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ASSESSMENT OF CURING TECHNIQUES FOR GRANITE/GRAVEL COMPOSITE TO ENHANCE STRUCTURAL STRENGTH AND DURABILITY IN CONSTRUCTION

G. O. BAMIGBOYE[1*], A. A. ADEYEMO[1] and J. K. JOLAYEMI[1]

[1]*Department of Civil Engineering, Abiola Ajimobi Technical University, Ibadan, Oyo State, Nigeria*

[*]*Correspondent Author:* gideon.bamigboye@tech-u.edu.ng

Abstract

Concrete remains the most widely used construction material, yet its performance is significantly influenced by aggregate type and curing technique. This study investigated the effects of varying granite–gravel combinations on the compressive strength and durability of concrete, with a focus on optimizing curing practices. The experimental process involved sieve analysis, water absorption tests, and preparation of concrete mixes incorporating granite and gravel in ratios ranging from 100/0 to 50/50 at a 1:2:4 mix proportion. Curing was carried out using air, water, and membrane methods, followed by compressive strength testing at 7, 14, and 28 days. Durability performance was assessed by immersing samples in saline solution (2.5% NaCl) for 28 and 56 days to simulate aggressive environments. Data were presented through comparative graphs and trend analysis across curing ages and methods. Results showed that increasing gravel content consistently reduced compressive strength, though mixes containing 10–20% gravel replacement still satisfied BS 8110 requirements for mass concrete (≥15 N/mm²). Water curing produced the highest compressive strengths, followed by membrane curing, with air curing yielding the lowest results due to limited hydration across the curing ages. In NaCl environments, concrete gained early-age strength up to 28 days but declined at 56 days, indicating reduced long-term durability under saline exposure. In conclusion, it is recommended that granite–gravel blends not exceed 20% gravel replacement for structural use, and that water curing be adopted where possible to achieve optimal strength and durability.

Keywords

concrete, compressive strength, curing, durability, gravel, granite

1. INTRODUCTION

Concrete is a heterogeneous material composed of three main ingredients: aggregate, cement, and water (Cui et al., 2017). When these components are mixed, the material called "concrete" is formed. Concrete consists of aggregate bonded together by a paste made from Portland cement and water. Each particle of aggregate is fully coated with paste, which fills the voids between the particles. After the freshly mixed concrete is placed, it hardens into a solid structural material capable of resisting high compressive forces (Fahem et al., 2018). Curing is the process of maintaining proper temperature and moisture conditions in concrete long enough for hydration to develop the desired properties (Ouyang et al., 2022). The full potential strength and durability of concrete are achieved only if it is properly cured (Ammar et al., 2022). Curing occurs immediately after concrete placement and finishing and involves sustaining ideal levels of moisture and temperature over extended periods, both below and above the surface ((Dewangan et al., 2019). Maintaining proper moisture conditions is crucial since cement hydration ceases once the capillary relative humidity drops below 80% (Goel et al., 2013; Elavarasi, and Sumathy, 2025).Concrete hydration stops when the water supply is insufficient; consequently, the resulting concrete may lack essential qualities like strength and impermeability (Rath et al., 2018; Pawar and Kate, 2020; Elavarasi, and Sumathy, 2025).

Granite is a widespread plutonic igneous rock that exhibits numerous textures and features a medium to coarse granular structure (Przychodzień, and Katzer, 2021). Quartz and feldspars represent the major mineral components that form granite into a hard, compact igneous rock. Archaeological evidence indicates that builders have utilized granite as a construction material since ancient times (Bustillo, 2024). Granite demonstrates essential mechanical and physical characteristics that fulfill various construction purposes, mainly during architectural finishing of buildings and bridge construction (Junaid et al., 2022). Granite exists as the densest and toughest intrusive igneous rock type (Agasnalli et al., 2022). Gravel is a naturally occurring coarse aggregate composed of unconsolidated rock fragments, typically ranging in size from granules to boulders. It is widely distributed across riverbeds, pits, and alluvial deposits and has historically been used in road construction and concrete applications due to its availability and ease of compaction (Njoku et al., 2020). Unlike crushed granite, gravel exhibits rounded to sub-rounded particle shapes and smoother surface textures, features that strongly influence its performance in concrete. The rounded morphology reduces internal friction within fresh mixes, enhancing workability, but provides less mechanical interlock and bond strength with cement paste compared to angular aggregates (Dahunsi et al., 2022).

