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Compressive Strength of Concrete Using Different Curing Methods

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Abstract: The structural use of concrete depends largely on its strength, especially compressive strength. Various tests were carried out to ascertain the properties of concrete materials, whereas test performances of the concrete with different mix ratios at specific ages of curing were undertaken. The study determined the compressive strength of concrete using different curing methods. Four different methods of curing (ponding, continuous wetting, open-air curing and sprinkling with water) were used. Seventy-two (72) cubes were cast using a mix ratio of 1:2:4 and 1:3:6 with 0.5 water cement ratio and with 0.6 waters cement ratio respectively. The compressive strengths were determined after 7 days, 14 days and at 28 days of curing. Findings show that for 1:2:4 concrete, maximum of 28-day compressive was the highest for concrete cured by ponding and the least was by sprinkling water. Further findings show that for 1:3:6 concrete, maximum of 28-day compressive strength was obtained using ponding and the least was open air curing. Despite ponding method producing the highest compressive strength of concrete, it is practically impossible to cure cubes above ground structural elements. Wet-covering method is recommended for structural elements, such as columns, beams and slabs in other to produce concrete of a required compressive strength.

Keywords: *Control strength; compatibility; curing conditions; concrete development; concrete production.*

1. Introduction

There are different types of curing: shading concrete work, covering concrete surfaces with hessian or gunny bags, sprinkling of water, ponding method, membrane curing and steam curing. The nature of work and climatic conditions as indicated by Padhi (2014), determines the curing method. Bushlaibi (2004) studied "the effect of curing methods on the compressive strength of silica fume high strength concrete" posited that there are five curing conditions such as: "water curing" for (28 days), "no curing", "sprinkle curing" (sprinkling two times in a day for 7days), "plastic curing" (sprinkling two times in a day with plastic cover sheet for 7 days) and "burlap curing" (sprinkling two times in a day with burlap cover for 7 days) and concluded as follows:

- "The compressive strength of the silica fume high strength concrete, as in normal strength concrete was related to curing duration".
- "The adverse effect on the development of concrete compressive strength increases with increasing temperature and test duration" and
- "The curing ages of 28 days and beyond, the strength reduction reaches up to 12% of the control strength in some curing conditions".

Several researchers' (Ogah, 2016; Padhi, 2014; Goel, et al., 2013; Raheem, et al., 2013; Bushlaibi, 2004) have different views on the suitable method of curing concrete. Out of the several curing methods suggested by Padhi (2014) and Goel, et al. (2013) "water curing" was found to be the most suitable curing method for concretes. Raheem, et al. (2013), were of the view that "moist sand" curing method was the most suitable curing method for concretes, "Drier curing" conditions was found by several researchers: Bingöl & Tohumcu, 2013; Ferreira et al. (2012); Silva et al. (2012) to perform worse than "wet curing" conditions. Bediako et al. (2015) emphasized that the importance of curing is to primarily help cement achieve more complete hydration, whereas Jackson and Akomah, (2018), ascertained concrete needs to be cured for a maximum number of days to attain the maximum strength required. Shih-Wei Cho (2013) posited that silt with fine content of 5% and less is optimum for concrete strength and durability. The study determines the compressive strength of concrete using different curing methods. Results showed OPS concrete were in consonance with conventional lightweight concrete.

2. Literature Review

Several studies on curing of recycled materials and alternative materials used in concrete production have been conducted by (Bingöl and Tohumcu, 2013; Ferreira et al., 2012; Silva et al., 2013; Mohamed, 2011; Fonseca et al., 2011; Ling and Teo, 2011; Al-Gahtani, 2010; Teo et al., 2010; Yazıcı et al., 2009; Velosa and Paulo, 2008). Silva et al. (2013) conducted a study on selected plastic waste aggregates (polyethylene terephthalate (PET) as partial replacement of course aggregate and concluded that there was a decrease in durability of concrete with plastic aggregates when compared to conventional concrete. All samples performed poorly under drier curing regimes and concrete with plastic aggregates deteriorated less under progressively drier curing conditions than conventional concrete. The volume of permeable voids (VPVs), sorptivity, water permeability, chloride diffusion coefficient and time to corrosion initiation from the 90-day salt ponding test, and Rapid Chloride Penetrability Test (RCPT) were the metrics used for the durability assessment. In another study by Ling and Teo (2011) where they determined the effect of four curing methods (full water curing, air dry curing, 3-day curing and 7-day curing) and use of waste rice husk ash (RHA) and expanded polystyrene (EPS) beads as partial replacement of cement and course aggregate respectively in lightweight concrete bricks production reported a decrease in water absorption capacity with a decrease in RHA.

