions of F-A and several cure techniques (in-air cure, in-water cure for 7-days, cure emulsified asphalt, and lasting water cure), The effects of porcellanite, a lightweight aggregate used as an interior curing operator, on RC-C-P were the main focus of Abed and Salih (2017). In comparison to the C-C-P with lasting water cure, the findings showed that the application of (5%) porcellanite enhanced RC-C-P (in-air cure) by calculations ranging (0.4–1.7%), (3.6–28.9%), and (15.9–41.3%) for third point-bending test (flexural-strength test), bulk density test and water absorption test respectively. Nahata et al. (2014) assessed the uniaxial compressive-strength test for twenty-eight day old cubic samples implemented using various curing agents and techniques, and subsequently compared the outcomes of the uniaxial compressive-strength test of various curing mechanisms. Comparing membrane curing chemicals to the conventional water curing process, the findings demonstrated an 80% to 90% improvement in uniaxial compressive-strength test. A quantitative evaluation of the effects of various curing techniques on the pace of the drying process as well as infiltration of lime-water and ions chlorides in concrete was provided in another research by Hajibabaee et al. (2018). The purpose of the study was to examine a concrete mixture for a cured bridge deck using 2-distinct curing chemicals, damp curing of varying durations, and no cure after that. When contrasted to no cure and cure chemicals, even a one-day of water curing produced notable benefits. The amount of mass lost while drying was greatly decreased by water curing. The impact of employing three distinct curing techniques (in-air cure, damp burlap or in-water cure, and cure chemical) on the earlier damp execution of high execution concrete was examined by Nassif et al. (2003). The findings shown that in order to enhance early age performance, a damp burlap cure must be used within a 60 minute of concrete placing. Deghfel et al. (2019) shown the efficacy of damp burlap cure in the hydration process by examining the influence of various curing techniques on the performance of RC-C-P. Three distinct curing techniques were employed in the study: (damp burlap, water and cure product), damp burlap produced the best results. In a different investigation Chhorn et al. (2019) examined the RC-C-P samples that had been air cured and moisture cured; they presented that moisture curing might increase compressive-strength-test by as much as (10%). Alebi and Mahachi (2021) looked on how various curing techniques affected the concrete of uniaxial compressive-strength test after adding fuel ashes from palm oil. The specimens were treated using 5-distinct techniques: water immersion, spray-water, polythene covering, wet damp casing, and curing membranes chemical application.

EXPERIMENTAL PROGRAM

Ingredients

Combined-aggregate

Preparation of the combined-aggregate adopting to (ACI 327R, 2015; ACI 211.3R, 2002) to choose the percentage of filler by (5%) and coarse-aggregate by (55%) and fine-aggregate by (45%). Crushed-stone aggregate and maximum particle size of (3/4 in) is the C-A utilized in the studies. Particle size (3/4 in, 1/2 in, 3/8 in and #4) were chosen for the C-A, and sieve analysis was

Figure 1. Utilized coarse-aggregate

Figure 2. Utilized fine-aggregate

Figure 3. Crushed-limestone aggregate

used to calculate particle distribution. The C-A utilized in the mixture was shown in Figure 1. The fine-crushed-stone aggregate (F-A) utilized in the studies. Particle size (#8, #16, #30, #50, #100 and #200) were chosen for the F-A, and sieve analysis was used to calculate particle distribution. The F-A utilized in the mixture was shown in Figure 2.

Crushed-limestone aggregate is the filler utilized in the studies. Particle size (passing #200 (0.075mm)) were chosen for the limestone filler as shown in Figure 3. The aggregate mixture-gradation-curve utilized in the research is presented in Figure 4 and the limits specification of aggregate mixture-gradation-curve were formed adopting (ACI 327R, 2015).

Cement

Ordinary portland cement (O-P-C) type 1 (42.5R) produced by company of mass-Iraq for the cement industry in according with (ASTM C150, 2011) utilized in the studies. The chemical characteristics of the cement utilized are given in Table 1.

Water

The mixes were made using the (Baghdad City Water) supply, because it complied with (ASTM C1602, 2012) standards.