Construction relies heavily on concrete, but poor curing methods can cause structural problems as the concrete ages (Pawar, and Kate, 2020). The mix of granite and gravel in concrete creates challenges that reduce both strength and durability (Rath et al., 2018). Continuous curing of concrete is essential not only to reach its maximum strength and durability but also to prevent shrinkage cracks and surface damage. Although there is existing research on concrete curing, the existing literature failed to address the curing of granite/gravel combination using different techniques; it focuses only on water curing. The goal of this study is to find the most effective curing techniques for granite/gravel composite concrete that can improve strength, durability, and overall performance in construction.

2. MATERIALS AND METHOD

2.1 Materials

The materials used for this study are Ordinary Portland cement, grade 42.5 N, in accordance with ASTM C109 (2020). Coarse aggregates used for the study are ½ inch granite and washed gravel. Granite was obtained from a quarry near Abiola Ajimobi Technical University, Ibadan, Nigeria. Gravel was obtained within the university premises. River sand used for the study was obtained from the University premises. The potable water used for the study was obtained from the water flowing within the Civil Engineering Laboratory of the University. A polythene sheet membrane used as one of the curing methods was procured in Ibadan, Oyo State, Nigeria.

2.2 Experimental Procedure

Sieve analysis was carried out on the three aggregates (fine, granite, and gravel) to determine the grading of aggregates in line with BS812-103 (1985). The water absorption test was conducted on the three samples to determine the amount of moisture the aggregate samples absorb over time, in accordance with ASTM C1585 (2020). Concrete proportioning was done by weight using a weighing balance available in the Civil Engineering Laboratory within the University. Gravel/granite combination was varied in the percentage proportion of 10/90, 20/80, 30/70, 40/50, 50/50, and 100% granite, which serves as a control. The 1:2:4 mix ratio was adopted. Fresh properties of concrete were determined using the slump test in accordance with ASTM C143 (2010). The concrete was prepared into 150 x 150 x 150 mm cube moulds. In preparation for curing using different curing techniques (Ponding, membrane, and air). Figures 1-3 show the three curing techniques used in this study. For the membrane method as shown in Figure 1, the concrete samples were demolded and covered with polythene sheets until it is needed for testing. Figure 2 shows the ponding method, where concrete samples demoulded were submerged in clean water inside the curing tank until they were needed for testing. Figure 3 shows the air curing method, where concrete samples demoulded were exposed to the natural atmosphere under direct sunlight at room temperature until they were needed for testing. Hardened properties of concrete were determined using a compressive strength test in accordance with BS EN 12390-3 (2002) Figure 4 shows the compression machine used for crushing the concrete samples. The compressive strength of concrete is the most common performance attribute used when designing structures ((Mulyono, 2019). Concrete samples were tested for 7, 14, and 28 days. A total of 108 samples were tested in accordance with BS 12390 (2002). Samples cured under the aggressive environment of a 2.5% solution of NaCl for 58 days, as shown in Figure 5, were crushed to examine the early-day durability of the samples in accordance with BSEN 12390 as shown in Figure 4.

