

# Comparative Analysis of Non-Destructive Strength of Water Cured and Air Cured Concrete

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**Abstract:** Non-destructive strength comparative analysis was carried out on water cured and air cured concrete cube samples. The investigation was for a period of 7, 14, 21 and 28 days. The concrete cube samples were designed using a mix ratio of 1:2:4 and water cement ratio of 0.55 with batching done in weight. The results reveal a substantial strength gain in the water cured samples to that of the air cured, having taking an average results of four cubes for each group of the samples tested for, using a Schmidt rebound hammer. The 28 day age concrete cube gave a strength difference of 5.1 N/mm<sup>2</sup> between the water cured and air cured samples in favor of strength gain of the water cured cubes, thereby pointing to the significant of curing in terms of concrete strength development.

**Keywords:** Concrete, Curing, Hydration, Non-Destructive, Strength

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## 1. Introduction

Curing of concrete plays a major role in developing the microstructure and pore structure of concrete. A good curing practice involves keeping the concrete damp until the concrete is strong enough to do its desired job or withstand its proposed imposed load. However, good curing practices are not always followed in most of the cases involving site practices which in turn leads to weak concrete structures. Curing of concrete simply means maintaining moisture inside the body of the concrete during the early ages and beyond in order to develop the desired properties in terms of strength and durability. Curing of concrete is a prerequisite for the hydration of the cement. For a given concrete, the amount and rate of hydration and furthermore the physical make-up of the hydration products are dependent on the time-moisture-temperature history. Generally speaking, the longer the period during which concrete is kept in water, the greater its final strength. It is normally accepted that concrete made with OPC and kept in normal curing conditions will develop about 75 percent of its final strength in the first 28 days [1]. The process of curing begins immediately after placement and finishing so that the concrete may develop the intended strength and durability [2]. Curing can be achieved by ponding or immersion, spraying or fogging and wet covering [3]. Hydration of cement is said to

be the combination of all chemical and physical processes that takes place after contact of the anhydrous solid with water [4]. For the process of hydration to be effective, it is important to saturate calcium silicate hydrate gels with water [5]. In a similar work done by [6], he pointed out his observations that cement hydration does not just improve when cured at relative humidity below 80% of the concrete vapor pressure. Hence, the importance of saturating the concrete by continuous wetting with water to keep the pores saturated enhances cement hydration. Proper curing enhances the reduction of the rate of moisture loss and as well provides a continuous source of water required for the hydration process which in turn reduces porosity by providing a firm pore size distribution in concrete [7]. The result of [8] revealed that the samples that were cured showed greater curling deflection and these effects increased with the length of curing for the drying conditions investigated. These findings could impact more on construction techniques for volume-change-sensitive structures such as slabs-on-ground in drying environments. [9] recommended that testing of concrete, mortar samples and other research related materials be cured in lime saturated water. A recent concrete strength research by [10] reports a compressive strength loss of 10-20% of concrete cubes that were ambient air cured compared to cubes wet cured. Compressive strength losses were recorded in that research at ages 28, 90 and 180 days for cubes specimens that were air

cured compared to those wet cured. Results show that those wet cured were more effective in improving compressive strength at later ages for higher water cement ratio than lower water cement ratio specimen. In like manner, [11] presents a report showing compressive strength increases of concrete cubes cured in water as compared to air cured cubes at 7 and 28 days using Portland cement at cement content of  $400\text{kg/m}^3$ . ACI 308 gives standard procedure for curing concrete however, experiment shows that the average strength of concrete can be considerably gained within 28 days. This does not negate the fact that concrete gains strength with age but it is worthy of note that once curing stops, the concrete dries out and the strength gain stops. [12] spells out that if concrete is not cured and is allowed to dry in air, it will gain only about 50% of the strength of continuously cured concrete, if cured for only three days it will reach about 60%, if cured for seven days, it will reach 80% of its strength of continuously cured concrete and if curing stops for some time and then resumes again the strength gain will also stop and reactivate. This however is encouraged within a temperature of  $20^\circ\text{C} - 21^\circ\text{C}$  as temperature below  $10^\circ\text{C}$  ( $50^\circ\text{F}$ ) is unfavorable for the hydration hence proper curing enhances effective hydration which in turn increases strength and other desirable properties of concrete structures such as durability, water tightness, abrasion resistance, volume stability, resistance to freeze and thaw and resistance to deicing chemicals [3]. Research showed that increase in the size of the concrete result in decrease in the effect of temperature on the compressive strength of concrete [13]. This paper is aimed at presenting the significant of curing concrete which can be of valuable assistance in adopting good construction practices at site.