Curing ingredients

Four distinct curing techniques were used in the study for RC-C-P following casting. Liquid membrane-forming compound, damp burlap, spray-water and normal curing were utilized in

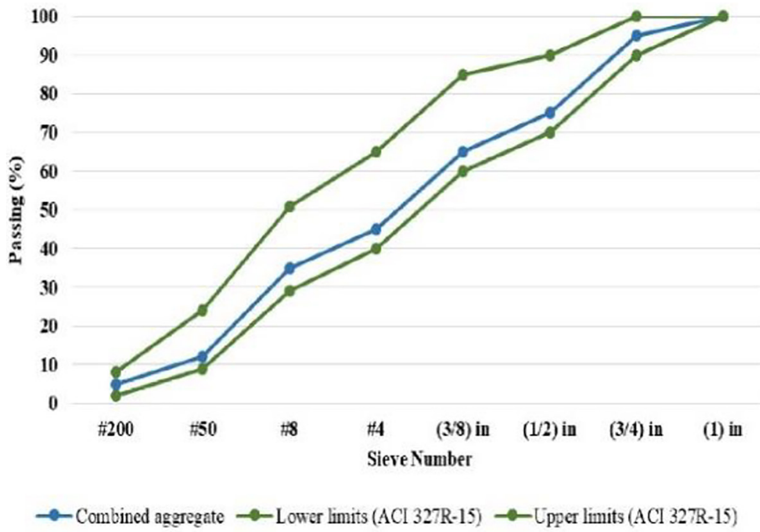

Figure 4. Combined-aggregate-gradation

Table 1. The chemical & physical characteristics of cement

Chemical composition		ASTM C150/C150M	Physical composition		ASTM C150/C150M
SiO_2	20.08	-	Specific surface area (kg/m²)	368	≥260
Al_2O_3	4.62	-	Initial setting time (hr: min)	1:05	≥0:45
Fe_2O_3	3.60	-	Final setting time (hr: min)	2:50	≤6:15
CaO	61.61	-	Autoclave expansion (%)	0.038	≤0.8
MgO	2.12	≤ 6.0%	3-day compressive strength (MPa)	23	≥12
SO_3	2.3	≤ 2.3 for C_3A ≤ 8%	7-day compressive strength (MPa)	27	≥19
I.R.	0.58	1.5%	Main compound by Bogue's Equation		
L.O. I	2.40	≤ 3.0%	C_3A = 6.15		-

this research. The use of liquid membrane-forming compound (Sika Antisol WB) confirming to (ASTM C309, 2019) was applied on concrete surfaces to reduce the loss of water, as presented in Table 2, showing the physical characteristics of liquid. The use of damp burlap curing (Burlap-white and polyethylene-sheet) that weighs at least 305 g/m^2 and is extruded with white opaque polyethylene that is at least 0.10 mm thick on one side will make up the sheeting (ASTM C171, 2016).

Table 2. The physical characteristics of the curing compound (Sika Antisol WB) *

Physical characteristics	
Appearance and color	White
Regularity	Liquid
Liquid density	(1.005 ± 0.01) g/cm^3
PH-Value	6–8
Composition	Water base, acrylic based polymer

Note: * according to the manufacturer.

Table 3. Mixing amount for RC-C-P in (1 m^3)

Materials	Weight
SSD Filler (kg)	102.14
Cement (kg)	273.11
Water (kg)	117.18

MIX DESIGN AND CASTING

Roller Compacted-Concrete-Pavement (RC-C-P) has a relatively dry nature, so compatibility is crucial to achieving the highest density adopting to ACI 327R. The mixture of moisture content was the factor that had the greatest impact on compatibility. The recommendation of using alternated proctor test (ASTM D1557, 2012) is a compression technique that can be used to ascertain the association between moisture-content in percent and dry density in (kg/m^3) of RC-C-P to obtain the optimum-moisture content % (O-MC) and maximum-dry density in (kg/m^3). A five-point alternated proctor curve was established utilizing moisture content range between (4.5–8.5) percent with rises (1) %. Figure 5 shows the modified proctor test steps. The materials ratio utilized for one meter cube (1 m^3) of RC-C-P are shown in Table 3, and (w/c) ratio of the mixture was established based on (O-MC). RC-C-P has a much drier consistency than conventional-concrete-pavements concrete (C-C-P), a distinct compaction method is needed while laying it. The cylinder samples and beam samples are compacted by vibrating-hammer and tamping-plates after preparing and mixing the materials as shown in Figure 6. The vibrating-hammer

