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ARTICLE

Influence of Selected Curing Techniques on Compressive Strength of Concrete From Palm Kernel Shell Ash and Ordinary Portland Cement

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ABSTRACT

This paper discusses the findings of an experimental study on the effect of various curing procedures on the compressive strength of concrete produced by partially substituting portland cement with Palm Kernel Shell Ash (PKSA). Palm kernel shell ash was utilized in a 1:2:4 mix ratio as a partial substitute for ordinary Portland cement (OPC) at percentage levels of 0%, 10%, and 15%. River sand with particles passing a 4.75 mm BS sieve was used, as well as crushed aggregate with a maximum size of 20 mm, and palm kernel shell ash with particles passing a 212 µm sieve. The compressive strength of the test cubes (150 mm x 150 mm x 150 mm) was determined after 7, 28, and 56 days of curing. The results demonstrated that test cubes containing Palm kernel shell ash developed strength over a longer curing period than ordinary Portland cement concrete samples and that the strength changes depending on the amount of PKSA in the cube samples. The findings showed that at 28 days, test cubes with 5%, 10%, and 15% PKSA content in all curing procedures utilized obtained a greater compressive strength. Curing by immersion produced the highest compressive strength in all replacement level while the concrete cured by sprinkling and spraying gives a lower strength in all replacement level.

1. Introduction

Concrete curing is an important step in the civil engineering construction industry, but it is also one of the most overlooked and misunderstood. It has a substantial influence on robust growth and long-term viability. Curing takes place shortly after the concrete has been placed and completed, and it requires maintaining moisture and temperature conditions both near and underneath the surface [1]. It is described as the treatment of newly laid concrete during the hardening process so that it maintains adequate moisture to prevent shrinkage and cracking [2]. Concrete curing is believed to be essential for the hydration of the cement content. The moisture-temperature history over time determines the amount and rate of hydration of concrete. For full and adequate strength development, evaporation of water in concrete should be avoided, and the water spent in hydration should be replaced. According to [3], for curing to be beneficial in concrete, it should begin as soon as the concrete hardens, because the negative effects of premature inappropriate curing are permanent [4].

Ordinary Portland cement (OPC) is the most significant building material on earth. The current annual production rate is roughly 2.1 billion tonnes, and it is predicted to increase rapidly to nearly 3.5 billion tonnes by 2023. According to [5], Nigeria's annual cement demand is esti-

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mated to be at 7.8 million tonnes, with just 5.0 million tonnes of Portland cement manufactured in the country. Imports account for the remaining 2.8 million tonnes. Researchers are assisting in the hunt for a low-cost alternative cement that may be made locally, reducing the need for Portland cement and, as a result, the cost of building. The search for acceptable agricultural wastes for this purpose was consequently increased, and some of the waste products explored for usage include rice husk ash [6,7], corn cob ash [8,9], and others. PKSA is another appropriate substance that may be used.

Most pozzolanic materials used in concrete production in developed countries are waste from industrial processes, such as pulverized fuel ash, also known as fly ash, crushed granulated blast furnace slag, silica fume, and palm oil fuel ash. Due to minimal industrial activity in most developing countries, particularly Nigeria, research on the application of SCMs has concentrated on waste recycling from the agricultural and forestry sectors. Agricultural and forestry materials and by-waste products abound throughout the nation and are sometimes massively burned in heaps or left in the open field, with just a small portion used as fuel or animal feed. As Kinuthia, Mofor, Melo, and Djialli (2006) [10] correctly recognized, trash from these sources represents a potential supply of construction materials in addition to natural non-renewable resources that are currently being mined due to their renewable nature when properly handled.

PKSA is a byproduct of the palm oil industry. It is produced from the burning of palm oil plant waste. The dumping of PKSA pollutes the environment and poses a health risk, as well as occupying the property. By using PKSA in concrete manufacturing, these issues may be greatly avoided.

This project aims to investigate the effect of various curing methods on the compressive strength and density of concrete with some of its cement replaced with PKSA.

However, this study examines the impact of different curing methods on the compressive strength of concrete with 5%, 10%, and 15% replacement of OPC with PKSA, to recommend the best method for Nigeria PKSA concrete.

