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Performance of self-curing concrete as affected by different curing regimes

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Abstract. In this study, polyethylene glycol (PEG) and polyacrylamide (PAM) have been used as self-curing agents to produce self-curing concrete (SC). Compressive strength, ultrasonic pulse velocity (UPV), bulk electrical resistivity, chloride ion penetrability, water permeability, and main microstructural characteristics were examined under different curing regimes, and compared to those of the control concrete mixture with no self-curing agents. One batch of a control mixture and one batch of a SC mixture were air-cured in the lab to act as non-water-cured samples. The water curing regimes for the control mixture included continuous water curing for 3, 7, and 28 days and periodical moist curing using wetted burlap for 3 and 7 days. Curing regimes for the SC mixtures included 3 days of water curing and periodical moist curing for 3 and 7 days. SC mixtures showed better microstructure development and durability performance than those of the air-cured control mixture. A short water curing period of 3 days significantly improved the performance of the SC mixtures similar to that of the control mixture that was water cured for 28 days. SC concrete represents a step towards sustainable construction due to its lower water demand needed for curing and hence can preserve the limited water resources in many parts of the world.

Keywords: self-curing concrete; water-soluble polymers; curing regimes; mechanical properties; durability; microstructure

1. Introduction

Concrete curing is an essential step in concrete construction. Curing describes the process by which hydraulic cement develops its properties over time because of continued hydration in the presence of sufficient water and temperature (ACI 308R-01 2008). Therefore, it is important to reduce water evaporation from concrete and maintain satisfactory moisture content, especially during the early ages for the continuation of hydration of the cement, and the development of cement microstructure. Proper curing is seldom achieved in many construction projects. The question of whether there will be self-curing concrete was raised by several researchers (Mather 2001, Bentz *et al.* 2005). Several investigations concluded that the concept of self-curing could be achieved by increasing water retention in the mix and reducing water evaporation (Dhir *et al.* 1994, 1995, Han *et al.* 2017). Two methods were considered to achieve internal curing from within the concrete; first using pre-soaked lightweight aggregate or highly porous normal weight aggregates in the mixture, and second by using super absorbent polymers as an ingredient in the mixture. The use of pre-soaked aggregates (i.e., lightweight aggregates and highly porous normal weight aggregates) as a source of internal curing water was investigated by several researchers (Zou *et al.* 2015, Shen *et al.* 2015, Tang 2017, Zhang *et al.* 2017, Wang *et al*. 2017). Shen *et al*. (2016), Farzanian *et al*. (2016), Ma *et al*. (2017), Kang *et al*. (2018) studied the effect of internal curing by using super absorbent polymers. Also, some investigators (Gifta *et al.* 2013, Mousa *et al.* 2015, Savva and Petrou 2018) investigated the use of combining pre-soaked aggregate and super absorbent polymers for internal curing. It was found that water-soluble polymers could be used as self-curing agents (Dhir *et al.* 1995, El-Dieb 2007, Venkateswarlu *et al.* 2015, Bashandy *et al.* 2017, Thrinath and Kuma 2017).

The use of self-curing agents is very important from the point of view that water resources are getting valuable every day (i.e., each one cubic meter of concrete requires about 3 cubic meters of water for construction most of which is used for curing). The benefit of self-curing agents is significant in areas where water is not adequately available. The use of water-soluble polymers in cement and concrete mixtures proved to be a good self-curing agent that had good ability to improve the water retention capacity of the mixture and improve cement hydration (El-Dieb 2007, El-Dieb *et al.* 2012). The use of these water-soluble polymers to produce self-curing concrete would represent a new trend in concrete construction. The performance of self-curing concrete mixtures incorporating water-soluble polymers as self-curing agents needs more investigation and comparison with control mixtures. The effect of adopting different curing regimes on the performance of SC concrete needs to be evaluated to optimize the curing needed. That will provide a better understanding of SC concrete to open the door for its use towards sustainable construction.

2. Objectives of Investigation

The primary objectives of the study are to produce SC mixtures and assess the effect of applying different curing

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Table 1 Concrete mixture proportions for 1 cubic meter

Cement	Fine Aggregate	Coarse Aggregate	Water (W/C)
328 kg	697 kg	1089 kg	210 kg (0.64)

regimes on the mechanical properties, durability and main microstructural characteristics. The SC mixtures have been produced by incorporating water-soluble polymers; polyethylene glycol (PEG) and polyacrylamide (PAM). The mechanical performance of the concrete mixtures has been evaluated by measuring the 28-day compressive strength and ultrasonic pulse velocity (UPV). The durability was evaluated at 28 days of age by measuring bulk electrical resistivity, chloride ion penetrability (i.e., rapid chloride penetrability test-RCPT), and water permeability. The main microstructural characteristics were examined using a scanning electron microscopy (SEM) at 28 days of age.