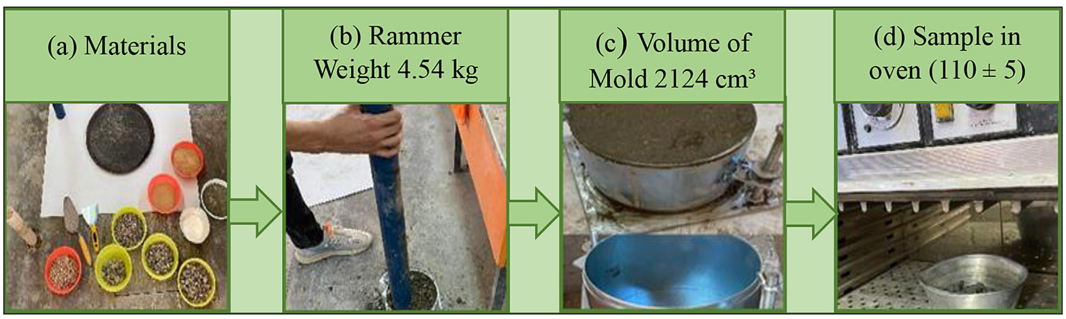

Figure 5. Modified proctor test steps according to ASTM D1557: (a) Preparing materials and mixing, (b) Tamping the specimen, (c) weight the mold, (d) The specimen in oven

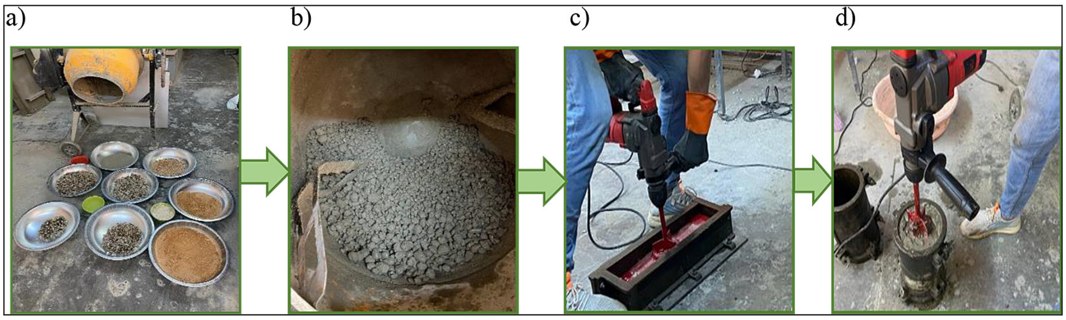

Figure 6. Compacting procedures according to ASTM C1435: (a) preparing ingredients, (b) ingredients after mixing, (c) compaction technique for cylinder, (d) compaction technique for prism

and tamping-plates that confirm to (ASTM C1435, 2004) were employed to carry out this procedure. Table 4, shown the details of manufactured vibrating-hammer and tamping-plate for cylindrical and prism mold. The RC-C-P samples that had been prepared were cured. The study looked at how application duration and cure type affected RC-C-P.

CURING

The scope of the research involved 4-types of curing used for prism RCC-P specimens for flexural-strength test and cylinder RCC-P specimens for compressive-strength test and splitting tensile-strength test. In the spray-water and

Table 4. The specifics of manufactured vibrating-hammer and tamping-plate for cylinder and prism

Vibrating-hammer		Tamping-plate for cylinder		Tamping-plate for prism	
ASTM 1435 specifications	Picture	ASTM 1435 Specifications	Picture	ASTM 1435 specifications	Picture
Power input (1500W) 2200 Impacts per minute		Diameter (149 mm)		Dimensions (98 × 498) mm	
Weight (8.8 kg)		Weight (3 kg)		Weight (9.3 kg)	