2. Materials and Methods

2.1 Materials

A coarse aggregate with a maximum particle size of 20 mm was used. As the fine aggregate, local river sand was used. The cement utilized in the study was ordinary Portland Cement, which is the most commonly used cement for building in Nigeria and meets [11].

The palm kernel shells utilized in this study were obtained from a palm oil processing plant in Akure's southern region (Ondo Road – Aba Oyo I, Adebowale area). The ash from Palm Kernel was generated by controlled burning (750 °C) in a kiln at the Federal University of Technology, Akure's Department of Mechanical Engineering. The ash solidified (Figure 1) and then ball-milled to obtain a powdered granulated shape, which was sieved via a 75 µm sieve and then a 45 µm sieve to obtain a particle size near to the 45 µm size of Portland cement (Figure 2). The specific gravity of sieved ash is 2.19. The fine aggregate (river sand) was also sourced locally and sieved using the No 4 sieve (4.75 mm). Similarly, the coarse aggregate was sourced from a nearby quarry. The fine aggregate had a specific gravity of 2.62, while the coarse aggregate (granite) had a specific gravity of 3.14 and a maximum size of 20 mm. Fresh tap water from the Geotechnical laboratory of the Civil Engineering Department of the Federal University of Technology, Akure, was utilized in the research for concrete preparation and curing. Figure 1 shows the experimental design for the concrete cube crushing test, while Figure 2 shows the material quantities for the concrete mix design.

Figure 1. Palm Kernel Ashes after burning (large particle size and porous texture)

Figure 2. Palm Kernel ashes after ball-milled into finer particle

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Table 1. Concrete cube crushing test experiment design

	Factors	Levels	Description
	Curing by Immersion Into Water		
A	Percentage Replacement % Curing Age (Days) Replicates	3 3 3	0%, 5%, 15% 7, 28, 56
	Total Number of Cubes = (3 × 3 × 3)		**27**
	Curing by Spraying With Water		
B	Percentage Replacement % Curing Age (Days) Replicates	3 3 3	0%, 5%, 15% 7, 28, 56
	Total Number of Cubes = (3 × 3 × 3)		**27**
	Curing by Covering Concrete with Plastic Sheets		
C	Percentage Replacement % Curing Age (Days) Replicates	3 3 3	0%, 5%, 15% 7, 28, 56
	Total Number of Cubes = (3 × 3 × 3)		**27**
	Curing by Saturated Wet Covering		
D	Percentage Replacement % Curing Age (Days) Replicates	3 3 3	0%, 5%, 15% 7, 28, 56
	Total Number of Cubes = (3 × 3 × 3)		**27**
	Curing by Application of Membrane Forming Curing Compound		
E	Percentage Replacement % Curing Age (Days) Replicates	3 3 3	0%, 5%, 15% 7, 28, 56
	Total Number of Cubes = (3 × 3 × 3)		**27**
TOTAL NUMBER OF CUBE (27 + 27 + 27 + 27 + 27)			**135**

Table 2. Mix components for test concrete in kg

Percentage Replacement	Concrete Constituents			
	Cement (Kg.)	*Coarse Aggregate (Kg.)*	*Fine Aggregate (Kg.)*	*PKSA (Kg.)*
0%	53.0	265.0	133.0	0.0
10%	47.0	265.0	133.0	1.20
15%	42.0	265.0	133.0	2.90

2.2 Methods

Chemical Test on Palm Kernel Shell Ash (PKSA)

The chemical test was carried out at the Engineering Materials Development Institute (EMDI) research facility in Akure, Nigeria, using an Energy Dispersive X-ray Fluorescence Spectrometer (EDXRF), model EDX3600B, as indicated in Figure 3. The system includes a vacuum pump for detecting light elements and a helium injection device for analyzing liquids. The samples were placed inside two containers and labeled B and C where B is the Cement (Figure 4) and C (Figure 5) is the PKSA and placed inside the spectrometer tray one after the other. The elemental composition of the PKSA was determined by X-ray fluorescence analysis, which was then translated to the oxide composition using [12]. The loss on ignition and the specific gravity of the samples were determined at the Engineering Materials Development Institute (EMDI) research facility in Akure, Nigeria.