Figure 1: Concrete Cubes Cured under Polyethene Sheets

Figure 3: Concrete Cubes under Atmosphere

Figure 2: Concrete Cubes inside Curing Tank

Figure 4: Compression Machine

Figure 5: Curing under 2.5% NaCl Solution

3. RESULTS AND DISCUSSION

3.1 Particle Size Distributions

The gradation analysis of the constituent aggregates reveals significant implications for concrete performance. The fine aggregates with a coefficient of uniformity (C_u) of 4.72 and a coefficient of curvature

(C_c) of 0.84 as shown in Figure 6, are gap-graded, indicating a deficiency of intermediate particles and a consequent tendency to increase deficiency of intermediate particles and a consequent tendency to increase paste and water demand for adequate workability. The granite aggregates exhibit a well-graded profile C_u =5.78, and C_c =2.0), which ensures dense packing, reduced voids, improved strength, and durability of the hardened concrete as shown in Figure 6 However, the gravel fraction with C_u = 2.85 and C_c = 1.25 is relatively uniform, offering limited packing efficiency and thus contributing to higher void content within the mix, as shown in Figure 6. Collectively, while the granite provides an excellent foundation for high-performance concrete, the gap-graded sand and moderately graded gravel necessitate careful proportioning or blending with better graded materials to optimize paste demand, minimize shrinkage, and durable, economical mix design (Fahem et al., 2018).