3. Experimental Work

3.1 Materials and mix proportions

Cement used in this study was ordinary Portland cement which confirmed to ASTM C150 Type I. The coarse aggregate was a natural crushed stone with a nominal size of 19 mm (3/4"), the specific gravity of 2.65, and water absorption of 1.0%. The two available types of fine aggregate were used in the mixture; natural crushed stone sand with a fineness modulus of 3.9 and a specific gravity of 2.63, and dune sand with a fineness modulus of 1.0 and specific gravity of 2.63. Both types of fine aggregates were mixed to get a fine aggregate with fineness modulus from 2.6 to 2.8. The concrete mixture was designed to have a slump ranging from 50 to 60 mm and to yield a cube compressive strength of 25 MPa. The mixture used was selected to resemble common concrete grade used in several applications in the UAE. Also, in previous studies (El-Dieb 2007, El-Dieb *et al.* 2012), lower w/c ratios were examined, and it was concluded that the effect of using self-curing agent in mixtures with high w/c ratio needs to be investigated. Table 1 gives the concrete mixture used in the study.

The water-soluble polymers used in the study as self-curing agents were PEG and PAM (El-Dieb 2007, El-Dieb *et al.* 2012). Table 2 gives the main properties of both polymers. It should be noted that the rate of water absorption of PAM is 100 times higher than that of PEG. Fig. 1 shows a low magnification SEM of the used polymers showing its shape and typical crystals' size. Polymers were added as dry ingredients to the wet concrete mixture after the addition of all the mixing water. Based on preliminary trials on PEG, the dosage of the polymer was selected to be 0.025% by weight of the cement. The use of a higher dosage of PEG resulted in a dry mixture with low workability and cement hydration (Dhir *et al.* 1998, El-Dieb 2007, El-Dieb *et al.* 2012). The PEG was used solely with a dosage of 0.025% by weight of the cement (mixture SC-PEG100). Polyacrylamide (PAM) was used in conjunction with PEG as another alternative. The dosage of PEG+PAM

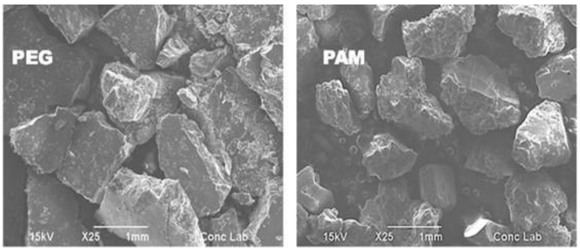


Fig. 1 SEM (low magnification) of used polymers showing its shape and typical crystal size

Table 2 Properties of used water-soluble polymers

Polymer Type	Property					
	Molecular Weight (g/mol)	Appearance	Moisture %	SG***	pH	Water Absorption Rate (g/g/min)
PEG*	6000	White Flakes	0.1% Max	1.08-1.09	5-7	0.03
PAM**	9000000	White Crystalline Powder	0.1% Max	0.75	5-7	3.01

*Polyethylene glycol
**Polyacrylamide
***Specific Gravity in 50% aqueous sol.

together was kept at 0.025% by weight of the cement. The weight ratios of the PEG and PAM were varied; the first ratio was 80% PEG and 20% PAM (SC-PEG80-PAM20) and the second ratio was 60% PEG and 40% PAM (SC-PEG60-PAM40). All SC mixtures had a slump in the designed range of 50-60mm except for SC-PEG60-PAM40, the mix was dry and sticky with a slump ranging from 20-30 mm. Sun and Xu (2008), Bashandy *et al.* (2017) reported a similar reduction in the workability of mixtures with high dosage of PAM.

3.2 Curing regimes

The curing regimes of the control concrete mixture included air curing, continuous water curing (i.e., water immersion) for 3, 7 and 28 days and periodic moist curing using wetted burlap for 3 and 7 days. Periodic moist curing consisted of covering the specimens with burlap, which was wetted once a day for the needed curing period. Periodic moist curing was used to resemble common curing used on construction sites. The SC concrete mixtures were exposed to air-curing, periodically moist curing for 3 and 7 days using wetted burlap and continuously water curing (i.e., water immersion) for 3 days. Table 3 summarizes the curing regimes adopted in this study.

