PRODUCTION OF RAPID HARDENING CONCRETE USING LOCAL AGGREGATE AND SODIUM CHLORIDE AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

Ordinary Portland cement (OPC) often lead to slow strength development and construction delays. This study explores the use of rapid-hardening concrete enhanced with sodium chloride (NaCl) to accelerate early strength gain. The use of locally sourced materials, including river sand, Bama gravel, and crushed stone, were used in mix designs guided by BS 8500 and conventional methods using Microsoft Excel spreadsheet. The study used a total of 90 standard concrete cubes (150 mm x150 mm x150 mm) were cast using a mix ratio of 1:0.63:0.09:0.95 and a water–cement ratio of 0.30, with NaCl incorporated at 1–4% as a partial cement replacement. Aggregate tests confirmed compliance with standard specifications. The research results showed that NaCl increased consistency, reduced setting time, and significantly enhanced early compressive strength; achieving 33.23 N/mm² at 1 day and 57.67 N/mm² at 28 days with 4% NaCl. The ratio of destructive to non-destructive strength test results ranged from 1.14 to 1.18 across NaCl dosages. The mix demonstrates strong potential for applications in cold-weather concreting, hydraulic structures, and precast elements requiring early strength. However, due to the risk of chloride-induced corrosion, especially in small-diameter tendons, its use in prestressed concrete is not advised.

Keywords: Bama Gravel, Rapid Hardening Concrete, Local Aggregate, Sodium Chloride

1 INTRODUCTION

Concrete is the most widely used man-made material in existence, and it is second only to water as the most-consumed resource on the planet and it is widely used to construct structural elements in Nigerian urban areas [1]. It is a composite construction material composed of cement, fine, and coarse aggregates mixed with water, which hardens with time [2]. It is an exceptionally durable and strong building material with a compressive strength that varies depending on the concrete grade [3]. The most significant attribute of concrete is its compressive strength, of which the 28-day compressive strength of concrete cylinders or cube samples has widely been accepted as the minimum specified concrete strength in most design codes of practice [4]. Rapid-hardening concrete (RHC) is commonly known for its accelerated strength gain and can be used to achieve a fast construction pace [5]. It is a type of high-performance concrete that can be produced using superplasticizers that minimize the water-cement ratio and increase early-strength development [6]. In addition, strength, durability, and workability are crucial requirements of Rapid-hardening concrete. Many researchers have focused on producing concrete

with these three essential properties in the past few decades [7]. Chemical admixtures have been developed to reduce the water-cement ratio, improve workability, and enhance strength, [8]. In the context of rapid-hardening concrete (RHC), ordinary Portland cement (OPC) is commonly used as the binding agent. Accelerants such as plasticizers, superplasticizers, and sodium chloride are usually combined with ordinary Portland cement to accelerate the hydration process, leading to rapid strength gain [6]. Rapid-hardening concrete (RHC) is known for its exceptional early strength development, achieving up to 20 N/mm^2 within 24 hours, making it ideal for fast-paced construction projects [9]. It features a significantly reduced setting time, typically ranging from 30 minutes to 2 hours, enabling quicker formwork removal and accelerated construction schedules [10]. The rapid-hardening concrete (RHC) is commonly known as concrete with accelerated strength gain and can be used to achieve a fast construction pace [5]. Rapid-hardening concrete is a type of high-performance concrete that can be produced using superplasticizers that minimize the water-cement ratio and increase early- age strength development [11]. High-performance concrete (HPC) has many requirements, according to ACI. Early-age strength development, compaction without segregation, toughness, and volume stability are the most important requirements for achieving HPC [12]. The demand for RHC with better behavior and lower costs has led to increased research on upgrading or exploiting the structural mechanical performance by introducing innovative materials, structures, and techniques [13, 14, 15, 16, 17, 18]. Globally, Rapid-hardening concrete was created to solve the setting time problems that occur in civil engineering infrastructures. Generally, it usually takes 7 to 14 days to achieve its required compressive strength, fc' of 0.7 to 0.85 fc' [6]. This setting time generated on ordinary concrete was generally not be fast enough to achieve the minimum quality required. These circumstances might concern public on cost production, time spent and efficiency [7]. Alternatively, High early strength concrete is one of the types of high-performance concrete which have the compressive strength of the concrete greater than 21 N/mm^2 at the first 24 hours after site-pouring [19]. This type of concrete is capable of reaching 50% fc' at 24 hours of age, with water to cement ratio ranging from 0.3 to 0.4 [20]. This research is aimed to produce Grade 55 Rapid-hardening Concrete (RHC) using local aggregates and table salt (NaCl) as a partial replacement for cement.