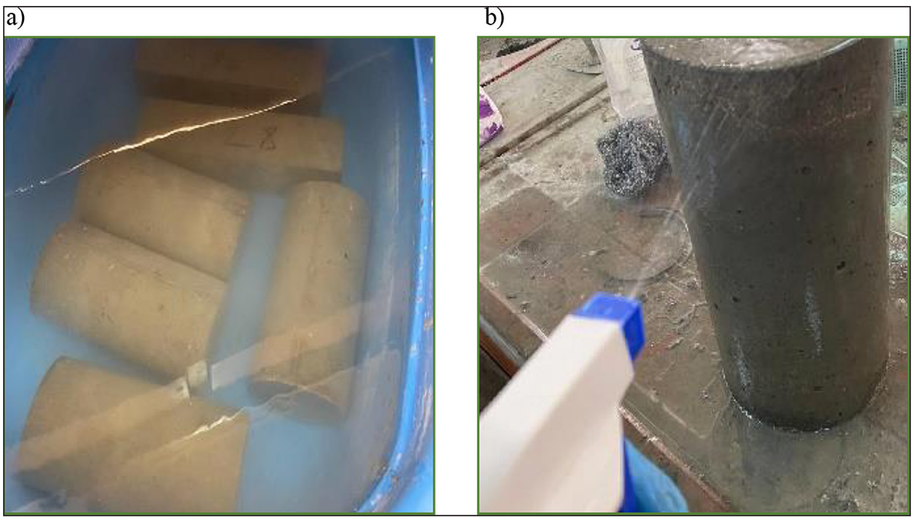

Figure 7. Curing of samples: (a) normal curing, (b) spray-water curing

normal curing, cure was applied to the samples in a period of time (1 day after casting), and then left in the room for (7, 28 and 90) days, but the spray-water curing continuous on spraying for 3 days (8:30 AM and 2:30 PM) as shown in Figure 7. The liquid membrane-forming compound (Sika Antisol WB) cure was applied to the surface of samples two hours after casting and then sprayed after removing the sample from the mold, the curing was continued for 3 days, and then left in the room for (7, 28 and 90) days, as shown in Figure 8. In the damp burlap treatment, the polyethylene material must be firmly adhered to the burlap to prevent material separation during concrete handling and curing. The curing was continued for 3 days, and then left in the room for (7, 28 and 90) days, as shown in Figure 9.

TEST METHODS

The mechanical characteristics of concrete are used as the best evaluating standard for concrete quality in several studies.

The compressive, flexural and tensile strength tests of the samples were carried out in this research to investigate the impacts of curing techniques, as presented in Table 5.

RESULT AND DISCUSSION

Compressive-strength test

The results of using normal curing technique are within the required compressive strength not less than 30 MPa and conform to the ACI 327R recommendation (minimum expected compressive-strength 28 MPa) at 28-days, as shown in Figure 10. Other curing techniques were used in order to simulate the most local curing in the field. Therefore, the comparison between (spray-water, burlap damp and liquid membrane-forming compound) can be presented in Figure 11 as percentage decrease (reduction) or increase (improvement) compared to normal curing compressive strength. From Figure 11 the reduction up to (9, 8.94, and 7.67)% at 7, 28 and 90 days, respectively, can be

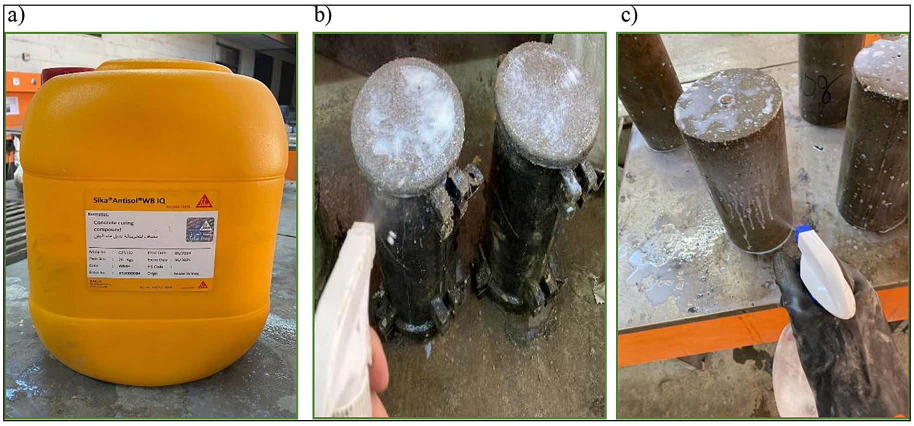

Figure 8. Liquid membrane-forming compound: (a) Sika Antisol WB, (b) after initial moist, (c) after removal from the mold