3.3 Specimens and testing

Compressive strength, ultrasonic pulse velocity (UPV), bulk electrical resistivity, initial water sorptivity, water permeability, and chloride ion penetrability (RCPT) tests were conducted at 28 days of age. The compressive strength and UPV tests were conducted on cubes 100×100×100 mm. The electrical resistivity test was conducted on concrete cylinders with 100 mm in diameter and 200 mm in length, according to ASTM C1760-12 (2017). The water

Table 3 Curing regimes applied to concrete mixtures

Concrete Mixture I.D.	Curing Regimes					
	Air-Curing	3 days Periodic Moist Curing	7 days Periodic Moist Curing	3 days Water Curing	7 days Water Curing	28 days Water Curing
Control	✓	✓	✓	✓	✓	✓
SCC-PEG100	✓	✓	✓	✓	-----	-----
SCC-PEG80-PAM20	✓	✓	✓	✓	-----	-----
SCC-PEG60-PAM40	✓	✓	✓	✓	-----	-----

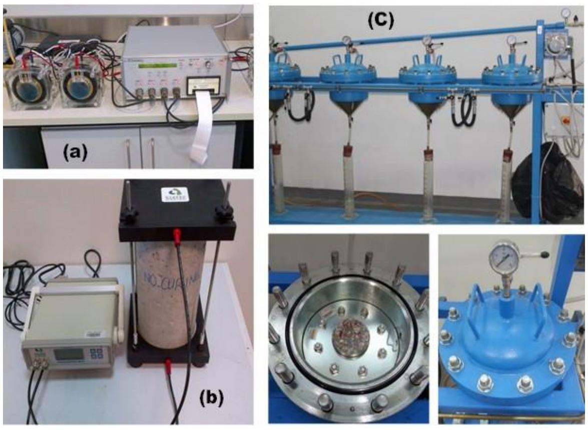


Fig. 2 Testing concrete specimens; (a) RCPT, (b) bulk electrical resistivity, and (c) water permeability

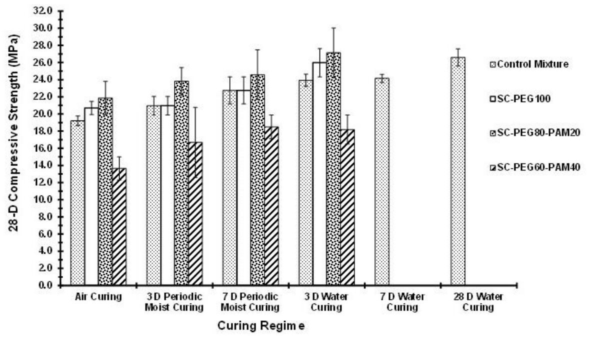


Fig. 3 28-day compressive strength of different mixtures put through different curing regimes

Table 4 Ultrasonic pulse velocity test results of different mixtures at 28 days of age

Concrete Mixture I.D.	Ultrasonic Pulse Velocity (m/sec)*					
	Air-Curing	3 days Periodic Moist Curing	7 days Periodic Moist Curing	3 days Water Curing	7 days Water Curing	28 days Water Curing
Control	4922 (64.0)	5065 (33.7)	5097 (59.7)	5102 (39.2)	5236 (64.9)	5253 (86.4)
SCC-PEG100	4934 (78.0)	5172 (42.3)	5233 (64.5)	5270 (136.8)	-------	-------
SCC-PEG80-PAM20	4927 (105)	5105 (88.8)	5244 (135.1)	5305 (59.3)	-------	-------
SCC-PEG60-PAM40	4779 (23.5)	4863 (125.2)	4912 (62.2)	4964 (62.2)	-------	-------

*Values in parenthesis are the standard deviation

permeability and chloride ion penetrability (RCPT) tests were conducted on concrete discs with a diameter of 100 mm and a thickness of 50 mm cut from concrete cylinders. All tests were conducted on 3 replicate samples. The RCPT was conducted according to ASTM C1202-17 (2017). The water permeability test was conducted using a pressure head ranging from 10-20 bars, and the side of the concrete discs was sealed using an epoxy sealer material. Fig. 2 shows different tests in progress. The microstructure characteristics were examined at 28 days of age using JOEL® scanning electron microscope.

4. Results and discussions

4.1 Compressive strength

The average 28-day compressive strength results and the corresponding standard deviations are shown in Fig. 3. For the control mixture, increasing the water curing time increased the compressive strength, with the 28 days water curing yielding the highest compressive strength.

In the absence of water curing, the compressive strength values of the air-cured SC mixtures SC-PEG100 and SC-PEG80-PAM20 were higher than that of the control mixture exposed to air curing. The 28-day compressive strength of the SC-PEG100 mixture exposed to 3 days of continuous water curing was almost the same as that of the control mixture continuously water cured for 28 days. Whereas, the application of 3 days water curing resulted in compressive strength for the SC mixture SC-PEG80-PAM20 higher than the control mixture exposed to water curing for 28 days. That indicated that the application of water curing for a short period of 3 days was enough for the SC-PEG100 and SC-PEG80-PAM20 mixtures to achieve the desired 28-day compressive strength of the similar control concrete continuously water cured for 28 days. The 3 days of water curing is shorter than the minimum curing period of 7 days specified by the ACI 318M-01 (2008) for ordinary Portland cement concrete mixtures. The mixture SC-PEG60-PAM40 had a compressive strength lower than that of the control mixture even after the application of 3 days of water curing. The inclusion of a high dosage of PAM as a self-curing agent resulted in a dry fresh mixture due to its high ability to retain water, which in turn impaired the concrete workability and consolidation, and hence negatively affected the concrete compressive strength. This effect was observed in other properties.