Properties investigated were hardened concrete density, compressive strength and water absorption of the EPS RHA concrete bricks as well as scanning electron microscopy (SEM) analysis. Teo et al. (2010) conducted a study on oil palm shell (OPS) replaced with course aggregate under four curing conditions. Yazici et al. (2009) investigated the dependence of compressive strength, flexural strength, and toughness of reactive powder concrete (RPC) produced with class-C fly ash (FA) and ground granulated blast furnace slag (GGBFS) cured under three conditions (standard, autoclave and steam curing). An increase in compressive strength and a decrease in flexural strength and toughness were recorded under autoclave and steam curing. Increasing the GGBFS and/or FA content improved the toughness of RPC under all curing conditions. However, Fonseca et al. (2011) did not notice any difference in the compressive strength, splitting tensile strength, modulus of elasticity, and abrasion resistance of recycled aggregate concrete (RAC) and conventional concrete (CC) under different curing methods. Ferreira et al. (2012) noticed a fall in compressive and splitting tensile strength and modulus of elasticity of concrete, and increase in wear resistance to abrasion in laboratory conditions, wet chamber, and outer environment curing conditions when increasing the plastic waste replacement of course aggregates.

Bingöl and Tohumcu (2013) reported a decrease in compressive strength under air curing in a study of three curing methods (air curing, water curing and steam curing) on the compressive strength of Self Compacting Concrete (SCC) produced from silica fume (SF). For steam curing optimum performance was obtained at 70 °C for 16 hours. Mohamed (2011) reported 28 days curing having higher compressive strength than 7 days curing in a study to determine the compressive strength of self-compacting concrete (SCC) with two cement content fly ash (FA) and silica fume (SF)). This is expected since concrete strengthens with age. In BS 882 (1992) the upper allowable limit of silt content is 8% and the average silt content of sand for preparing concrete is 3.33%. However, Olanitori (2012) reported a maximum value of 3% as silt content suitable for concrete production in his study. Velosa and Paulo (2008) also studied the mechanical properties and curing methods of concrete produced from hydraulic-lime binder and pozzolanic material, a residue from expanded clay production. Al-Gahtani (2010) investigated curing of Type I, silica fume, and fly ash cement concrete specimens with wet burlap covering, by applying curing water-based and acrylic-based compounds. Strength development was found to be higher with covering with wet burlap than the other two methods of curing.

3. Methodology

This section presents the various methods used during the laboratory experiment. The use of "Hessian sac" in the form of mulch to maintain water on the surface of the concrete cubes and it is important to ensure that all the sides of the cubes were covered (Mohamed and Najm, 2019). As soon as the concrete cubes were sufficiently hardened, wet materials were used to cover the cubes to prevent surface damage. Through the curing period, the sac was kept saturated with water. Materials used were Ordinary Portland cement, fine washed sand as fine aggregate and granite of nominal size 20mm as coarse aggregate, and clean drinkable (pipe borne) water. Concrete mixes of 1:2:4 and 1:3:6 by weights with water/cement ratio 0.5 and 0.6 respectively for the production of different types of concrete. Slump and compaction factor test done based on the BS 1881-102 and BS 1881-103 respectively, to determine the workability of the fresh concrete. Seventy-two (72) concrete cubes, as shown in Table 1 were cast and compacted, in iron - molds with internal measurement of 150mm × 150mm × 150mm were used in casting the concrete cubes. Three (3) cubes each for the mix ratio 1: 2: 4 at 0.5 water cement ratio and 1: 3: 6 at 0.6 water cement ratio were tested after their respective curing days. All specimen from the laboratory test were used (Jackson, Mustapha, & Kotey, 2019; Tijani and Mustapha, 2017).