Figure 3. Spectrometer machine (EDX3600B EDXRF)

Figure 4. Test Sample (Palm Kernel Shell Ash)

Figure 5. Test Sample (Ordinary Portland Cement)

Moisture Content of the Fine Aggregate (River sand)

The test portion of fine aggregates (river sand) was put in a container and dried at 105˚C ± 5˚C until it reached a consistent mass. The moisture content was estimated by expressing the mass of total moisture in the sample as a percentage of the mass of the dry sample. The technique descriptions were consistent with [13].

Aggregates Grading

The sieve analysis of coarse aggregate (granite), fine aggregate (river sand), and PKSA used for casting the concrete mixtures under investigation was performed at FUTA's Civil Engineering Department's Structural Laboratory. The sieves were arranged from 25 mm to 4.76 mm for granite, 4.75 mm - 72 µm for river sand, and 500 µm - 45 µm for PKSA. The percentage retained on each sieve was calculated by dividing the weight retained on each sieve by the original sample mass, whereas the percentage passing (or percentage finer) was calculated by beginning with 100 percent and removing the percentage retained on each sieve cumulatively. The entire operation was carried out following [14].

Bulk Density and Specific Gravity of Components

For granite, river sand, and PKSA, the bulk density test was carried out following [15]. The test was performed in a weighted metal cylinder with a predetermined height and diameter. To determine the compacted bulk density, the container was divided into three layers and stamped with a rod on each layer. The overflow was collected, and the bulk density was calculated by dividing the sample's net mass in the cylinder by its volume.

The specific gravity test on fine aggregates (river sand), coarse aggregates (granite), and PKSA was carried out following the British Standard [16]. The specific gravity was calculated as the ratio of the sample mass to the mass of the corresponding water volume.

Standard Consistency and Setting time of Cement and PKSA

The test was performed following British Standard [17] standards on grade 42.5 Dangote 3X ordinary Portland cement and each of the cement components resulting from varied percentage replacements of OPC with PKSA. Vicat's standard equipment was employed. The plunger of the device was allowed to penetrate 33 mm from the top of each of the cement pastes in the molds during the test. As a standard consistency for each paste, the ratio of the mass of water necessary to form a paste that allows 33 mm of penetration to the mass of the cementing component (in percentage terms) was recorded.

The initial and final setting time for the OPC and each of the pastes produced by partially substituting the OPC with the PKSA were determined. The initial setting time was calculated as the time between adding water to the paste and losing plasticity.

The final setting time was estimated as the time elapsed between the addition of water to the paste and the loss of flexibility and attainment of appropriate firmness to bear a certain specified pressure. This test was carried out under the instructions of the British Standard [17].

Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) of the Coarse Aggregate

This test was performed in compliance with British Standard [18]. The sample was placed into the mold in three stages, with 25 tampings between each layer. The weight was computed as A. The equipment was then put in the compression testing machine at a steady pace to achieve a 40 kN load in 10 minutes. After then, the load was lifted. The sample was then sieved through a 2.36 mm sieve, and the fraction that went through the sieve was calculated as B. $(B \div A) \times 100$ was used to compute the aggregate crushing value. The test was done three times, and the average value was used to calculate the ACV.

The AIV test was carried out following British Standard [18]. A sample was passed through a 12.5 mm sieve and retained on a 10 mm sieve. The material was put into the mold in three layers and tamped 25 times at each layer before being weighted in grams as weight "C." The sample was put into the AIV machine and subjected to 15 blows, each given at a one-second interval. The sample was removed and sieved through a 2.36 mm sieve; the percentage passing through was measured in grams as weight "B." Three such tests were performed, and the mean of the findings was reported. The total impact value was calculated as $(C \div B) \times 100$.

Fineness Test of the Cement and PKSA

A dry sieve technique test was used for this test it was according to British Standard [11]. OPC and PKSA were shaken for 8 minutes in a Sieve No.325 (45 µm) sieve. The fineness of the 45 µm sieves was stated in terms of the percentage weight of residue and determined as the ratio of sample mass retained in the 45µm sieve to total sample mass.