Fig. 3 indicates that although the periodic moist curing using wetted burlap was not as effective as the continuous water curing, it helped the concrete to develop its compressive strength. For the control mixture and all of the SC mixtures, increasing the periodic moist curing time resulted in increasing the compressive strength. It can be

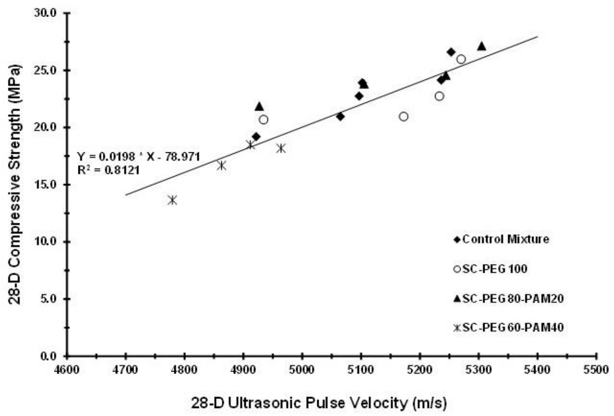


Fig. 4 Relation between 28-day UPV and compressive strength for tested mixtures

seen that adopting 7 days of periodic moist curing for the SC-PEG100 mixture increased its compressive strength to a level close to that of the control mixture continuously water cured for 3 days. Adopting 7 days of periodic moist curing for the SC-PEG80-PAM20 mixture resulted in a compressive strength almost similar to that of the control mixture water cured for 7 days. That demonstrated that the use of small dosage of PAM together with PEG improved the strength development with minimum water curing period.

4.2 Ultrasonic Pulse Velocity (UPV)

The UPV test results at 28 days of age are given in Table 4. The UPV of the control mixture increased with the increase in the water curing period. That was attributed to the fact that the mixture became denser due to the continuation of hydration and filling of the pore space initially occupied by water with hydrated cement products. Also, periodic moist curing yielded lower UPV values compared with water curing regime, which was also demonstrated by the lower compressive strength results of the control mixture achieved by the application of periodic moist curing relative to the results of the same mixture exposed to water curing.

The UPV results of the SC mixtures were consistent with the compressive strength results. The UPV of the SC-PEG100 mixture after 3 days of water curing was almost the same as that of the control mixture subjected to 28 days of water curing. Also, the UPV of the SC-PEG80-PAM20 water cured for 3 days was slightly higher than that of control mixture water cured for 28 days. That could be attributed to the continuation of hydration and the densification of the microstructure as observed in the microstructure examination. As for the SC-PEG60-PAM40 mixture, the UPV was lower than that of the air-cured control mixture, indicating less dense microstructure, which was also observed in the compressive strength results.

Periodic moist curing was not adequate for the control mixture, while there was a significant impact of periodic curing on the UPV values of the SC mixtures SC-PEG100 and SC-PEG80-PAM20. However, the effect of periodic moist curing was not that significant in the case of the SC mixture SC-PEG60-PAM40.

Table 5 Relation between concrete electrical resistivity and corrosion protection (ACI 222R-01 2008)

Resistivity (kΩ.cm)	Corrosion Protection
< 5	Low
5 to 10	Low to Moderate
10 to 20	High
> 20	Very High

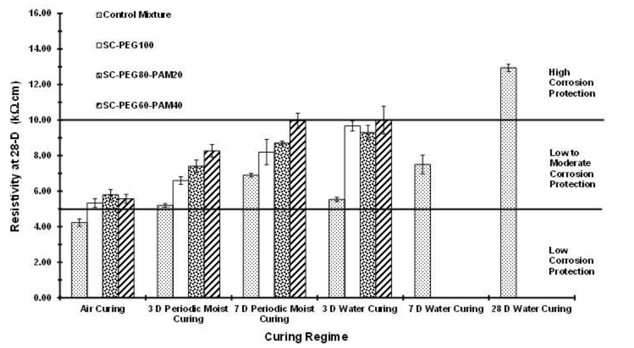


Fig. 5 28-day bulk electrical resistivity of different mixtures subjected to different curing regimes

Fig. 4 shows the relationship between UPV results and compressive strength values for all tested mixtures. The relation shows the agreement between UPV results and compressive strength values as affected by the different curing regimes.