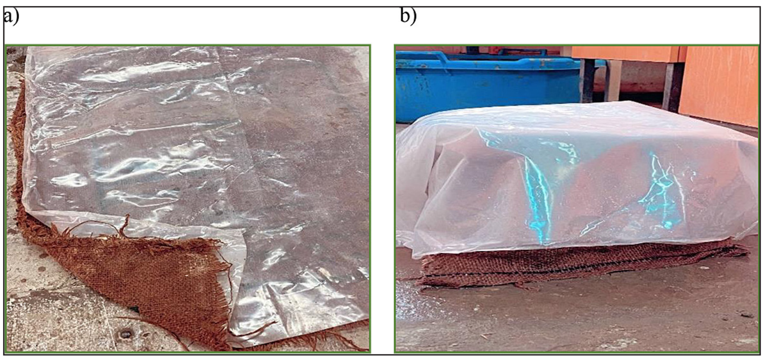

Figure 9. Damp burlap curing: (a) burlap-white-polyethylene-sheet, (b) after casing

Table 5. The mechanical characteristics of samples*

Test strength method and specification	Mold type and dimensions	Number of layers	Picture
Compressive-strength (ASTM C39)	Cylinder mold (150 × 300) mm	4-layers	
Tensile-strength (ASTM C496)	Cylinder mold (150 × 300) mm	4-layers	
Flexural-strength (ASTM C78)	Prism mold (100 × 100 × 400) mm	2-layer	

Note: * All for 7, 28 and 90 days.

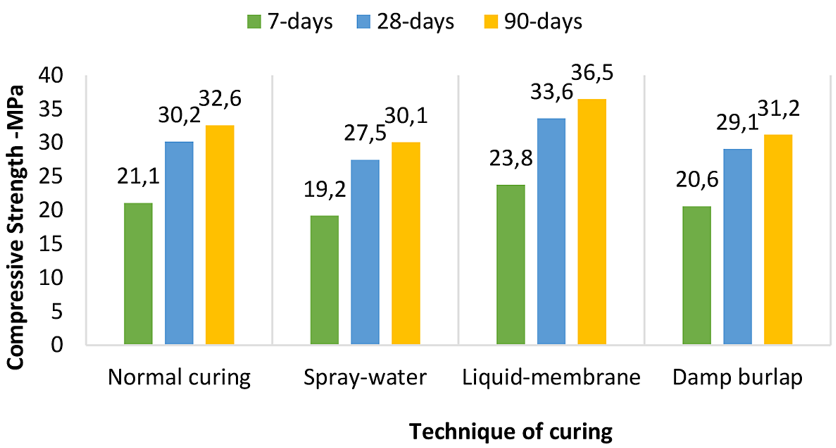

Figure 10. The results of compressive-strength test with different curing techniques

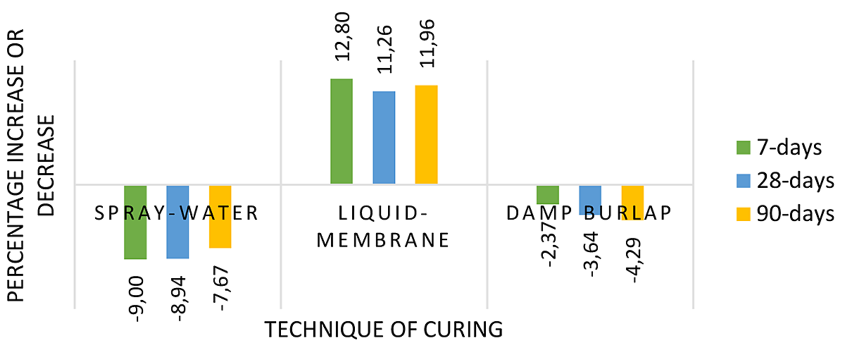

Figure 11. The percentage of compressive-strength test compared with normal curing

noted for spray-water. It should be taken into consideration that the compressive-strength at 28-days is also within guide requirement. The results were compatible with (Hussein and Abbas, 2024). The liquid membrane–forming compound technique gives the best results, compared to other curing methods, with an improvement compared to normal curing up to (12.80, 11.26 and 11.96)% at 7, 28 and 90 days, respectively. This technique can be the most suitable because liquid membrane-forming compounds have the capacity to retain moisture and minimize evaporation loss. Finally, the burlap damp methods which can also be recommended minimize reduction up to (2.37, 3.64 and 4.29)% at 7, 28 and 90 days, respectively. These results are higher than the (ACI 308R, 2016) recommendation. The evaporation from the surface is reduced. It is suitable with high surface area in pavement construction, as recommended in ACI 308R.