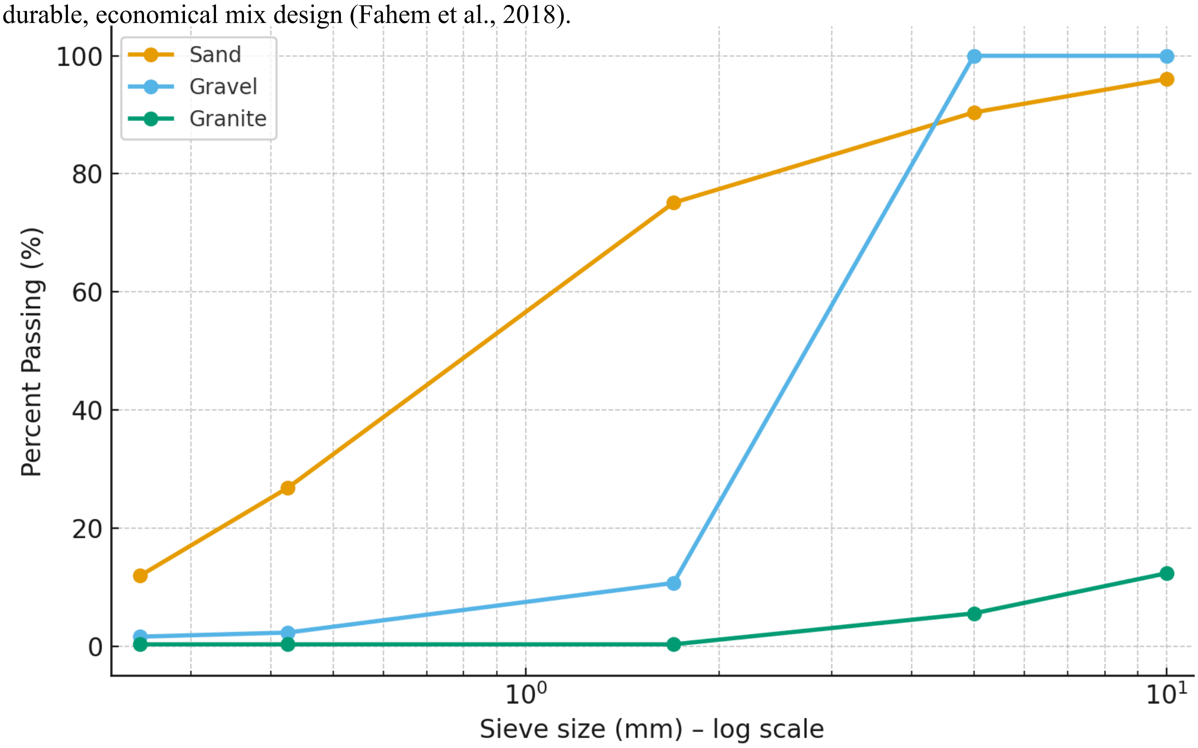

Figure 6: Sieve gradation curve for sand, gravel, and granite

3.2 Water Absorption

The water absorption of each aggregate type (sand, granite, and gravel) was determined in agreement with ASTM C1585 (2020). Based on established material properties, natural fine aggregates (sand) typically exhibit moderately higher water absorption compared to coarse aggregates such as gravel and granite, with fine aggregates having a water absorption rate of 1.02%. Very little water is absorbed as a result; the effective water-cement ratio of 0.5 remains stable, reducing variability in workability and strength (Ammar et al., 2022). In contrast, the 0.61% and 0.69% water absorption values for gravel and granite, respectively, show that the two coarse aggregates are denser and less porous, and tend to absorb less water, indicating high strength, low porosity, and long-term durability. It also suggests reliable resistance to environmental stresses. Table 1 presents the measured water absorption results for natural fine aggregate, gravel, and granite, which shows that the entire aggregate system demonstrates low water absorption, signifying dense, durable materials.

Table 1: Water Absorption of Fine, Granite, and Washed Gravel

Materials	Water Absorption (%)
River sand	1.02
Granite aggregates	0.61
Gravel aggregates	0.69

3.3 Slump Test Result

Slump is one of the most widely used indicators in concrete production because it directly relates to workability and consistency. It serves as a quality control tool, helps maintain the balance between workability and strength/durability, and ensures that fresh concrete can be handled, placed, and compacted effectively for the intended structural application. From the current study, the slump decreased sharply when 10% of the coarse aggregate was replaced with gravel (12.7mm). It then increased gradually with more gravel, reaching 29.0 mm at 40% and 33.0 mm at 50%, which is slightly above the baseline of 31.5 mm for the 100% granite mix. The initial drop is due to a change in the original grading and paste distribution at low gravel replacement. It created a harsher, gap-graded mix with higher inter-particle friction. At higher gravel amounts, the rounded and smoother gravel particles lowered inter-particle friction and paste demand, which improved workability. These results suggest that mixes with 40% to 50% gravel can improve the slump compared to the all-granite mix, as shown in Figure 7. Khaleel *et al*. (2011) investigated the influence of three types of coarse aggregates, crushed gravel, uncrushed gravel, and crushed stone, on the fresh and hardened properties of self-compacting concrete (SCC). Their results showed that aggregate type significantly affected workability. The findings reflect the trend observed in the present study, where increasing the proportion of gravel, a more rounded and smoother aggregate, generally improved slump values at higher replacement levels. The presence of well-graded granite improves the cohesion and reduces segregation risk to balance workability with strength and durability requirements (Elavarasi and Sumathy, 2025).