## 2. Materials and Method

The cement used in this study is one of the available commercial brands of Ordinary Portland Cement (OPC). Portland cement type I (normal Portland cement) conforming to the requirement of [14] and clean water from a nearby stream were used. [15]. Also used were coarse aggregate of crushed granite of 12mm size with density  $1600\text{kg/m}^3$  and fine aggregate of natural white color river bed sand with density  $1460\text{kg/m}^3$ . Concrete cube mold, trowel, head pan, weighing balance, water, curing tank, thermometer, bull nose rod (rammer), Schmidt rebound hammer, slump cone and its accessories are also useful materials used to carry out the required practical.

The mixture was batched by weight using a mix ratio of 1:2:4 and it was mix in a clean dry manual tilting concrete mixing drum. Batching by weight was adopted by measuring the constituent materials such as cement, sand, granite stone and water. Batching by mass was achieved by using a weighing balance. This was done for all mix proportions. Water for mixing was also weighed out as a function of the weight of cement used for each mix proportion.

Preparation and filling of moulds, hand compaction of concrete, surface levelling and curing were all done according to the requirement of [16]. The mixed concrete was scooped

into a metal mould of  $150\text{mm} \times 150\text{mm} \times 150\text{mm}$  and then temped in three layers in accordance with [17], having conducted the slump test for the various water cement ratio. The slump test was conducted in accordance with [18] and with reference to the work of [19]. The workability of the concrete mix was satisfactory with a water cement ratio of 0.55. The compacting factor test conducted gave same value of water cement ratio obtained from the slump test. The concrete was properly mixed, transported and placed manually. The concrete cubes produced were properly cured in a pond at room temperature. The strength of cubes produced were determined using a non-destructive device (Schmidt rebound hammer). The strength was determined for day 7, 14, 21 and 28 days.

## 3. Presentation of Results

*Table 1. Composition of Portland Cement.*

Compound	Chemical Formula	Common Formula*	Usual Range by Weight (%)
Tricalcium silicate	$3\text{CaO} \cdot \text{SiO}_2$	$\text{C}_3\text{S}$	45-60
Dicalcium silicate	$2\text{CaO} \cdot \text{SiO}_2$	$\text{C}_2\text{S}$	15-30
Tricalcium Aluminate	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	$\text{C}_3\text{A}$	6-12
Tetracalcium Aluminoferrite	$4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$	$\text{C}_4\text{AF}$	6-8

\*The cement industry commonly uses shorthand notation for chemical formulas: C = Calcium oxide, S = Silicon dioxide, A = Aluminum oxide and F= iron oxide. Source: [3].

*Table 2. Concrete Mix Proportion.*

Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	0.55 WCR
54	105	216	0.55 (29.7kg)

*Table 3. Slump Test Results.*

W/C Ratio	Slump (mm)	Slump Interpretation	Workability
0.45	0mm	No slump	Very Low
0.55	25mm	True slump	Low
0.65	150mm	Shear slump	High
0.75	180mm	Collapse slump	High

*Table 4. Average Strength of Day 7 Cubes.*

Identity	Cube1	Cube2	Cube3	Cube4	Average strength ( $\text{N/mm}^2$ )
Water cured	23.2	22.9	23.0	23.5	23.15
Air cured	16.1	15.5	16.0	15.7	15.8

*Table 5. Average Strength of Day 14 Cubes.*

Identity	Cube1	Cube2	Cube3	Cube4	Average strength ( $\text{N/mm}^2$ )
Water cured	26.1	25.9	25.3	25.9	25.8
Air cured	18.4	18.7	18.9	18.3	18.6

**Table 6.** Average Strength of Day 21 Cubes.

Identity	Cube1	Cube2	Cube3	Cube4	Average strength (N/mm <sup>2</sup> )
Water cured	27.4	28.1	28.3	27.7	27.87
Air cured	19.8	20.2	20.6	20.1	20.2

**Table 7.** Average Strength of Day 28 Cubes.

Identity	Cube1	Cube2	Cube3	Cube4	Average strength (N/mm <sup>2</sup> )
Water cured	30.7	32.1	33.0	30.9	31.67
Air cured	21.9	22.1	21.8	22.4	22.1