Tensile-strength test

The results of using normal curing technique are within the required tensile strength, not less than 30 MPa and conforms the ACI 327R recommendation (minimum expected tensile-strength 28 MPa) at 28-days, as shown in Figure 12. Other curing technique were used in order to simulate the most local curing in the field. Thus, the comparison between (spray-water, burlap damp and liquid membrane-forming compound) can be presented in Figure 13 as percentage decrease (reduction) or increase (improvement) compared to normal curing tensile strength. From Figure 13, the reduction up to (7.08, 6.57, and 6.27)% at 7, 28 and 90 days, respectively, for spray-water, taking into consideration that the tensile strength at 28-days is also within guide requirement. The results are compatible with (Hussein and Abbas, 2024). while the liquid membrane-forming compound technique gives the best results, compared to other curing with an improvement compared to normal curing up to (10.21, 9.23 and 8.23)% at 7, 28 and 90 days, respectively. This technique can be the most suitable to field with the best results because liquid membrane-forming compounds have the capacity to retain moisture and minimize evaporation loss. Finally, the burlap damp methods which can also

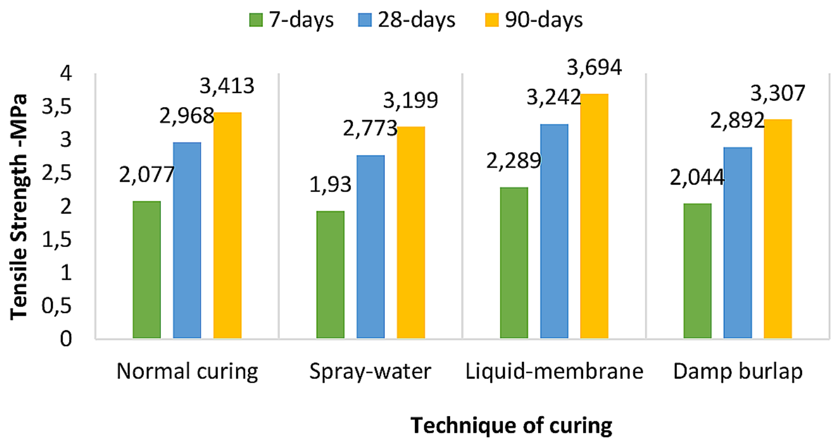

Figure 12. The results of tensile strength test with different curing techniques

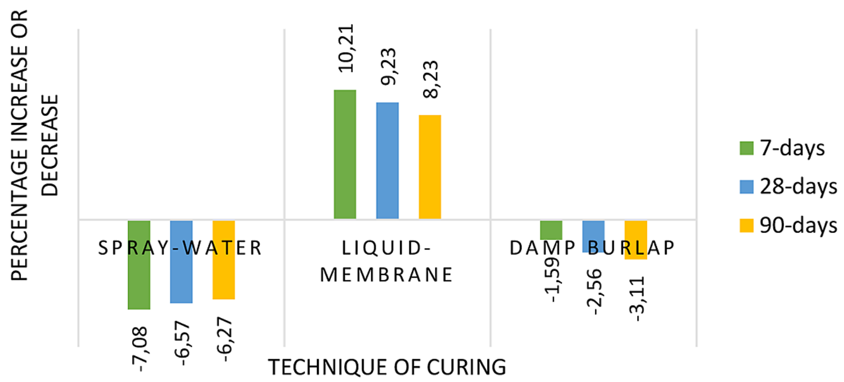

Figure 13. The percentage of tensile strength test compared with normal curing

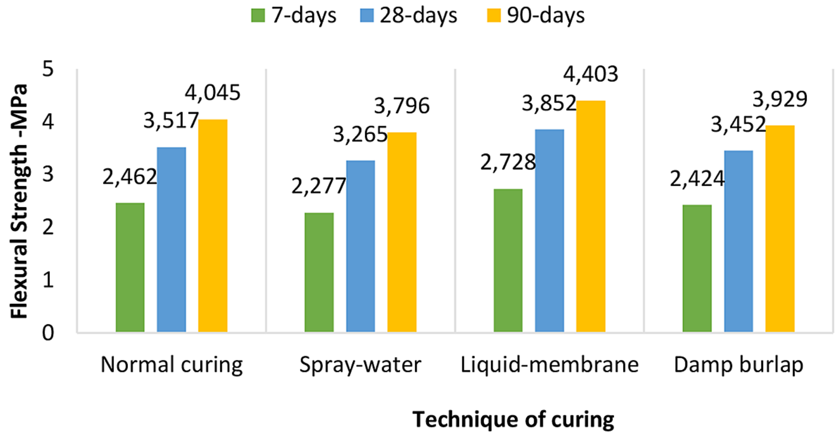

Figure 14. The results of flexural-strength test with different curing techniques