2 EXPERIMENTAL DETAILS

2.1 Materials

Cement: The cement used in this research is the Ordinary Portland Cement (OPC) and Rapid-hardening Cement (RHC) Grade 42.5 N/mm^2. Dangote brand obtained in an open market in Maiduguri and served as the main binder.

Fine Aggregate: The fine aggregate used in this research is river sand which was obtained from the Alau River.

Coarse Aggregate: Bama gravel was used as a coarse aggregate which was obtained from nominated vendors along Bama Road, Maiduguri, Borno State.

Crushed Stone: 19mm crushed stone was used and obtained from Maiduguri, Borno State.

Mixing and Curing Water: Portable tap water fit for consumption at Maiduguri, was used for the production and curing of all the concretes.

Table Salt (NaCl): Table Salt (NaCl) used for this research was Dangote table salt which was obtained in an open market and serves as an additive in the production of the rapid-hardening concrete.

2.2 Methods

2.1.1 Index Properties of Aggregate

Aggregate Crushing Value (ACV): gives a relative measure of the resistance of an aggregate to sudden shock or impact; this is the reason an aggregate must be stronger than the concrete strength it is expected to produce. [21] was used to determine the test. The ratio of the weight of fines formed to the weight of the total sample in each test shall be expressed as a percentage, the result being recorded to the decimal place. Aggregate crushing value, ACV can be calculation using equation (1).

$$ACV = \left(\frac{W_3}{W_3 - W_2}\right) \times 100\ \% \quad (1)$$

Where; ACV = Aggregate Crushing Value, W_1 = Weight of the empty cylinder, W_2 = Weight of cylinder + sample before crushing, W_3 = Weight of sample passing 2.36 mm sieve (g) after crushing.

Aggregate Impact Value (AIV): It is a measure used to assess the resistance of an aggregate to sudden shock or impact. It is an important parameter in determining the mechanical properties and overall quality of aggregates. [21] was used to determine the test. This gives a relative measure of the resistance of an aggregate to impact under a gradually applied load. [21] was used to determine the test. The aggregate impact value can be computed using equation (2).

$$AIV = \left(\frac{W_2}{W_1}\right) \times 100\% \quad (2)$$

Where; AIV = Aggregate Impact Value, W_1 = Total weight of dry sample taken before impact. W_2 = Weight of portion passing 2.36mm after impact.

Flakiness Index: is the percentage by weight of the material that is passing the various thickness gauges or sieves. [22] procedure was used to determine the test. The Flakiness index can be computed using equation (3).

$$Flakiness\ Index = \left(\frac{W_1}{W_2}\right) \times 100\% \quad (3)$$

Where; *FI* = Flakiness index, W_1 = Weight passing through flakiness gauge (g), W_3 = Total weight of aggregate retained on the sieve (g).

Elongation Index: is a means of classifying coarse aggregate. Aggregate particles are classified as elongated when they have a length (greatest dimension) of more than 1.8 of the mean sieve sizes. The sample is found by separating the elongated particles and expressing their mass as a percentage of the mass of the sample tested. [21] procedure was employed to determine the test. The elongation index of an aggregate can be obtained using equation (4).

$$Elongation\ Index\ = \left(\frac{W_1}{W_2}\right) \times 100\% \quad (4)$$

Where; *EI* = Elongation index, W_1 = Weight passing through elongation gauge (g), W_2 = Total weight of aggregate retained on the sieve (g).

Specific Gravity: the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water at a standard atmospheric temperature of 27 °C. [23] procedure was used to determine the specific gravity.

Bulk density: the bulk density or unit of an aggregate, is the mass or weight of the aggregate that is required to fill a container of a specified unit volume. The test was conducted as per [24].