4.3 Bulk electrical resistivity

The electrical resistivity of concrete is considered a measure of its protection to embedded reinforcement against corrosion (ACI 222R-01 2008). Table 5 shows the relation between electrical resistivity and concrete corrosion protection. The concrete corrosion protection is improved as the electrical resistivity increases. The average resistivity values measured at 28 days of the tested mixtures exposed to different curing regimes and the corresponding standard deviations are presented in Fig. 5. The resistivity of the control mixture increased with the increase in the water curing period. The adoption of 28 days of water curing yielded the highest resistivity value, which indicated better corrosion protection. The application of 3 days and 7 days periodic moist curing did not have a significant improvement in the resistivity values. Similarly, the application of 3 days water curing was not effective in improving the resistivity. Therefore, a minimum of 7 days of water curing was needed for control mixture to avoid any negative impact on its corrosion protection level.

The resistivity of the SC mixtures exposed to air curing was slightly higher than that of the control mixture exposed to air curing. Nevertheless, the resistivity of all air-cured mixtures, with and without the self-curing agents, was around the 5.0 kΩ.cm value which indicated ‘low to moderate’ corrosion protection (ACI 222R-01 2008). The periodic moist curing for 3 and 7 days improved the resistivity of the SC mixtures, but their corrosion protection

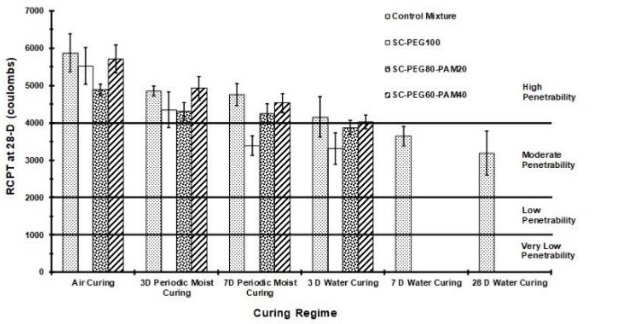


Fig. 6 28-day RCPT results of different mixtures exposed to different curing regimes

Table 6 Chloride ion penetration classifications (ASTM C1202-17 2017)

Charge passed (coulombs)	Chloride Ion Penetrability
> 4000	High
2000 to 4000	Moderate
1000 to 2000	Low
100 to 1000	Very Low
< 100	Negligible

category was still 'low to moderate'. The adoption of 3 days water curing regime increased the resistivity of the SC mixtures significantly. The resistivity of the SC mixtures exposed to 3 days of water curing was about 10.0 kΩ.cm. This value is the upper bound for the 'low to moderate' corrosion protection category and the lower bound for the 'high' corrosion protection category (ACI 222R-01 2008).

It was observed that the application of periodic moist curing for 3 and 7 days and the application of 3 days water curing increased the resistivity values for the SC-PEG60-PAM40 compared to the other two SC mixtures, in spite that the compressive strength and UPV results for the same mixture were inferior to the other two SC mixtures. That could be attributed to the fact that the application of any short period of curing to SCC-PEG60-PAM40 has a significant influence on its pore size distribution and connectivity and not the total pore volume which in turn affected its electrical resistivity values. The electrical resistivity of concrete is mainly affected by pore size distribution and connectivity, which influence the ionic mobility in the pore solution (Shahroodi 2010). Discontinuity of pores will reduce the ionic mobility and will increase concrete resistivity. Fine pore size distribution and discontinuity of pores is a function of cement hydration, and therefore any action that will increase cement hydration is beneficial (Shahroodi 2010).

4.4 Chloride Ion Penetration (RCPT)

The RCPT was conducted at 28 days of age to evaluate the concrete durability concerning its resistance to chloride attack and chloride-induced corrosion. Fig. 6 shows the RCPT values of tested mixtures for different curing regimes and the corresponding standard deviations. Water curing resulted in lowering the charge passing for control mixture with the 28 days water curing has the lowest value, which is

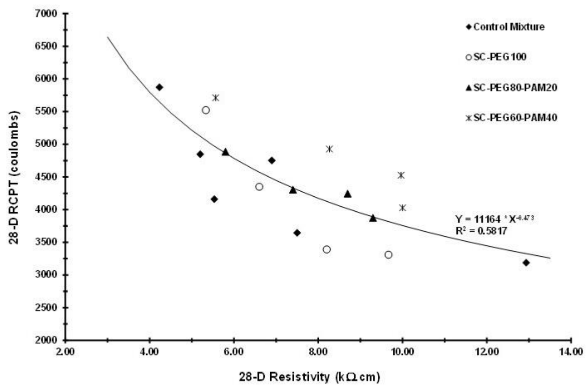


Fig. 7 Relation between 28-day electrical resistivity and RCPT values for all tested mixtures

ranked as 'Moderate penetrability' according to ASTM C1202-17 (2017) classification shown in Table 6. The periodic moist curing regime, as well as the 3 days continuous water curing, did not change the permeability category as 'High penetrability' for the control mixture. The control mixture needed a minimum of 7 days of continuous water curing to achieve a permeability ranking of 'Moderate penetrability' similar to that achieved by applying 28 days of continuous water curing.