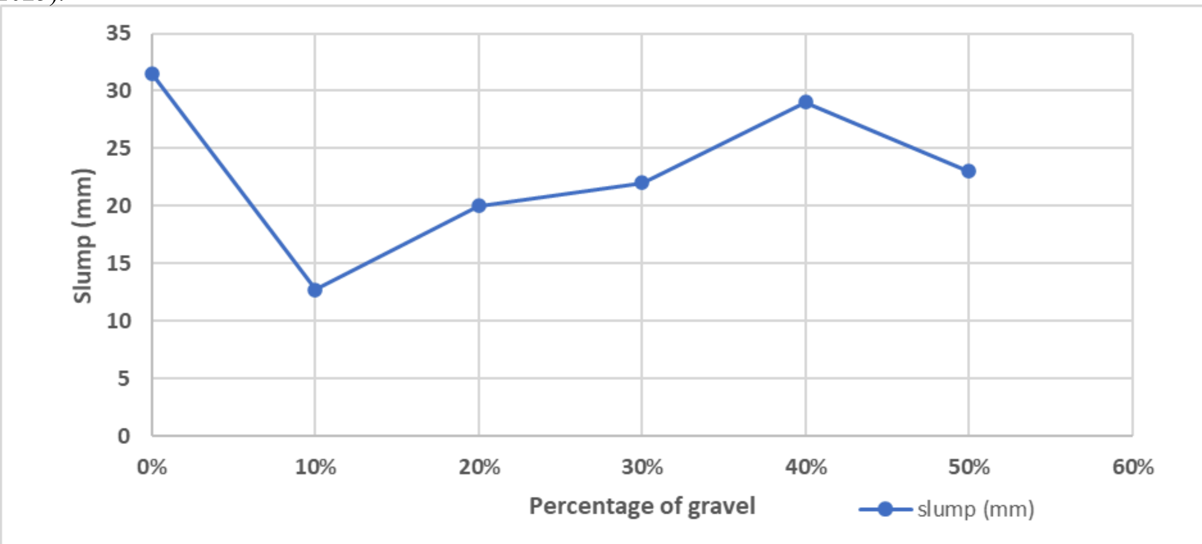

Figure 7: Slump Test Comparison for Various Replacement Percentages

3.4 Test on Hardened Concrete

3.4.1 Compressive strength

Compressive strength is the cornerstone property of concrete production because it dictates structural capacity, durability, and mix design and quality control. It is the benchmark by which concrete quality is judged, and it directly determines the safety and service life of concrete structures. Also, curing conditions are critical because they control the hydration of cement pore structure development and strength gain. Figure 8 shows the compressive strength results of various percentages of replacement of granite with gravel cured using water, air, and membrane. Also, Figure 9 shows the trend of compressive strength and the influence of curing methods on concrete strength across curing ages. It was observed that the compressive strength of concrete reduced with increasing gravel content. In the present study, however, mixes containing 10% and 20% gravel replacement met the BS 8110 minimum requirement of 15 N/mm² for mass concrete, suggesting that gravel can be used in partial replacement where workability and cost considerations are prioritized. The compressive strength increased as the curing ages increased with water curing, having the highest compressive strength, followed by membrane curing and air curing, having the least compressive strength. Water curing keeps the paste saturated; as a result, cement hydration continues for longer and more completely. More hydration means a greater volume of binding product that increases strength (Ammar et al., 2022; Goel et al., 2013). In air curing, surface and internal water evaporate, causing self-desiccation and shrinkage microcracks that reduce strength (Goel et al., 2013). Similar trends were observed for membrane curing. The aggregate combination suggests that concrete produced without grading correction will exhibit moderate compressive strength due to increased paste and water demand from the gap-graded fine aggregate and uniform gravel. Concrete with granite and gravel aggregates achieves its highest compressive strength when subjected to continuous moist curing at moderate temperatures. Granite contributes to dense packing, while gravel provides adequate strength when hydrated fully. Inadequate curing leads to incomplete hydration, a weak interfacial transition zone (ITZ), and reduced strength, especially since granite and gravel are low-absorption aggregates and cannot internally supply curing water.

This trend is consistent with the findings of Bamigboye *et al.* (2019), who reported that concrete made with granite aggregates exhibited higher compressive strength than those made with gravel due to the angularity and rough surface texture of granite, which promotes stronger interlock and bonding. Similarly, Dahunsi *et al.* (2022) deduced that the use of granite for pervious concrete is stronger than gravel. Gravel can excellently be used in areas that are not subjected to repeated heavy loads.