Water absorption: this describes the percentage increase in weight between the dry aggregate and the saturated aggregate. It is used to determine the amount of water absorbed by aggregate under specified conditions. B S 812 part 2 was used to determine this parameter and can be calculated using equation 5.

$$Water\ Absorption = \frac{W_s - W_d}{W_s} \times 100\% \quad (5)$$

Where; $W_d =$ Dry weight of the specimen, $W_s =$ Saturated weight of the specimen after immersed in water.

Moisture content: this is a process of determine the amount of water present in aggregates expressed as percentage of the mass of dry aggregates.

Bulk density: the bulk density or unit weight of an aggregate is the mass or weight of the aggregate that required to fill a container of a specified unit volume.

Particle size distribution: This test is primarily used to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance with the particle size distribution with application specification requirements and to provide necessary data for the control of the production of various.

Specific gravity: is the ratio of weight of a given volume of aggregate to the weight of an equal volume of water.

2.1.2 Experimental Design

Concrete mix design was evaluated using Microsoft Excel spreadsheet Application based on BS 8500 Mix Design Method and Concrete Mixture Matrix Design Method by [25]. The study specifically used cement grade 42.5 N/mm^2. Similarly, the wet concrete density is given as a function of aggregates specific gravity, quantity of water and cement [25]. The standard cube of 150mm × 150mm × 150mm were produced for compressive strength tests using the constituent materials in Table 1.0. A total of 90 cubes were produced using the appropriate mix proportions [25]. The zero percent Table Salt (NaCl) serves as the control, subsequently a 1% variation was tested between 0 to 4% by weight of cement respectively. A mechanical mixer with 0.5 m^3 and 120 second mixing duration was used to obtain a homogenous mix for all the mixes throughout the experiment. Similarly, manual compaction was carried out with a tamping rod and hand mallet to remove the voids in the concrete. The produced concrete samples were cured for 1, 3, 7, 14, and 28 days respectively. The average of three (3) samples of concrete cubes was tested for compressive strength using a hydraulic compressive strength machine with specification: model number of NL TPR-57, capacity of 2000 kN, loading rate of 120 kN/min, and relative error of ±1%. Additionally, the non-destructive test was carried out using a rebound hammer with specification: model number of ZC3-A-JJG817-2011, an impact capacity energy of 10 to 70 N/mm^2, hammer mass of 370g, spring extinction of 76mm and weight of 1090g respectively to compare the results obtained in hydraulic press test.

Table 1. Constituent materials for the concrete mix proportion

Constituent Materials	Proportion (kg)
Water	236.67
Cement	788.22
Bama Gravel	495.5
Rivers Sand	66.79
Crushed Stone (19mm)	744.01
Mix Proportions	1:0.63:0.09:0.95; w/c= 0.3

Note that, the above five constituent materials are cement: river sand: Bama gravel: 19mm crushed stone: and water-cement ratio

3 RESULTS AND DISCUSSION

3.1 Particle Size Distribution

The particle size distribution for the river sand and Bama gravel materials as shown in Figure 1. Based on [26], the river sand material is in conformity with the standard (overall limit) not withing the additional limit of the graduation that is course (C), medium (M) and fine (F). in the same vein Bama gravel aggregate used is not in conformity with the standard which indicate as higher finer particle in the material as shown in Figure 2. Consequently, Figure 3 shows the results of the 19mm crushed stone. The result indicates that the material is not in conformity with [27]. The implication is that, it may affect the strength performance of the concrete matrix.