Table 1: Number of Cubes for Casting and their Respective Days

Curing Method	**Number of Cubes**					
	Mix Ratios					
	1:2:4 at 0.5			1:3:6 at 0.6		
	Days			Days		
	7	14	28	7	14	28
	Number of cubes for each Day			Number of cubes for each Day		
Ponding	3	3	3	3	3	3
Sprinkling	3	3	3	3	3	3
Open air	3	3	3	3	3	3
Wet covering	3	3	3	3	3	3

Curing Method and Test Performance: Four methods (Ponding, Sprinkling, Air Curing and Wet- covering) curing were used on concrete mix (Nahata et al., 2014; Surana et al., 2017), both in its fresh and hardened states for the experiments. The first method of curing was "Ponding". Cubes were immersed in-side water throughout the curing period and the water for the curing was maintained at an average laboratory temperature of 28C to prevent thermal stresses that could result in cracking. The second method of curing was "Sprinkling water". Sprinkling with water is an excellent method of curing when the ambient temperature is well above freezing and the humidity is low. The third method of curing was "Wet-covering". The fourth method of curing was 'Totally uncured types" (open air). Throughout the curing period, concrete cubes were in the open air without any curing applied. During the Test Performance: Sieve analysis was performed on crushed granite and the fine aggregate, as prescribed in the BS 812: section 103.1: 1985. First, the performance of "Silt test" according to the BS 812 to determine the amount of silt, clay, or any other fine dust that may be present in the sand sample. Then, "Slump test", according to BS 1881-102 standard and the difference in slump in time recorded Followed by "Compaction factor test" according to BS 1881-103. This test was done to measure the degree of compaction resulting from the application of standard amount of work. Finally, the "Compressive test" was performed after a curing period of 7days, 14days and 28days. The cubes were loaded until failure and test was performed as prescribed in BS 1881: part 116:1983 (Neville 2010).

4. Results and Discussion

This section presents the results of the laboratory experiment conducted on different types of cube. Table 2 shows the average silt content as 3.33% and this was in accordance with BS 882 (1992), with sample 2 having percentage by volume of silt depth to sand thickness and thickness of visible silt two times than the other two samples.

Table 2: Silt Test Results (Sand)

Determination of Silt Content

Observation Sheet

Number	**Description**	**Sample No**		
		Sample 1 (ml)	Sample 2 (ml)	Sample 3 (ml)
1	Level of content (ml)	150	150	150
2	Depth of sand without silt - V1 (ml)	80	80	80
3	Thickness of visible silt V2 (ml)	2	4	2
4	Volume of Water (ml)	70	70	70
5	Percentage by volume of Silt depth to sand thickness (%) $\frac{V2}{V1} \times 100$	2.5%	5%	2.5%
	Average Content		3.33%	

Compacting Factor Test and Slump Test of Concrete (1:2:4): The compacting factor test and slump test on concrete using a mix ratio 1:2:4 by weight and water/cement ratio of 0.5 shows that the slump with the highest figure of 21 had the highest compacting factor of 0.91 and the remaining two slump with a similar figures had a compacting factor difference of 0.02. A low degree of workability from the slump and compacting factor test (Neville, 2010) were recorded from the mix.

Compacting Factor Test and Slump Test of Concrete (1:3:6): The compacting factor test and slump test on concrete using a mix ratio 1:3:6 by weight and water/cement ratio of 0.6 shows that the slump with the highest figure of 80 had the least compacting factor of 0.82, and indicates a medium degree of workability for the concrete mix (Neville 2010). Table 3 shows the seven (7) day compressive strength test result for 1:2:4 concrete. "Ponding" had the highest average compressive strength of 17.3N/mm^2, followed by "sprinkling" and the cube with least average compressive strength was "open air curing,"

Table 3: Seven (7) Day Compressive Strength

Name of cubes	**Mass in air (g)**	**Mass in water(g)**	**Density of cubes (kg/cm^{-3})**	**Peak load (kN)**	**Compressive strength (N/mm^{-2})**	**Average Compressive strength (N/mm^{-2})**
Sprinkling						
S1	8038	3955	1969	355.6	15.8	
S1	7952	4567	2349	315.8	14.0	14.6
S1	7998	4580	2340	316.5	14.1	
Ponding						
P1	8270	4785	2373	406.0	18.0	
P1	8460	4879	2362	404.4	18.0	17.3
P1	8133	4684	2358	356.1	15.8	
Wet covering						
W1	8117	4614	2317	287.5	12.8	
W1	8259	4754	2357	310.2	13.8	13.6
W1	8212	4751	2373	316.5	14.1	
Open air curing						
O1	7923	4521	2329	277.8	12.3	
O1	8095	4613	2325	303.0	13.5	12.9
O1	7774	4444	2335	289.8	12.9	

Table 4 shows the 14-day compressive strength test result for 1:2:4 concrete. Ponding" had the highest average compressive strength, followed by "wet-covering" and the cube with least average compressive strength was "sprinkling."