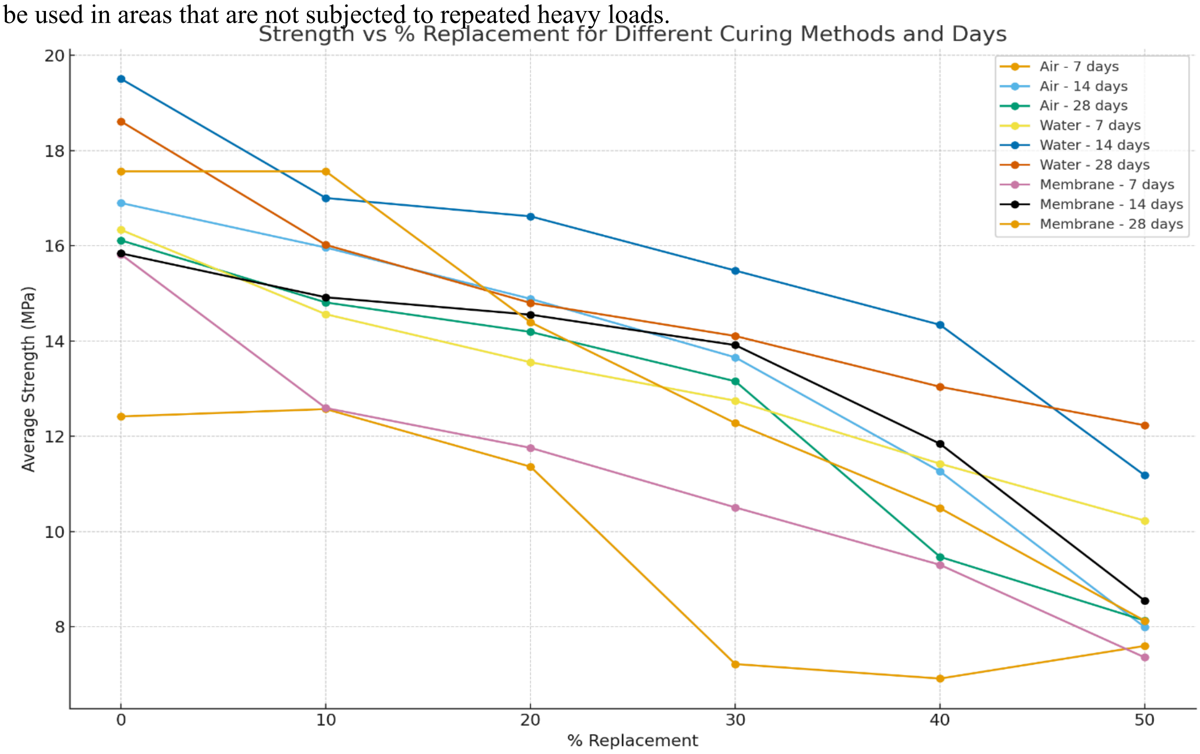

Figure 8: Comparison of Strength Performance of Concrete for Different Curing Methods for 7,14, and 28 days

