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Effects of Curing Temperature on the Engineering Properties of Cement Treated Lateritic Soil

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ABSTRACT

This study investigated the engineering properties of lateritic soil stabilized with cement under different curing temperatures, compactive efforts, and curing durations. The natural soil exhibited Maximum Dry Density (MDD) values of 1.68 Mg/m³ to 1.71 Mg/m3, 1.76 Mg/m³ to a maximum value of 1.796 Mg/m3, and 1.87 Mg/m³ to 1.96Mg/m3 all at 6% cement treatment under British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH) compactive efforts, respectively, For all the compactive efforts the BSL, WAS and BSH the OMC increased from 20.20%,15.90% and 14.20% for the natural soil to peak values of 25.3% at 6% cement, 19.8% at 8% cement and 15.9% at 8% cement, respectively. The natural soil recorded UCS values of 335.25 kN/m², 400 kN/m², and 537 kN/m² under BSL, WAS, and BSH compaction at 25°C. The UCS values increased progressively with cement content, curing time, and compactive effort. At 7 days curing, the highest UCS values were recorded at 8% cement, reaching 899 kN/m², 1232 kN/m², and 1541 kN/m² under BSL, WAS, and BSH compactive efforts respectively. At 14 days curing, substantial strength development occurred, with the highest value of 2002 kN/m² obtained at 8% cement under BSH compaction and curing temperature of 25°C. The results indicate that moderate curing temperature (25°C), higher compactive effort, and adequate cement content significantly improve the strength and performance of lateritic soil.

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INTRODUCTION

The term curing in concrete and soil stabilization refers to the practice of maintaining adequate moisture and temperature conditions in cementitious materials after placement to promote hydration and strength development. According to Al-Na`amani & Al-Hashmi (2023), curing is essential because it regulates the ongoing hydration reaction in cement systems, which continues long after initial setting. Similarly, Singh et al. (2022) define curing as the controlled retention of moisture and temperature to expedite chemical reactions between cement and water, significantly improving compressive strength and durability. Research by Zhang & Wang (2024) also highlights that curing regimes involving controlled temperatures can accelerate early-age strength gain in both concrete and soil-cement mixtures Cement-stabilized materials are increasingly used in pavement structural layers to mitigate the scarcity of high-quality stone aggregates and improve pavement performance.

A pavement is the engineered surface material intended to sustain vehicular traffic, and can be broadly classified as flexible or rigid. Flexible pavements consist of asphaltic materials and aggregates layered over compacted subgrade, and their design is based on the principle that applied loads diminish in intensity as they are transmitted downward through successive layers of graded materials (Huang & Singh, 2022). Rigid pavements, on the other hand,

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are constructed from concrete slabs whose high modulus of elasticity distributes loads over a wider area (Khan et al., 2023).

Lateritic soils are widely available in tropical regions, including Nigeria, and are commonly used as subgrade, subbase, or base materials in flexible pavement construction. However, lateritic soils exhibit considerable variability in engineering properties due to differences in mineralogy, particle size distribution, and plasticity characteristics (Okoro & Eze, 2022). As a result, untreated laterite often fails to meet specification requirements for load-bearing layers in highway pavements, leading to poor performance if left unmodified (Adewumi & Balogun, 2023).

MATERIALS AND METHODS

Materials

Lateritic Soil

The lateritic soil sample was gotten from a borrow pit at Shika, Zaria (latitude 11^0 15'N and longitude 7^0 45'E). The soil sample was collected at a depth of 1.5m underneath the soil surface to maintain a strategic distance from natural matter influence

Cement

This was gotten from the Dangote Cement Depot of Mando open market kaduna state, Nigeria. It was stored in air-tight containers for use

Natural moisture content

BS 1377 (1990) Part 2 was used to determine the natural moisture content of the soil obtained from the site. Three weighing containers were thoroughly cleaned and weighed to the nearest 0.01g (M_1). The sample was crumbled and loosely placed in the containers, and the containers with the samples were weighed together to the nearest 0.01g as M_2. The containers were then dried in an oven at 105-110^{o}C for 24 hours. After that, the containers and samples were removed and weighed dry to the nearest 0.01g as M_3. The natural moisture content (as collected on site) is calculated as the average of the three oven dried samples given by eqn. (1):

$$w = \frac{M_2 - M_1}{M_3 - M_1} \times 100 \qquad (1)$$

Maximum dry density

The compaction tests were carried out for the natural soil and the stabilized soils (in different percentages); all concurring to BS 1377 (1990) Part4, utilizing the British Standard light, West African Standard and the British Standard heavy, in accordance with the Nigerian General Specifications (1997). Three (3) kg of the soil/soil-admixtures sample were blended properly with 8% of water (and the water is added at 8% for each of the compactions). The sample was compacted into the 1000cm^3 (of mass as m1); in three layers of approximately equal mass with each layer accepting 27 blows of 2.5kg rammer falling through a height of 300mm, for the BSL; 10 blows of 4.5kg rammer in five layers for WAS and 27 blows of 4.5kg rammer in five layers for the BSH.

$$\rho = \frac{m_2 - m_1}{1000} \qquad (2)$$

The dry density was also calculated using the equation:

$$\rho_d = 100\rho/(100 + W) \qquad (3.6)$$

The values of the dry densities as gotten from eqn. (3.6) were plotted against their particular moisture contents and the maximum dry density (MDD) was derived as the peak on the resultant curves.