**Table 8.** Percentage of Strength Gained by Both Cubes Cured in Water and Air.

Ages	Day 7	Day 14	Day 21	Day 28
Water cured	21.4%	23.8	25.7%	29.2
Air cured	20.6%	24.3%	26.3%	28.8%
% Difference	0.8%	-0.5%	-0.6%	0.4%

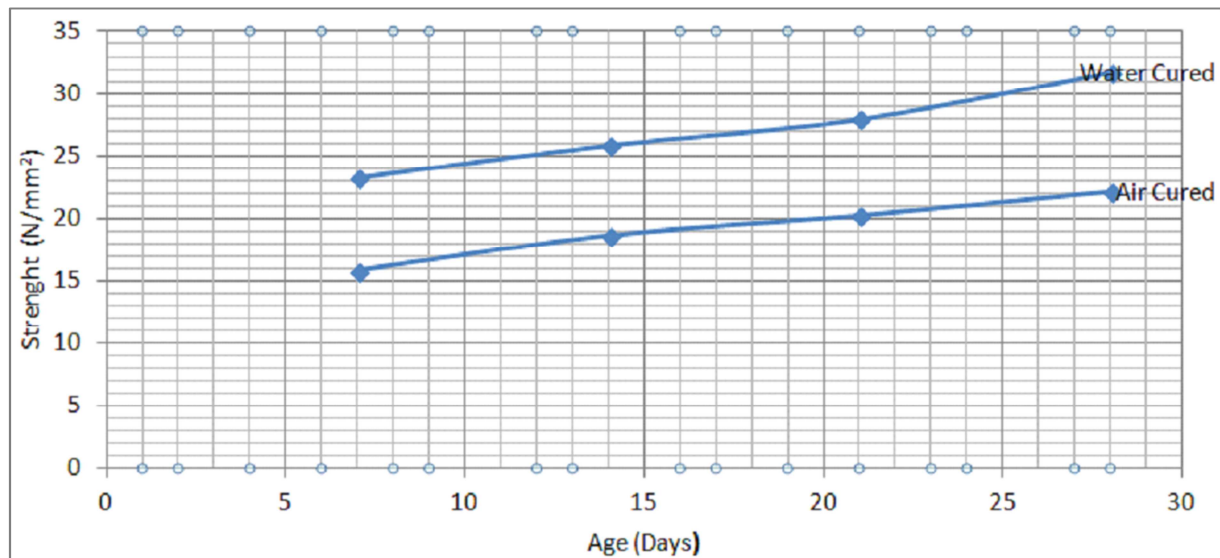
**Figure 1.** Strength of Cubes versus Age of both Water and Air Cured Concrete.

Table 3 showed the various water cement ratios and their corresponding slump value, slump interpretation and workability. The result of the slump test conducted gave a true slump at 25mm. The workability was low, this result is satisfactory, in view of the fact that compaction of the concrete was done by manual method as explained in the methodology.

From table 4-7, the results obtained from the water curing effect condition on the non-destructive strength test analysis of concrete cubes specimen having water cement ratio of 0.55 at ages 7, 14, 21 and 28 days respectively are compared with concrete cubes specimen of the same water cement ratio tested for, within the same duration or ages but air cured. In like manner, percentage of strength by both cubes cured in water and air are presented in table 8, as well as the variation and consequently graphs of strength of cubes versus age of both water and air cured concrete are as well shown figure 1.

## 4. Discussions

Table 1 showed the proportions of Tricalcium Silicate, Dicalcium Silicate, Tricalcium Aluminate, Tetracalcium Alumina Ferrite that is required for a sound Ordinary Portland Cement. The Tricalcium Aluminate accounts for the initial setting time of the concrete, The Tricalcium silicate is responsible for the strength of the concrete from the first day to the twenty eighth day after which the remaining strength that is expected to develop for the life time of the concrete is accounted for by Dicalcium Silicate. The Tetracalcium Alumina Ferrite accounts for strength and color. The results obtained from the experiments conducted agree with these properties of the cement.

Table 2 showed the results of the weight of the proportion of the concrete mix used to conduct the experiments. The batching was done by weight and the value of the cement, fine aggregate, coarse aggregates and water cement ratios are 54,105,216, and 0.55 respectively.

Results obtained from the non-destructive strength analysis of water cured and air cured concrete cubes samples are as shown above in tables 4-7.