Table 4: Fourteen (14) Day Compressive Strength

Name of cubes	Mass in air (g)	Mass in water(g)	Density of cubes (kg/cm-³)	Peak load (kN)	Compressive strength (N/mm-²)	Average Compressive strength (N/mm-²)
Sprinkling						
S5	7961	4534	2323	351.8	15.6	
S5	8083	4605	2324	349.0	15.5	15.4
S5	7842	4408	2211	343.2	15.2	
Ponding						
P5	8246	4735	2468	414.1	18.4	
P5	8202	4744	2475	431.8	19.2	18.4
P5	8346	4682	2428	398.6	17.7	
Wet-covering						
W5	8004	4519	2313	351.8	15.6	
W5	7628	4545	2331	365.1	16.2	15.9
W5	8188	4508	2306	355.6	15.8	
Open air curing						
O5	8172	4720	2456	379.8	16.9	
O5	7911	4550	2334	335.6	14.9	15.5
O5	8117	4706	2446	332.2	14.8	

Table 5 shows the twenty-eight (28) day compressive strength test result for 1:2:4 concrete. "Ponding" had the highest average compressive strength, followed by "wet-covering" and the cube with least average compressive strength was "sprinkling."

Table 5: Twenty-Eight Day Compressive Strength

Name of cubes	Mass in air (g)	Mass in water(g)	Density of cubes (kg/cm-³)	Peak load (kN)	Compressive strength (N/mm-²)	Average Compressive strength (N/mm-²)
Sprinkling						
S7	8083	4640	2314	398.9	17.2	
S7	8051	4604	2291	333.5	14.8	16.7
S7	8097	4666	2332	407	18.1	
Ponding						
P7	8334	4835	2450	444.5	19.8	
P7	8185	4734	2478	460.4	20.5	20.3
P7	8245	4777	2408	464.0	20.6	
Wet-covering						
W7	8157	4707	2310	382.2	17.0	
W7	8224	4728	2374	446.1	19.8	19.4
W7	8416	4837	2451	479.5	21.3	
Open air curing						
O7	8326	4742	2383	413.0	18.4	
O7	8069	4580	2276	431.2	19.2	18.4
O7	8067	4577	2274	394.9	17.6	

Table 6 shows the seven (7) day compressive strength test result for 1:3:6 concrete. "Ponding" had the highest average compressive strength, followed by "wet-covering" and the cube with least average compressive strength was "sprinkling."

Table 6: Seven Day Compressive Strength

Name of cubes	Mass in air (g)	Mass in water(g)	Density of cubes (kg/cm-3)	Peak load (kN)	Compressive strength (N/mm-2)	Average Compressive strength (N/mm-2)
	Sprinkling					
S1	8071	4625	2342	226.7	10.1	
S1	8034	4597	2338	238.6	10.6	10.6
S1	7929	4574	2364	253.9	11.2	
	Ponding					
P1	819 7	4705	2347	329.8	14.7	
P1	8369	4702	2482	302.6	13.4	13.2
P1	7830	4419	2396	259.0	11.5	
	Wet-covering					
W1	8165	4730	2526	272.1	12.1	
W1	8020	4627	2445	263.8	11.7	12.1
W1	8199	4705	2347	283.5	12.6	
	Open air curing					
O1	8105	4661	2347	278.9	12.4	
O1	8094	4658	2282	237.7	10.6	11.1
O1	8202	4731	2296	234.7	10.4	

Table 7 shows the fourteen (14) day compressive strength test result for 1:3:6 concrete. "Ponding" had the highest average compressive strength, followed by "sprinkling" and the cube with least average compressive strength was "open air curing."

Table 7: Fourteen Day Compressive Strength

Name of cubes	Mass in air (g)	Mass in water(g)	Density of cubes (kg/cm-3)	Peak load (kN)	Compressive strength (N/mm-2)	Average Compressive strength (N/mm-2)
	Sprinkling					
S5	8211	4693	2436	346.3	15.4	
S5	8191	4739	2471	311.1	13.8	13.7
S5	8324	4785	2907	264.7	11.8	
	Ponding					
P5	8249	4734	3467	317.5	14.1	
P5	7834	4448	2966	328.3	14.6	13.9
P5	7600	4320	2186	293.4	13.0	
	Wet-covering					
W5	801	4620	2383	272.0	12.1	
W5	8556	4957	2650	294.5	13.1	12.8
W5	8117	4812	2528	299.8	13.2	
	Open air curing					
O5	8267	4720	2456	262.0	11.6	
O5	7628	4348	2203	277.0	12.3	12.5
O5	8188	4682	2428	308.1	13.7	

Table 8 shows the twenty-eight (28) day compressive strength test result for 1:3:6 concrete. Ponding" had the highest average compressive strength, followed by "sprinkling" and the cube with least average compressive strength was "open air curing."