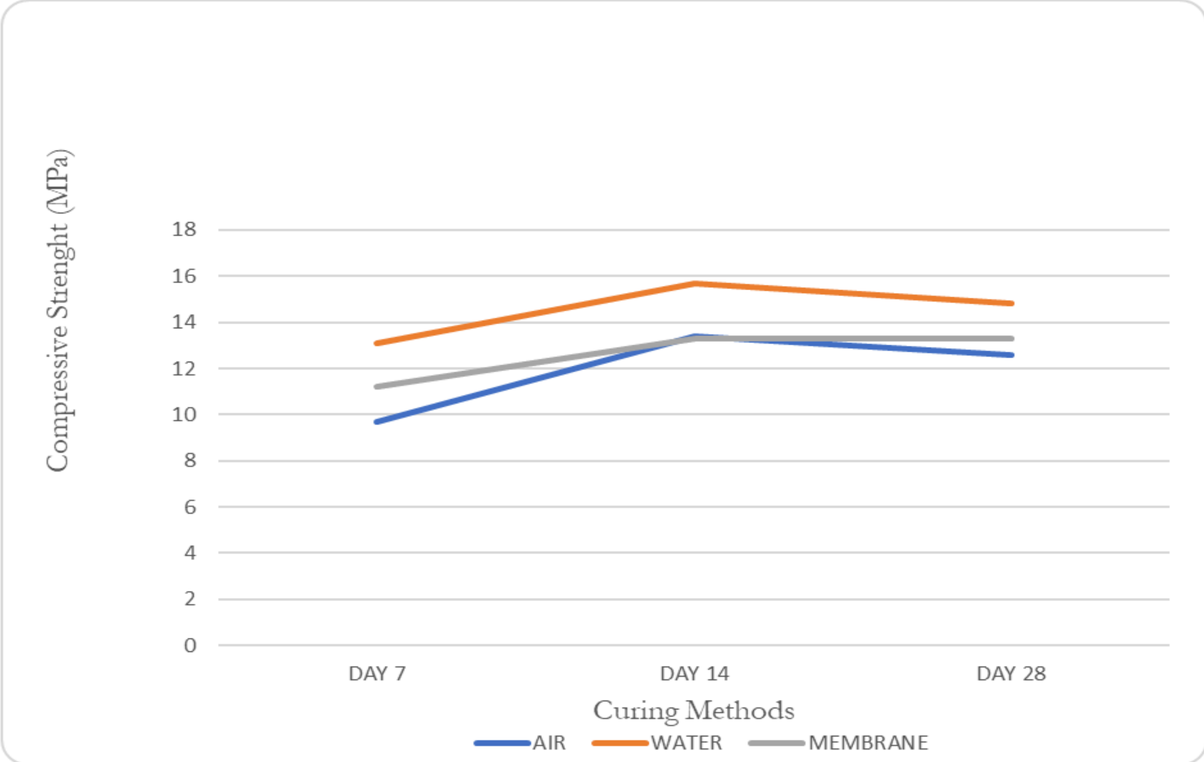

Figure 9: Comparison of the Strength Performance of Concrete for Different Curing Methods

3.4.2 Durability test

The role of durability testing in concrete produced from a granite/gravel aggregate combination is to evaluate resistance to environmental and mechanical degradation. While granite provides high strength and chemical stability, the inclusion of gravel may increase permeability; durability tests are therefore essential for verifying that the final concrete meets structural and durability requirements for its intended application. The role of curing concrete in NaCl solution is primarily experimental and diagnostic: it accelerates hydration initially, allows simulation of saline or marine service conditions, and provides insight into chloride penetration, pore structure development, and reinforcement corrosion risks. The results from the study show that compressive strength decreased consistently with increasing gravel replacement of granite at both curing ages. At 28 days, the 0% gravel mix recorded the highest strength of 21.85 MPa, while the 50% gravel mix had the lowest at 9.91 MPa, representing a reduction of over 50% as shown in Figure 10. This behaviour suggests that while hydration initially dominates and improves strength, prolonged exposure to chlorides compromises the cement matrix, meaning that high compressive strength cannot be sustained under saline conditions. This finding is consistent with Ariffin *et al.* (2013) who reported that chloride ingress and the associated formation of expansive salts accelerate deterioration, leading to a reduction in strength after prolonged exposure. Furthermore, granite's higher crushing resistance and superior hardness contribute to better load-bearing capacity. The trend also indicates that, although all mixes initially developed measurable strength at 28 days, the chloride-rich curing environment (2.5% NaCl) appeared to limit continued hydration, reducing long-term strength potential. Between 28 and 56 days, most mixes showed a slight decline in strength, indicating that early strength gain could not be maintained over time in the saline environment. This finding corresponds with research made by Bamigboye *et al.* (2019), where it was observed that NaCl solutions had early age accelerating compressive strength properties that could not be sustained for the long term. Also, the strength pattern suggested that saline solutions cause long-term deterioration of concrete strength.