From the results obtained from the 7 day age samples as shown in table 4, the average variation between the water cured and air cured concrete samples is 7.4 N/mm<sup>2</sup>, hence the average result gotten for the water cured is 23.15 N/mm<sup>2</sup> and the air cured as 15.8N/mm<sup>2</sup> and the percentage strength variation is 21.4% and 21.3% for water cured and air cured cubes samples respectively, thereby resulting to a difference of 0.8%.

The average results differences obtained might seem insignificant here at present but this is as a result of age which represents the duration of testing and the content of water cement ratio at which true slump was achieved as aimed at in this research work, this however will obviously be seen in the

behavior of the concrete cubes with respect to performance and durability. Even if the results variation does not differ much, the air cured concrete will be prone to rotting while the water cured will continue in strength gaining by age due to the initial subjection to hydration and the concrete cube microstructure water entrapment as mixing, placing and temperature of concrete has roles to play in concrete strength and durability, as well as design mixture.

Table 5, presents the results as obtained from the 14 days samples from where differences between the water cured and air cured was  $7.2 \text{ N/mm}^2$ , while the percentage strength variation gave a value of  $-0.5\%$  which by interpretation indicates that for the adopted water cement ratio the strength for the air cured cube samples however supersedes the water cured in terms of percentage strength variation but not in terms of the actual strength value obtained. In essence, this negative percentage result has no effect on the concrete strength and duration as this is just a commutation of strength result values.

Table 6 and 7 which shows the results obtained for 21 and 28 days cubes samples, presents the following results for the differences between water cured and air cured concrete cubes respectively;  $7.7 \text{ N/mm}^2$  and  $9.6 \text{ N/mm}^2$ . The percentage strength variations are also given as  $-0.8\%$  and  $1.0\%$ . Strictly speaking by interpretation on the values obtained from the 28 day test samples precisely in terms of the strength result, it will be observed that concrete rapidly gains strength with age as the strength variation calls for attention which is in consonance with the work of Stark, (2011). The graphs shown above explicitly provide better understanding to these facts. In essence the strength of the water cured cubes increases from  $23.5$  to  $31.7 \text{ N/mm}^2$  from day 7 to day 28 on the first graph series, while the air cured increases from  $15.8$  to  $22.1 \text{ N/mm}^2$  for 7 and 28 days indicating the significance of water curing against air curing by interpretation.

## 5. Conclusion

The results presented in this research work shows that cured concrete structures possesses more strength than uncured or air cured concrete structures as seen from the results, the strength gain of the cubes on average strength scale for 7 day increased from  $15.8 \text{ N/mm}^2$  to  $23.15 \text{ N/mm}^2$  for air cured and water cubes concrete cubes respectively. Similarly, that of day 14 increased from  $18.6 \text{ N/mm}^2$  to  $25.8 \text{ N/mm}^2$ , day 21 increased from  $20.2 \text{ N/mm}^2$  to  $27.87 \text{ N/mm}^2$  and day 28 increased from  $22.1 \text{ N/mm}^2$  to  $31.67 \text{ N/mm}^2$  for air cured and water cubes concrete cubes respectively. The strength of cubes versus age of water cured and air cured concrete curve as presented in figure 1, apparently shows the insignificant slope increase from  $15.8 \text{ N/mm}^2$  to  $22.1 \text{ N/mm}^2$  between day 7 to 28 on the lower curve which represents the air cured sample and a significant slope increment on the upper curve which represents the water cured cube sample ranging from  $23.15 \text{ N/mm}^2$  to  $31.67 \text{ N/mm}^2$  between day 7 to 28. Hence, in order to obtain the desired strength of concrete, it should be thoroughly cured using any of the methods of curing which include ponging or immersion, sprinkling, spraying or fogging,

wet coverings using moisture-retaining fabric or membrane such as burlap, cotton mats or rugs and as well as allowing the concrete in its formwork which could be plastic sheeting, ply boards woods or steel sheets. Amidst any of the methods to be adopted, it should be carried out immediately after 24 hours of concrete placement and within a temperature of  $20^\circ\text{C} - 21^\circ\text{C}$  to enhance effective hydration, rapid increase in strength, avoidance of cracks, durability, water tightness, abrasion resistance in terms of rigid pavement to be more precise, volume stability, resistance to freeze and thaw and as well as resistance to deicing chemicals.

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