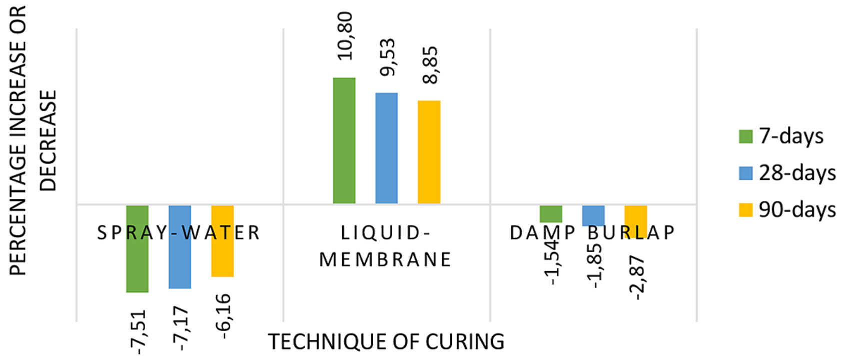

Figure 15. The percentage of flexural-strength test compared with normal curing

be recommend minimized reduction up to (1.59, 2.56 and 3.11)% at 7, 28 and 90 days respectively. The obtained results were higher than the (ACI 308R, 2016) recommendation. Evaporation from the surface was reduced. Hence, it is suitable with high surface area in pavement construction, as recommended in ACI 308R.

Flexural-strength test

The results of using normal curing technique are within the required flexural strength of not less than 30 MPa and conform to the ACI 327R recommendation (minimum expected flexural-strength 28 MPa) at 28-days, as shown in Figure 14. O curing techniques were used in order to simulate the most local curing in the field. Thus, the comparison between (spray-water, burlap damp and liquid membrane-forming compound) can be presented in Figure 15 as percentage decrease (reduction) or increase (improvement) compared to normal curing flexural strength. Figure 15 shows the reduction up to (7.51, 7.17, and 6.16)% at 7, 28 and 90 days, respectively for spray-water; the flexural-strength at 28-days is also within guide requirement. The results are compatible with (Hussein and Abbas, 2024). The liquid membrane forming-compound technique gives the best results compared to other curing with an improvement compared to normal curing up to (10.80, 9.53 and 8.85)% at 7, 28 and 90 days, respectively. This technique can be the most suitable to adopt with the best results, because liquid membrane-forming compounds have the capacity to retain moisture and minimize evaporation loss. Finally, the burlap damp methods which can also be recommend in filed with minimize reduction up to (1.54, 1.85 and 2.87)% at 7, 28 and 90 days, respectively. These results are higher than (ACI 308R, 2016) recommendation. Evaporation from the surface was reduced. It is suitable with high surface area in pavement construction, as recommended in ACI 308R.

CONCLUSIONS

Comparing lab-normal curing technique with curing in field is important in order to predict the efficiency factor compressive strength safety by predicting the reduction or improvement of strength in field results. The main conclusions that can be drawn from in production RCC-p curing method are as follows:

1. Using the spray-water curing technique led to a reduction up to (9, 8.94 and 7.67)% at 7, 28 and 90 days, respectively, for the compressive strength test, compared to lab-normal curing results.
2. The compressive strength results reduced by (2.37, 3.64 and 4.29)% at 7, 28 and 90 days, respectively, for using burlap damp curing technique compared to lab-normal curing results.
3. The improvement of compressive strength results adopting liquid membrane-forming compound curing technique reached up to (12.80, 11.26 and 11.96)% at 7, 28 and 90 days. Respectively. compared to lab-normal curing results.
4. The results of tensile and flexural strength for RC-C-P with different cures follow a similar trend with compressive strength results.

Finally, the production of RC-C-P adopting the liquid membrane-forming compound led to enhanced performance and quality and was the most suitable in field.

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