Similar to the control mixture, the periodic moist curing was not effective in improving the chloride penetrability ranking of all SC mixtures, except for the mixture SCC-PEG100. The application of water curing for 3 days was sufficient to reduce the RCPT values of all SC mixtures to be in the 'Moderate penetrability' category (ASTM C1202-17 2017). The SC mixture SC-PEG100 exhibited the lowest RCPT values among all SC mixtures for the different curing regimes, which indicated that the SC mixture SC-PEG100 was able to produce a dense microstructure with the application of a short curing period as observed in the microstructure examination. Increasing the time of the periodic moist curing from 3 to 7 days did not result in any considerable improvement in the RCPT values of the SC mixtures SC-PEG80-PAM20 and SC-PEG60-PAM40. Fig. 7 shows the relation between electrical resistivity and RCPT values for all mixtures. The relation shows that the effect of applying different curing regimes on the RCPT values was in agreement with the effect on the electrical resistivity values for all tested mixtures.

4.5 Water permeability

Water permeability test is a measure of water movement through the concrete which mainly depends on the microstructure of the concrete and also can be used as an index of concrete durability (Basheer *et al.* 2001). Fig. 8 shows the water permeability measured at 28 days of age for the tested mixtures and the corresponding standard deviations. Similar to the RCPT and electrical resistivity results, the water permeability values of the control mixture was significantly reduced by applying water curing. The reduction was significantly improved by increasing the water curing period. Control mixture exposed to periodic moist curing with wet burlap did not show a significant

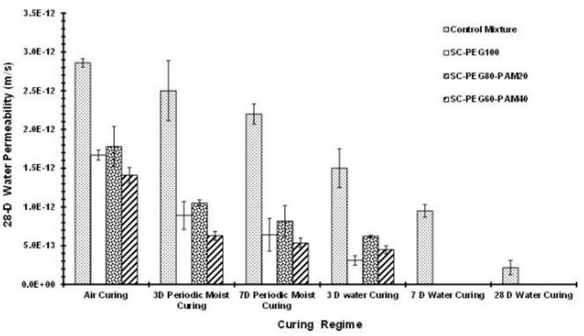


Fig. 8 Water permeability results of different mixtures under different curing regimes at 28 days

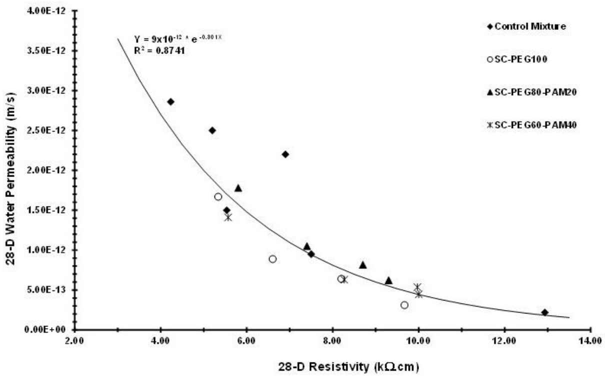


Fig. 9 Relation between the 28-day electrical resistivity and water permeability values for all tested mixtures

effect on the permeability results. The permeability value started to be significantly affected when applying 7 days of water curing.

All SC mixtures showed lower permeability compared to air-cured control mixture. The reduction was around 50% in the permeability values. The exposure of SC mixtures to 3 days water curing resulted in a significant reduction yielding permeability values similar to that of the control mixture water cured for 28 days. Periodic moist curing slightly reduced the permeability values of SC mixtures. The permeability values for SC mixtures exposed to periodic moist curing were slightly higher than those of the same mixtures subjected to 3 days water curing. The improvement in water permeability could be attributed to the discontinuity of pores as a result of the continuation of cement hydration and the densification of the microstructure as was observed in the microstructure examination. Fig. 9 shows the relation between electrical resistivity and water permeability results for all tested mixtures, while Fig. 10 shows the relation between RCPT and water permeability results. It was noted that the effect of applying different curing regimes on the water permeability results was consistent with the effect on the electrical resistivity and RCPT results.