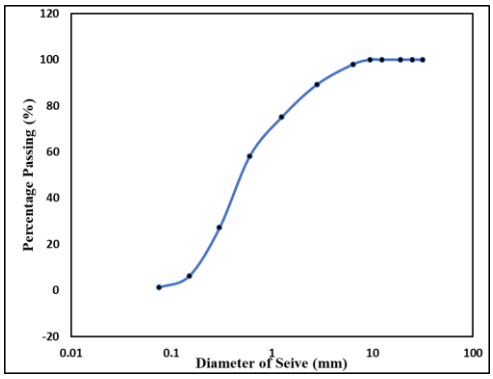

Figure 1. Particle size distribution of river sand aggregate

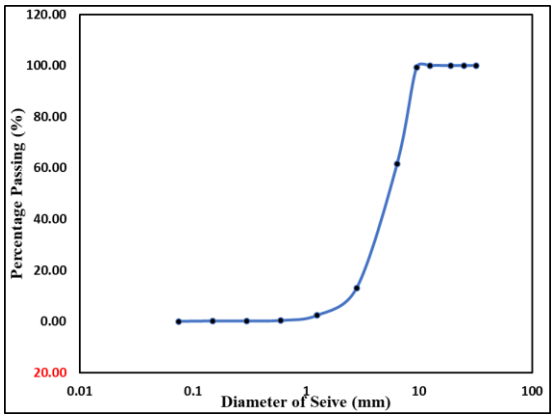

Figure 2. Particle size distribution of Bama gravel aggregate

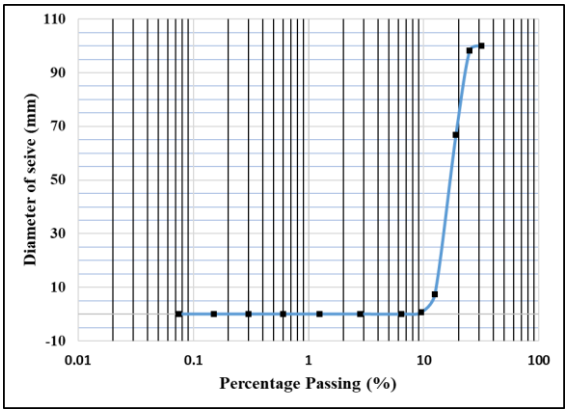

Figure 3. Particle size distribution of 19mm crushed stone aggregate

3.2 Physical Properties of Cement

Table 2 presents the Bulk density, specific gravity and strength results for OPC and RHC. The result indicates a specific gravity value of 3.11 and 2.89 for ordinary Portland cement and Rapid-hardening cement. The outcome of the research is similar to the findings of [28] which obtained the values of 3.0 and 2.87 respectively. This reduction could be as a result of the rapid-hardening cement is grinded much finer than ordinary Portland cement [29]. Moreover, the cement strength test results depict values of 41.05 N/mm^2 and 41.5 N/mm^2 or ordinary Portland cement and rapid-hardening cement respectively. These results were slightly lower than the manufacturer's strength of 42.5 N/mm^2 by 3.41 % and 2.35 % respectively. However, these differences are within the allowable specification limit given by [30], which allows the maximum fall of 3.5 N/mm^2.

Table 2. Physical Properties of Cement

Properties	OPC	RHC
Bulk Density (g/cm^3)	1.02	1.1
Specific Gravity (g/cm^3)	3.11	2.89
Cement Strength Test at 28 days (N/mm^2)	41.05	41.5

3.3 Relative Resistance of Aggregates (ACV and AIV)

Table 3 shows the aggregate crushing and impact values for 19mm and Bama gravel respectively. The results depict the aggregate crushing and impact values of 21.85 and 13.13 % for 19 mm crushed stone and 29.27 and 30.01 % for Bama gravel respectively. These materials are within the specification limit as per [31] and [23] which state that aggregate crushing and impact values should not exceed 30% and 35% for concrete work.

Table 3. Relative Resistance of Aggregates (ACV and AIC)

Test Type	Sample	Test Result	Specification
(ACV) (%)	19mm Crushed stone	21.85	≤30%
	Bama gravel	29.27	
(AIV) (%)	19mm Crushed stone	13.13	≤35%
	Bama gravel	30.01	

3.4 Aggregate Water Absorption

Table 4 presents the water absorption results of 19mm crushed stone, Bama gravel and river sand aggregate. The results depict the values of 3.41 %, 2.72 %, and 1.38 % for river sand, Bama gravel and 19mm crushed stone respectively. The outcome of the research is in line with specification limit given by [31] which recommend the values of 5 and 3% fine and coarse aggregates respectively.