Optimum moisture content

The corresponding values of moisture content at maximum dry densities (MDD), concluded from the chart of dry density against moisture content, gives the optimum moisture content (OMC).

Unconfined Compressive** Strength **(UCS)

The unconfined compressive strength (UCS) tests were performed on the soil tests in line with BS 1377; 1990 Part 7 using the BSL, WAS and BSH energy levels. The common soil

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sample/the stabilized soil sample were compacted in 1000cm^{3}moulds at their particular OMC. The tests were expelled from the moulds and trimmed into a cylindrical specimen of 38.1mm breadth and 76.2mm length. The three cylindrical specimens from the mould were cured for 7 days, second for 14 days and the third for 28 days. At the elapsed day of curing, the samples were set centrally on the lower platen of a compression testing machine and a compressive force in connected to the sample with a strain control at 0.10% mm. Record was taken concurrently of the axial deformation and the axial force at regular interval until the sample fizzles. The UCS of the test was decided at the point on the stress–strain curve at which the sample fizzled. The UCS was calculated from the following equation:

$$\text{Compressive strength} = \frac{\text{Failure load}}{\text{Surface Area of Specimen}} \quad (3.8)$$

RESULTS AND DISCUSSION

Natural Laterite Soil

The maximum dry density (MDD) under BSL, WAS and BSH compactive efforts were determined as 1.68 Mg/m³ 1.76 Mg/m³ and 1.87 Mg/m³ respectively, with corresponding optimum moisture contents (OMC) of 20.2%, 15.9 and 14.2%. The Unconfined Compressive Strength (KN/m^2) at Normal Temperature of 25^{0}C conducted under BSL, WAS and BSH compactive efforts, yielded values of 335.25 *KN/m^2* a, 400 *KN/m^2* and 537 *KN/m^2*, respectively.

Table 3.1a: Physical Properties of the Natural Soil used for the Study

PROPERTY	*QUANTITY / VALUE*
Maximum Dry Density (MDD) (mg/m^3)	-
British Standard Light (BSL)	1.68
West African Standard (WAS)	1.76
British Standard Heavy (BSH)	1.87
Optimum Moisture Content (OMC) (%)	-
British Standard Light (BSL)	20.2
West African standard (WAS)	15.9
British Standard Heavy (BSH)	14.2
Unconfined Compressive Strength (KN/m^2) at Normal Temperature of 25^{0}C	-
British Standard Light (BSL)	335.25
West African Standard (WAS)	400
British Standard Heavy (BSH)	537
Colour	Light Brown
Dominant Clay Mineral	Kaolinite

Table 3.1b: Chemical Composition of Natural Soil

ELEMENTAL OXIDE	**COMPOSITION (%)**
SiO_2	41.05
AL_2O_3	24.16
Fe_2O_3	10.16
CaO	0.23
MgO	0.21
SO_3	1.04
Na_2O	1.37
K_2O	0.34
TiO_2	0.39

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ELEMENTAL OXIDE	COMPOSITION (%)
P_2O_5	1.31
MO_2O_5	0.02
Rb_2O_5	0.27
PbO	0.01
Cr_2O_3	0.02
MnO	ND
LOI	19.35

Table 3.1c Oxide composition of cement

Oxide	CEMENT(%)
CaO	71.32
SiO_2	20.34
Al_2O_3	7.56
Fe_2O_3	5.53
MgO	0.73
Cl	0.25
Na_2O	0
K_2O	1.84
SO_3	2.05

Compaction Characteristics

Maximum Dry Density

MDD values increased with increasing cement content and also increases with compactive effort. For the British Standard Light (BSL) compaction, MDD increased generally with increase in cement content from a value of 1.68 Mg/m^3 for the natural soil to a maximum value of 1.71 Mg/m^3 at 6% cement treatment. For the West African Standard (WAS) compaction MDD increased from 1.762Mg/m^3 for the natural soil to a maximum value of 1.796 Mg/m^3 at 6% cement treatment. While for the British Standard heavy (BSH) compaction, MDD also increased from a value of 1.88 Mg/m^3 for the natural soil to a maximum value of 1.96Mg/m^3 at 6% cement treatment. This finding is in agreement with the findings reported by Rizal *et al* (2022) on the Effects of cement on the Compaction Characteristics of Lateritic Soil in UTM, Johor, (Ogundipe and Adekanmi, 2019), Sani *et al.,* (2018) and Sani *et al.,* (2021)