4.6 Microstructural characteristics

Microstructure investigation was conducted at 28 days of age. Microstructure investigation was conducted on the control concrete mixture exposed to air curing and 28 days

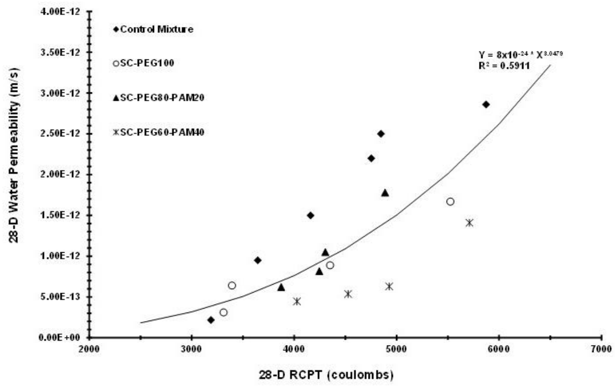


Fig. 10 Relation between the 28-day RCPT and water permeability values for all tested mixtures

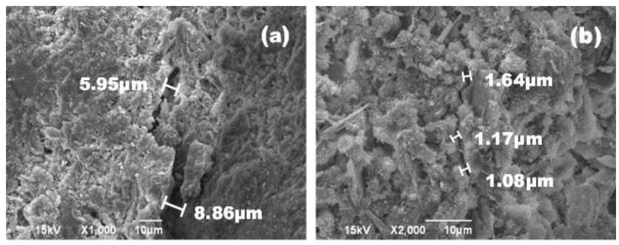
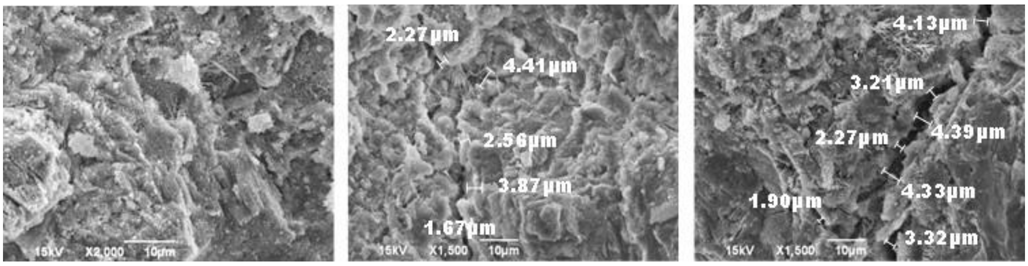


Fig. 11 Microstructure of control concrete mixture; (a) air curing, (b) 28 days water-curing

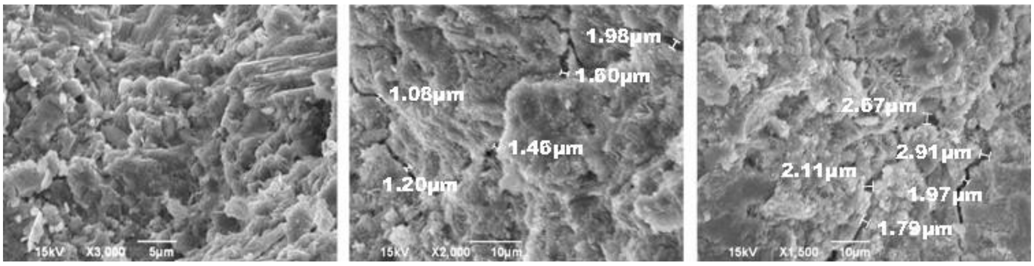
water curing. For the SC concrete mixtures, the mixtures examined for microstructure were those exposed to air curing and 3 days water curing. Figs. 11(a) and 11(b) show SEM micrographs of the control mixture exposed to air curing and 28 days water curing respectively. Microstructural investigation of the control mixtures exposed to the 28 days water curing exhibited denser microstructure compared to the same mixture exposed to air curing. The microstructure densification could be associated with the better cement hydration. For the air cured control mixture, larger voids were observed compared to those of the control mixture subjected to 28 days water curing. Also, several microcracks, up to 9.0 μm in width, were observed in the air-cured control mixture, while the width of microcracks was up to 2.0 μm for the 28 days water cured control mixture. The densification of the microstructure and small microcracks width of the control mixtures water cured for 28 days supported the superior performance noted in all tested properties. Likewise, the large pore size and microcracks width of the air cured control mixture supported the inferior performance in all of the tested properties.

Figs. 12(a), 12(b), and 12(c)) show the SEM micrographs of air-cured self-curing mixtures SC-PEG100, SC-PEG80-PAM20 and SC-PEG60-PAM40 respectively. The microstructure of all SC concrete mixtures was not as dense as that of the control mixtures water cured for 28 days. On the other hand, the microstructure of all SC mixtures exposed to air curing was denser than the air-cured control mixture. That confirmed the results of the measured properties. It was observed that crystalline hydration products such as $Ca(OH)_2$ did not have clear edges and corners in all SC mixtures which could be attributed to the



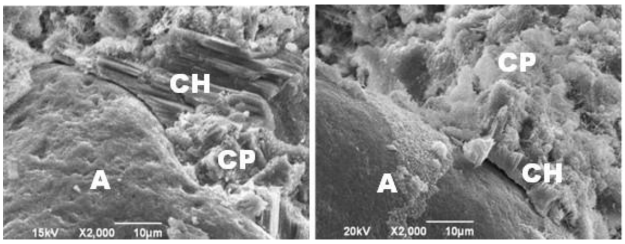
(a) SC-PEG100 (b) SC-PEG80-PAM20 (c) SC-PEG60-PAM40