Table 4. Water absorption values for river sand, Bama gravel and 19mm crushed stone

Aggregate Samples	Water Absorption (%)	Specification
River Sand	3.42	≤5%
Bama Gravel	2.72	≤3%
19mm crush Stone	1.38	≤3%

3.5 Flakiness and Elongation

Table 5 presents the flakiness and elongation results for 19mm crushed stone. The values of 21.73 and 22.06% where obtained. The outcome of the research indicates that the material is within the standard specification limit as per [32] which stated that the flakiness and elongation values of coarse aggregate should be ≤25% of the total aggregate considered.

Table 5. Flakiness and elongation of 19mm crushed stone aggregate

Samples	Flakiness (%)	Elongation (%)
19mm crushed stone	25.12	32.64
Bama Gravel	1.16	0.7

3.6 Specific Gravity

Table 6 shows the specific gravity results for 19mm crushed stone, Bama gravel, and river sand aggregates. The results showed that 19mm crushed stone, Bama gravel and river sand attained the values of 2.61, 2.63 and 2.55 respectively. The outcome of the research is within the specified limit as per [24] which states value range of 2.55 to 2.9. In addition, the obtained results are in line with the findings of [33].

Table 6. Specific gravity values of 19mm crushed stone, Bama gravel, and river sand aggregates

Samples	Specific Gravity	Specification
19mm crushed stone	2.61	
Bama Gravel	2.63	2.55 - 2.9
River Sand	2.55	

3.7 Hydration Properties of Binder Material

3.7.1 Consistency

Figure 3 shows the consistency results of rapid-hardening cement and ordinary Portland cement with the percentage replacement of table salt (NaCl). The results revealed that the consistency of ordinary Portland cement changes from 31.4% at 0% NaCl to 33.1% at 4% NaCl. Generally, the result implies that the consistency increases with the increase in percentage of NaCl. This indicates that more amount of water is required for the hydration of the cement paste to complete. Moreover, RHC cement exhibit the consistency of 32.8% which is similar to value obtained at 4% NaCl replacement. This early setting could be attributed to the fact that RHC is grinded much finer than OPC [34]. These results are in line with the usual range of 26 % to 33 % specified in [35]. The outcome of this work is similar to the findings of [36] which obtained the consistency value of 34.8% and achieve a desired result.

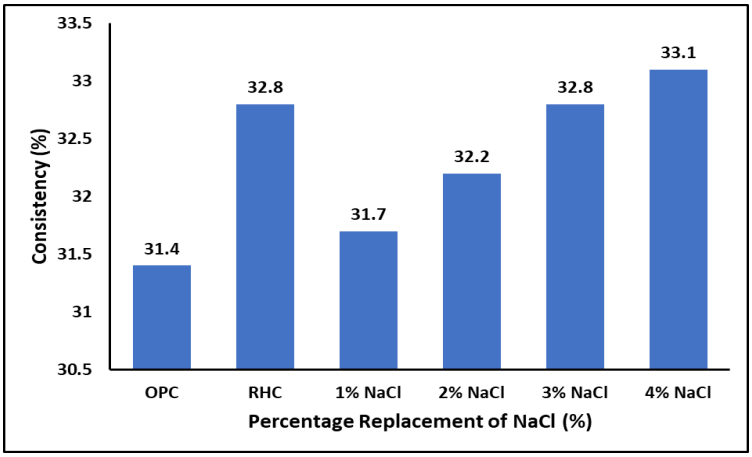

Figure 3. Effect of NaCl replacement on the consistency of concrete

3.7.2 Setting Times

Figure 4 presents the variation of setting times of different percentage of table salt (NaCl). The result showed that ordinary Portland cement (OPC) exhibit initial and final setting times of 54 minutes and

240 minutes, which is higher compared with RHC which attained the values of 30 minutes and 91 minutes respectively. This indicates that rapid-hardening concrete sets faster as compared with ordinary Portland cement. Moreover, incorporation of table salt (NaCl) at 1% replacement of ordinary Portland cement showed the initial and final setting times of 45 minutes and 180 minute which is low compared with OPC. Furthermore, it was also observed that incorporation of sodium chloride at 4% decrease the setting times which yielded the values of 30 minutes and 97 minutes respectively. This translates to the fact that inclusion of sodium chloride to ordinary Portland cement decreases the setting times and accelerate early strength gain. The outcome of this work is in line with the finding of [37]. In addition, all the results obtained are in conformity with [38] which state that the initial setting time of ordinary Portland cement should not be less than 45 minutes and the final setting time should not exceed 600 minutes. These results are also in line with the findings of [39].