Table 8: Twenty-Eight Day Compressive Strength Test Results

Name of cubes	Mass in air (g)	Mass in water(g)	Density cubes (kg/cm^{-3})	Peak Load (kN)	Compressive strength (N/mm^{-2})	Average Compressive strength (N/mm^{-2})
	Sprinkling					
S7	8171	4633	2314	354.7	15.8	
S7	8029	4594	2285	284.3	12.6	14.8
S7	8280	4721	2369	362.3	16.1	
	Ponding					
P7	8906	4695	2551	376.1	16.7	
P7	8207	4763	2498	370.1	16.4	17.1
P7	8178	4669	2451	408.7	18.2	
	Wet covering					
W7	8336	4836	2451	367.3	16.3	
W7	8187	4740	2387	352.3	15.7	16.0
W7	8147	4700	2354	363.1	16.1	
	Open air curing					
O7	8157	4684	2344	329.4	14.6	
O7	7926	4505	2229	335.0	14.9	14.5
O7	8060	4584	2278	312.9	13.9	

The 1:2:4 concrete cured during the 7th day, by ponding method had the highest compressive strength with the least compressive strength recorded from open air curing. The strength development continued in the 14th day under all curing conditions with the ponding method still maintaining the highest value of compressive strength. Sprinkling curing recorded the least value of strength which was in contrast to Raheem et al. (2013) who had ponding and open air curing recording highest value of compression on the 7th and 14th day of testing respectively and spray curing having least compressive on the 1st and 2nd week of testing. On the 28th day, concrete cured by ponding method again had the highest compressive strength, but fell short of 25N/mm^2 of equal ratio. Yanusa as cited in Anum et al. (2014) and M20 according to IS: 456 (2000) whereas the least strength was again recorded by sprinkling method. Yanusa as cited in Anum et al. (2014) accorded 1:3:6 ratio with a compressive strength 15N/mm^2 whereas IS: 456 (2000) also prescribed a compressive strength of M10 after 28 days of curing and testing. All the curing methods recorded a strength values that are more than the standards. Concrete cured by ponding method had the highest compressive strength. On the 14th day, concrete cured by ponding method had the highest compressive strength, as the least was open air curing, whiles on the 28th day concrete cured by ponding method had the highest compressive strength and the open air curing recording the least strength.

Summary of Findings: The compressive strength of concrete from all the respective curing methods of ponding, sprinkling and open-air and wet covering for the mix ratio of 1:2:4 and 1:3:6 all exhibited increase in strength from the 7th day to the 28th day of crushing. Ponding method of curing recorded a highest strength development on the 7th day of testing for the various mix ratios but increased 3N/mm^2 after the 28th day crushing for 1:2:4 ratio and 3.9N/mm^2 for the 1:3:6 ratio. Open-air curing method also recorded a difference of 5.5 N/mm^2 and 3.4 N/mm^2, whiles wet covering method recorded 5.8 N/mm^2 and 3.9 N/mm^2 and sprinkling method recording 2.1 N/mm^2 and 4.8 N/mm^2 respectively. "Ponding method" of curing produced the highest compressive strength for both 1:2:4 concrete and 1:3:6 concrete during the 28th day of curing. Irrespective of curing method, the strength of concrete increased with age.

5. Conclusion and Recommendations

The study examined the compressive strength of concrete using different curing methods. In conclusion, concrete cured by "ponding method" produced the desired strength, it gained adequate early strength as there was sufficient water around it to facilitate the necessary chemical reaction of the binding agent for it strength development. Sprinkling, wet-covering and the open-air methods on the other hand had an unsatisfactory strength for the1:2:4, ratio for the 28th strength but satisfied IS standard with the 1:3:6 strength. Sprinkling method of curing should be applicable for areas where there is availability of water, since large volume of water is required. "Wet covering method" should be applicable for structural elements, such as columns, beams and slabs. Despite "ponding method" having the highest compressive strength of concrete, it is practically impossible to use "ponding method" to cure above ground structural elements.

Further Research: Further research should be conducted different mix ratios of concrete and same water cement ratio or one of the same mix ratio with two different water cement ratio to compare their respective strengths.

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