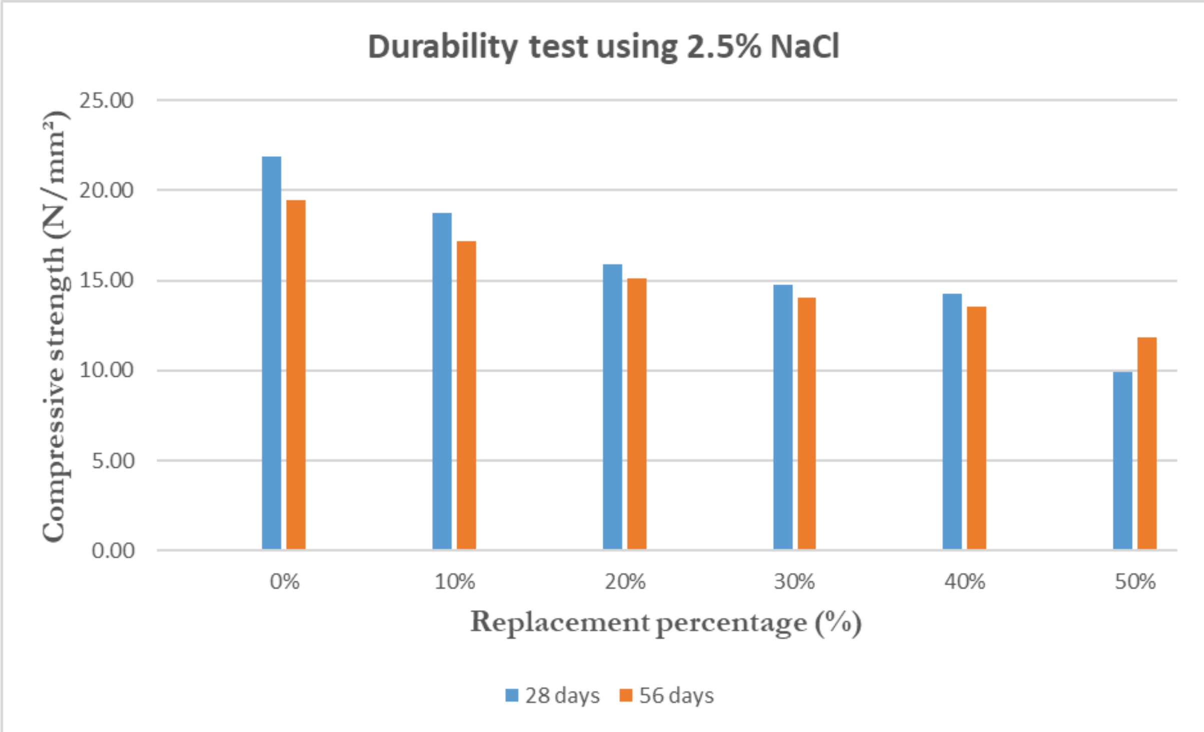

Figure 10: Comparison of the Strength Performance of Concrete for Different Curing Methods

4. CONCLUSION

This study investigated the effect of gravel replacement of granite on the workability, compressive strength, and durability of concrete under different curing regimes and in a chloride-rich environment. Based on the experimental findings, the following conclusions were drawn:

i) The gradation analysis of the constituent aggregates reveals significant implications for concrete performance. Collectively, while the granite provides an excellent foundation for high-performance concrete, the gap-graded sand and moderately graded gravel necessitate careful proportioning or blending with better-graded materials to optimize paste demand, minimize shrinkage, and achieve a durable mix.

ii) The workability of concrete reduced initially with the introduction of coarse gravel aggregate, but increased gradually with an increment in gravel content. This was attributed to the relatively larger, rounded particle size present in gravel.

iii) Concreted cured using ponding had the highest compressive strength over 28 days, followed by concrete cured under membrane (polythene sheets), while concrete cured under air had the lowest compressive strength overall.

iv) Concrete with 10% and 20% replacement of gravel meets the BS8110 standard requirement for $15N/mm^2$. Hence, it can be used for producing mass concrete.

v) Concrete cured using 2.5% NaCl gained early age strength with strength peaking at 28 days and reducing at 56 days. This indicates that high compressive strength cannot be sustained over time under saline conditions.

Overall, the findings confirm that while limited gravel replacement (10-20%) can yield concrete suitable for mass applications, granite-rich mixes not only provide superior compressive strength but also exhibit greater resistance to deterioration in aggressive chloride environments. Gravel-rich mixes, although beneficial for workability, are more vulnerable to long-term degradation.

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