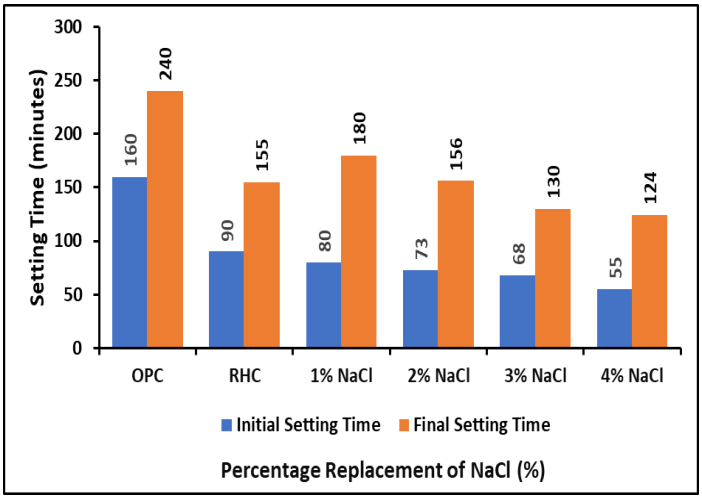

Figure 4. Effect of NaCl replacement on the setting time of concrete

3.8 Physical and Mechanical Properties of the Rapid-hardening Concrete

3.8.1 Workability

Figure 5 presents the results of slump test of various concrete mixes considered in the study. The control mix with 0% NaCl recorded the lowest slump at a water-cement ratio of 0.33 compared to the mix with 4% NaCl which recorded the highest slump value of 58 mm at a water-cement ratio of 0.36. In general, the result showed that the workability of the fresh concrete increases with an increase in the percentage of NaCl. These results are within the limit specification of 25 – 100mm as specified by [40].

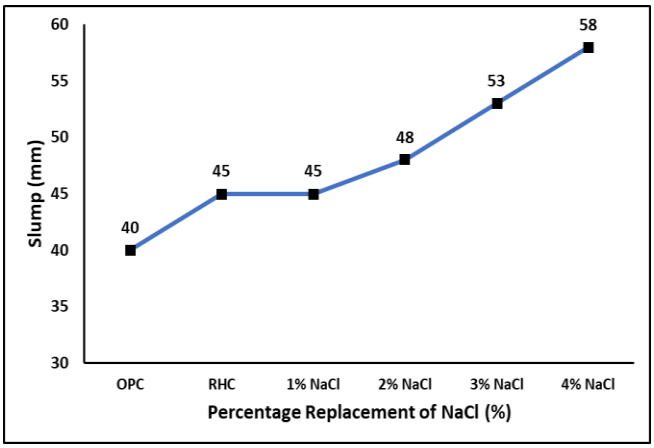

Figure 5. Effect of NaCl replacement on the workability of concrete

3.9 Mechanical Properties of High-Performance *Concrete*

Compressive Strength

Figures 6 and 7 presents the destructive and non-destructive compressive strength results for Grade 55 High-performance concrete. The strength development experiment for 1, 3, 7, 14 and 28 days, revealed a general increase in the strength of all the samples. The increase of the strength ranges from 26.90 N/mm^2 to 57.67 N /mm^2 for destructive test and 24 N/mm^2 to 50/mm^2 for non-destructive test respectively. This range of values covers the strength of the control specimens (OPC), RHC, and those with NaCl replacement. The result showed that the percentage of NaCl increases the early strength gain. The optimum early strength gain was attained at 4% NaCl which revealed value of 36.36 N/mm^2, 43.59 N/mm^2, 51.27 N/mm^2, 56.21 N/mm^2, and 57.67 N/mm^2 at 1, 3, 7, 14, and 28 days for destructive test and 32 N/mm^2, 38 N/mm^2, 44 N/mm^2, 47 and 49 N/mm^2 1, 3, 7, 14, and 28 days for non-destructive test respectively. The resulting strength at 4% NaCl replacement is more than the control values by 26.02, 29.69, 17.98, 21.56, and 0.81% respectively for destructive test and 25.00, 26.32, 18.18, 19.15, and 0.00% for non-destructive test respectively. Hence, the result generalized the early strength gain with the increase in the percentage of NaCl. This is similar to the findings of [41]. which depicts that the application of NaCl would improve mechanical properties of concrete at early ages.