Slump and Compacting Factor

A water-to-cement ratio of 0.56 was used to make the concrete mix ratio of 1:2:4. The height of the slumped concrete was used to determine the slump. This experiment was conducted following British Standards [19]. A mass ratio, i.e. the ratio of the mass of partially compacted concrete to the mass of completely compacted concrete, was used to determine the degree of compaction known as the compacting factor.

Batching, Curing and Compressive Test of Concrete

The concrete cubes were produced using 150 mm x 150 mm x 150 mm molds in compliance with [20]. The molds were first lubricated to ensure that the concrete cubes

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could be removed without stress. The new concrete was poured in three equal layers and pounded with 25 strokes of a 50 mm round-ended rod. The tops of the cubes were labeled for identifying purposes. Following that, the samples were immediately stored in the laboratory at room temperature. After 24 hours, the samples were demold.

Five different curing methods were used to cure the samples until the testing days. Curing procedures included immersion in water (A), water spraying (B), polythene covering (C), Curing with hessian cloth (wet covering) (D), and the use of Curing chemicals (E) as shown in Table 1.

The samples were submerged in water until the crushing days of water immersion. Spraying with water kept the samples wet until the crushing days by spraying them with water twice daily (morning and evening). In the Curing by Covering Concrete with Plastic Sheets method, the samples were covered with polythene until the crushing days. The specimen was covered with a Hessian cloth in the saturated membrane covering till the curing day, In the case of membrane-forming curing compounds, the specimen was immersed in calcium chloride (CaCl) solution before being exposed to air until the curing days. One hundred thirty-five (135) cubes were cast using a water/cement ratio of 0.56 and crushing tests were performed using a compression machine in conformity with the provisions in [21].

3. Results and Discussions

Oxide Composition of PKSA

Table 3 shows the results of the chemical analysis of PKSA. According to [22], for a product to be classified as a pozzolan, the addition of Al_2O_3, SiO_2, and Fe_2O_3 must account for at least 70% of the total oxide composition. Al_2O_3 + SiO_2 + Fe_2O_3 for PKSA generated 64.5 % of the result shown in Table 3. This fulfills the requirement for [22]. The ignition loss (LOI) obtained for PKSA was 8.05 percent. This amount, according to [22], is less than the 10% limit required for pozzolan. Based on the results of the chemical tests, PKSA may be classified as a Class N pozzolan.

Table 3. Oxides composition of PKSA

Compound	Al_2O_3	SiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI
Oxides (%) in PKSA	3.7	59.5	1.3	5.3	3.4	5.9	0.3	0.4	8.05

Physical Properties of Aggregates and PKSA

The aggregates' physical characteristics tests, as well as the PKSA for the concrete test, are summarized in Table 4. The table illustrates that the aggregates' natural moisture content and specific gravity are suitable for creating standard concrete. The specific gravity of PKSA cement is lower than that of Portland cement. The PKSA has a bulk density of 825.3 kg/m^3 compared to 3053.4 kg/m^3 for OPC. When OPC is largely replaced with PKSA, the conclusion is that the concrete will be less dense. For coarse aggregates (granite), the aggregate crushing value (ACV) and aggregate impact value (AIV) are respectively 23.05 percent and 20.33 percent, indicating that the coarse aggregate is extremely strong and suitable for concrete. The cement has a fineness percentage of 99.5 percent, and the PKSA has a fineness percentage of 100 percent because the PKSA was passed through a 45 µm sieve before being used in concrete production.

Table 4. Physical properties of aggregates and PKSA

Properties of all Materials Used	Fine Aggregate	Coarse Aggregate	Binders	
	River Sand	Granite	OPC	PKSA
Fineness (%)	-	-	99.5	100
Moisture Content (%)	2.3	1.4	-	-
Fineness Modulus	2.4	6.53		
Specify Gravity	2.62	3.19	3.12	2.19
Bulk Density (kg/m^3)	1325	1675	3053.4	825.3
Aggregate Crushing Value (%)		23.05		
Aggregate Impact Value (%)		20.33		

Grading of the Aggregates

Table 4 shows the computed fineness modulus of the fine aggregate based on the material's sieve analysis results. The grading curves demonstrate that the sand was properly graded and acceptable for concrete production. The grain size analyses of the materials (fine aggregates) utilized are shown in Figure 6.