Fig. 12 Microstructure of self-curing concrete mixtures exposed to air curing

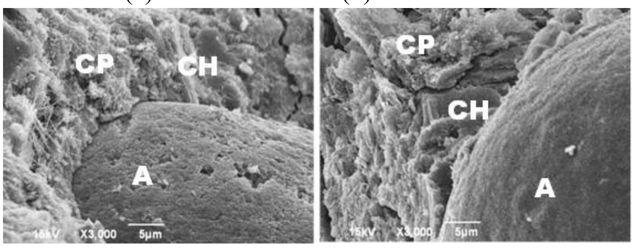


(a) SC-PEG100 (b) SC-PEG80-PAM20 (c) SC-PEG60-PAM40

Fig. 13 Microstructure of self-curing concrete mixtures exposed to 3 days water curing



(a) Control Mixture (b) SC-PEG100



(c) SC-PEG80-PAM20 (d) SC-PEG60-PAM40

Fig. 14 Microstructure of aggregate matrix interfacial transition zone (ITZ), A=aggregate, CH=calcium hydroxide, CP=cement paste

unavailability of space for the crystals to grow and well develop due to dense microstructure as a result of the continuation of hydration. Similar observations were previously reported in the literature (Dhir *et al.* 1996, Reinhardt and Weber 1998). Also, the width of microcracks observed in all SC mixtures ranged from 2.0 μm to 5.0 μm, which was smaller than those observed in the control mixture exposed to air curing.

Figs. 13(a), 13(b), and 13(c)) show the SEM micrographs of the 3 days water cured SC mixtures SC-PEG100, SC-PEG80-PAM20 and SC-PEG60-PAM40 respectively. The microstructure of all SC concrete mixtures exposed to 3 days water curing exhibited a dense microstructure similar to that of the control mixture exposed to water curing for 28 days. It was noted that the C-S-H cross-links with the crystalline hydration products forming a discrete skeleton network. The width of the microcracks ranged from 1.0 μm to 3.0 μm, which was comparable to those observed for the 28 days water cured control mixture. That explained and confirmed the comparable test results.

Fig. 14 shows the aggregate matrix interfacial transition zone (ITZ) for the control and SC mixtures exposed to air curing. The air-cured control mixture, Fig. 14(a), demonstrated more porous ITZ with well-formed and large-sized crystalline hydration products. While the ITZ zone of the SC mixtures exposed to air curing was dense and contained less sized and not well-formed crystalline hydration products as shown in Figs. 14(b), 14(c), and 14(d).

5. Conclusions

The following are the main conclusion based on the test results obtained in this study:

- Production of self-curing (SC) concrete is viable with the use of two different water-soluble polymers; polyethylene glycol (PEG) and polyacrylamide (PAM). Self-curing mixtures investigated in this study showed better performance compared with those of air-cured control mixtures.
- Water-soluble polymers with high molecular weight (i.e., PAM) should not be used solely, and when used in conjunction with low molecular weight polymers (i.e., PEG), its dosage should be kept to a minimum to avoid the drying of the fresh concrete mixture.
- The application of different curing regimes showed a similar effect on all tested properties (i.e., compressive strength, UPV, electrical resistivity, RCPT, and water permeability).

• Compressive strength of SC mixtures PEG100 and PEG80-PAM20 showed marginal improvement when exposed to periodic curing for 3 and 7 days. The improvement was less than 12%, while SC mixture PEG60-PAM40 showed moderate improvement ranging from 20% up to 35%.
• Periodic moist curing with wet burlap for 3 and 7 days showed minimal improvement of the UPV results for all SC mixtures (i.e., less than 6.5%).
• Moderate improvement was observed in the RCPT and electrical resistivity results for all SC mixtures when exposed to periodic moist curing (i.e., improvement ranged from 12% to 40%).
• Water permeability results showed good improvement (i.e., 40% to 60%) for all SC mixtures when subjected to periodic moist curing.
• The adoption of a short water curing period of 3 days to SC mixtures significantly improved the different performances to a level similar to that of the control mixture exposed to continuous water curing for 28 days (i.e., improvement was up to 33%, 40%, 80% and 81% for compressive strength, RCPT, electrical resistivity, and water permeability respectively). That can change the trend in construction with regards to water demand, especially in regions where water is not adequately available.
• The microstructure of SC mixtures exhibited denser microstructure with smaller microcracks and reduced size of crystalline hydration products compared to air-cured control mixture.
• Microstructure characteristics of the 3 days water cured SC concrete mixtures resembled those of the control mixture subjected to 28 days of water curing.

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