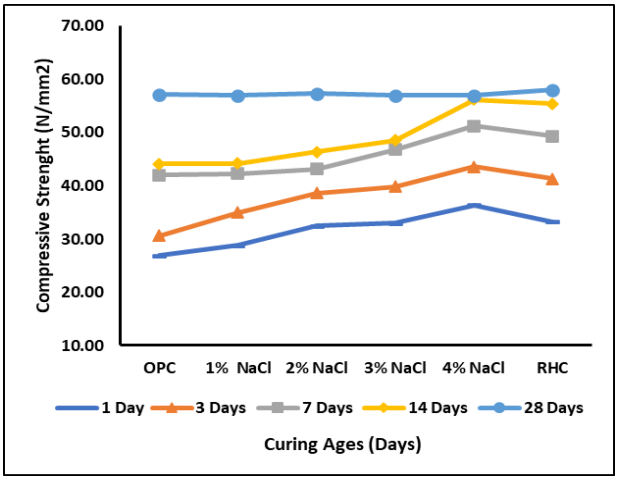

Figure 6. Compressive strength for Grade 55 rapid-hardening concrete (destructive test)

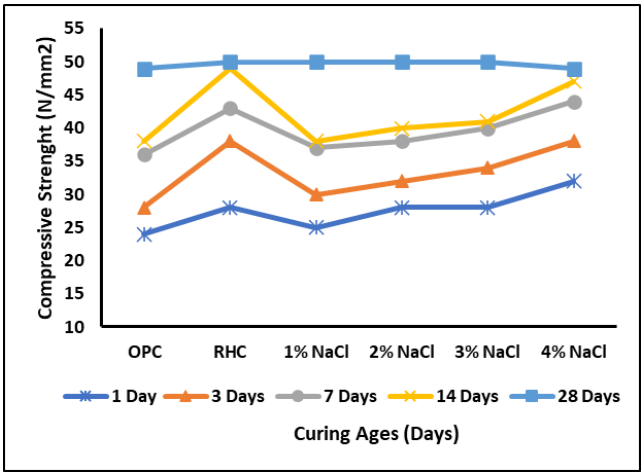

Figure 7. Compressive strength for Grade 55 rapid-hardening concrete (non-destructive)

3.10 Relationship Between Destructive and Non-destructive Tests

Table 7 present a relationship between the destructive and non-destructive compressive strength test with respect to OPC, RHC and 1-4% NaCl replacement. The result revealed a ratio between 1.14 to 1.18 for all samples considered.

Table 7. Relationship between destructive and non-destructive 28 days compressive strength of Grade 55 RHC

Concrete Samples	Compressive Strength (N/mm2)		Ratio
	Destructive Test	Non-destructive	
OPC	57.2	49	1:17
RHC	56.99	50	1:14
1% NaCl	57.33	50	1:15
2% NaCl	57.01	50	1:14
3% NaCl	57.01	50	1:14
4% NaCl	58	49	1:18

4 CONCLUSIONS

Based on the research, the following conclusions were drawn: The index properties of the constituent materials are within the stipulated standards and codes of practice. The hydration properties of the cement paste are within the specifications, Hence, the results demonstrated concrete efficiency with good hydration properties. The mix proportion used adequately produced rapid-hardening concrete with early and later compressive strength of 33.230 N/mm^2 and 57.67 N/mm^2 respectively, cured for 28 days at a water-cement ratio of 0.3 – 0.36. The slump values for all mixes are within the ACI mix design specification for high-performance concrete (25 – 100 mm). The optimum results of compressive strength were achieved at 4% NaCl. The study conclusively suggests that NaCl can be used as a good mineral accelerator at 4% replacement for rapid-hardening concrete but most not be used for the construction of prestressed concrete; because of the risk of the long-term corrosion of the tendons.

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