Standard Consistency and Setting Time

Table 5 shows the results of the standard consistency test for OPC as well as the appropriate PKSA replacement levels for OPC. The table indicates that the amount of water required to obtain the specified consistency increases as the percentage of Portland cement replaced with PKSA increases. The table also shows the results of the setting time test for OPC and other substitutes. The table indicated that paste with a replacement level of 15% has a higher initial setting time than the 45-minute recommended by the BS Code while all the final setting time falls into the 600-minute recommended by [17]. As a result, at the replacement levels used in this study, adding PKSA to Ordinary Portland Cement at 15% and above affects the binder's initial and set time.

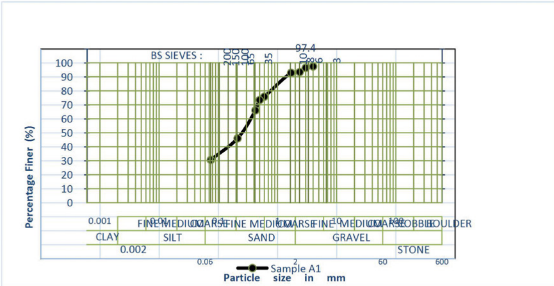

Figure 6. Particle size distribution curves for fine aggregate

Table 5. Standard consistency test result and setting time test result

Replacement of OPC by PKSA (%)	0	10	15
Cement's mass (g)	400	360	340
PKSA's mass (g)	0	40	60
Water (g)	125	126.75	129.87
Setting time – Initial (min)	30	42	48
Setting time – Final (min)	360	392	420

Tests on Fresh Concrete

Table 6 presents the data of the slump test. The results show that the slump test increases as the level of PKSA increase. This suggests that both concrete with OPC/PKSA mixes are more workable than concrete made entirely of OPC.

Table 6. Test results on fresh concrete

Concrete (%)	0	10	15
Slump test (mm)	45	24	19

Compressive Strength

The results of the compressive strength of the PKSA Concrete at different curing ages and different replacement (i.e. 0, 10, and 15%) are presented in a graphical representation of average compressive strength versus curing age for different curing methods used in the experiment, as shown in Figures 7, 8 and 9 and Table 7.

The outcomes showed that the compressive strength of concrete samples containing palm kernel ash increased with increasing curing age, exactly as it does with typical ordinary Portland cement concrete at all replacement levels investigated. After the 10% replacement level, despite the slow rate of strength gain until 28 days, the strength is about the same as that of regular concrete at 56 days, although other replacement levels exhibited improvement with time. It could be shown that the concrete strength performance increased with time up to 15% replacement levels. This is true in the sense that the strength of pozzolanic materials rises with increasing cementitious material hydration owing to the interaction between the free lime generated during OPC hydration and the silica content of SCM.

Another aspect that may be accountable for the strength pattern is the curing method used. In concrete technology, it is believed that curing impacts the strength of concrete. As shown in Figure 5, concrete cured by Immersion (A) produce the highest strength (19.8 N/mm^2) at 28 days, followed by Concrete cured by covering with polythene (B) which produces strength of 17.3 N/mm^2. For concrete cured by Membrane covering, it produced a strength of 15.6 N/mm^2 at 28 days. Concrete cured saturated wet covering method, concrete cured by spraying and fogging produced the lowest strength which is 15.9 N/mm^2 and 15.6 N/mm^2 respectively However, Figure 10 shows that the most effective curing process is immersion in water of concrete.

Table 7. Compressive Strength of Various concrete mixes

Curing Regime	% Replacement	Strength (N/mm^2)		
		7 DAYS	28 DAYS	56 days
A (Immersion in water)	0	13.5	19.8	20
	10	14.3	20.3	21.1
	15	14.5	20.5	22
B (Water spraying)	0	11.1	15.6	15.8
	10	13.2	16.2	17.2
	15	14.6	16.5	17.9
C (Polythene covering)	0	13.4	17.3	17.5
	10	13.3	17.9	19.8
	15	14.1	18.2	20.1
D (Saturated wet covering)	0	13	15.9	16.2
	10	13.5	17.8	19.9
	15	13.8	18.3	20
E (Membrane-forming curing chemicals)	0	13.3	15.6	15.8
	10	13.8	18.2	19.3
	15	14	18.7	19.9

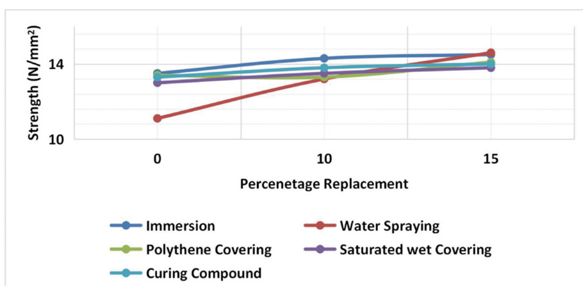

Figure 7. Compressive strength of concrete with various curing methods for 7 days

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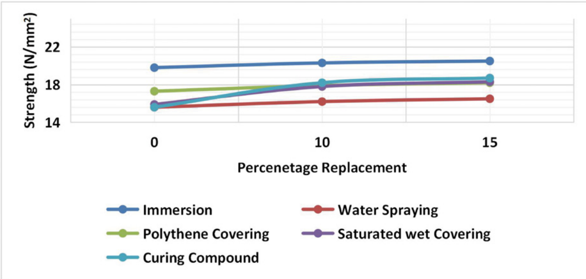

Figure 8. Compressive strength of concrete with various curing methods for 28 days

Statistics and Analysis of Variance (ANOVA)

In the analysis of variances, a two-way ANOVA was used to investigate the influence of curing technique on concrete strength and the influence of curing age on concrete strength (ANOVA). There is a statistically significant difference in the average the compressive strength of concrete of various groups (p = 0.0.00875 < 0.05) and (p = 0.000109 < 0.05), according to Table 8. It demonstrates that the strength growth in the concrete sample is influenced by curing ages and methods.

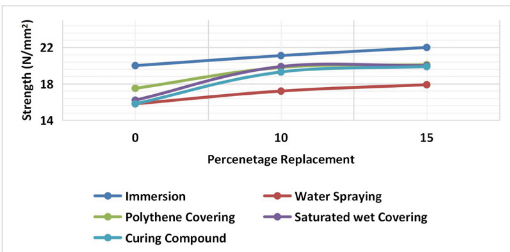

Figure 9. Compressive strength of concrete with various curing methods for 56 days

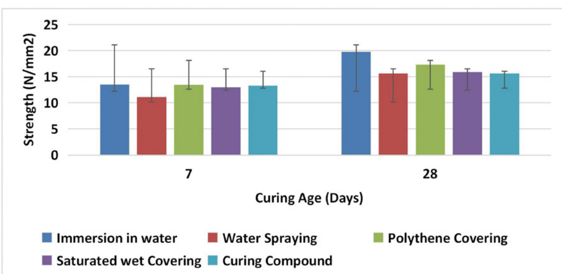

Figure 10. Graph showing the strength of concrete and the various curing methods for 7, 28 and 56 days

Table 8. Analysis of Variance (ANOVA) table

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Curing Method	23.33	4	5.83	7.33054	0.008745	3.837853
Curing Age (Days)	55.88	2	27.94	35.11605	0.000109	4.45897
Error	6.37	8	0.8			
Total	85.58	14				

4. Conclusions

The study looked at the impacts of PKSA on the compressive strength development of ordinary Portland cement concrete. The study has brought to the body of knowledge the potentials of agricultural waste as supplemental cementitious materials that may be enhanced to increase its performance and utilization in a developing nation like Nigeria. Based on the findings, the following conclusions were reached:

The addition of PKSA increases the amount of water necessary to make a workable concrete mix, impacting concrete workability and resulting in a high water/cement ratio.

Because the pozzolanic effects of PKSA concrete have not yet been determined, it may require other characteristics to be identified as a pozzolan.

Curing by immersion in water found to be the most effective curing technique for concrete because it creates minimal moisture loss and so increases cement hydration reaction, followed by covering with polythene, which generates better compressive strength than spraying and fogging techniques of curing. Curing by Application of Membrane Forming Curing Compound (Curing Compound) is only suited for short-term concrete curing.

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