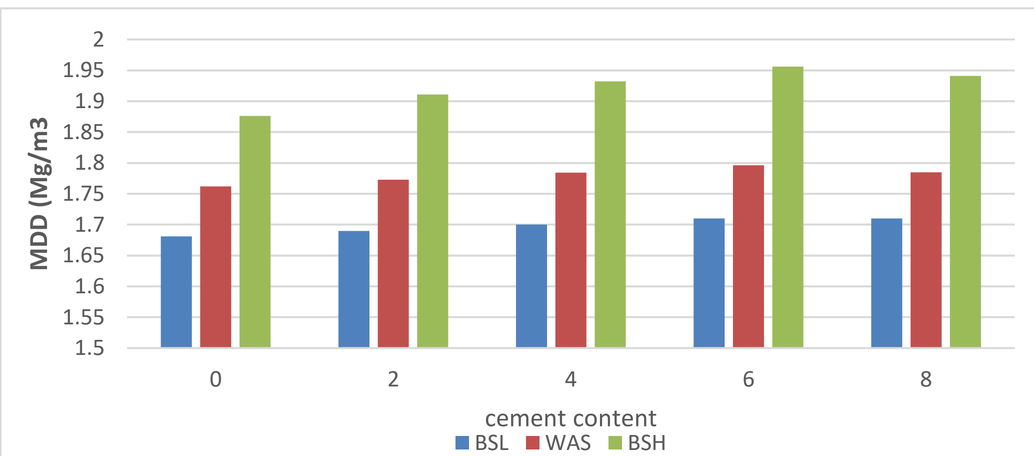

Fig. 1: Variation of MDD with cement content

Optimum Moisture Content

The variation of Optimum Moisture Content (OMC) of lateritic soil- cement for BSL, WAS and BSH compactive efforts are shown in figure 2. There was a general increase in OMC with cement treatment for all compactive efforts.

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For all the compactive efforts the BSL, WAS and BSH the OMC increased from 20.20%,15.90% and 14.20% for the natural soil to peak values of 25.3% at 6% cement, 19.8% at 8% cement and 15.9% at 8% cement, respectively. The increase in OMC was due increasing desire for water which commensurate with the higher amount of the additives because more water was required for the dissociation of admixtures with Ca^{2+} and OH^{-} ions to supply more Ca^{2+} for the cation exchange reaction (Sani *et al.,* 2021) **.**

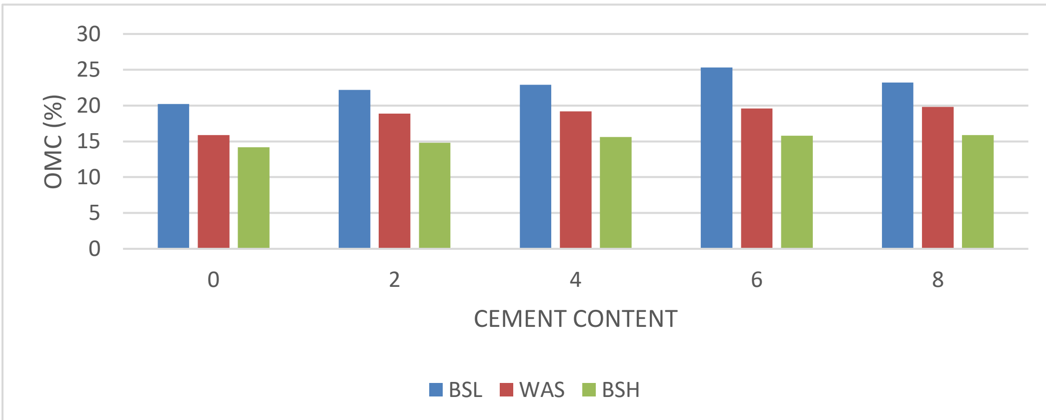

Figure 2**:** variation of OMC with cement

Unconfined Compressive Strength

7 Days Curing

The Unconfined Compressive Strength (UCS) results of the BSL-compacted specimens cured for 7 days at 0°C, 25°C, and 45°C show that both cement content and curing temperature significantly influenced strength development. At 0% cement, the UCS values (341, 335, and 320 kN/m² at 0°C, 25°C, and 45°C respectively) are relatively low and slightly decrease as temperature increases with 2% cement, UCS increased significantly (554–558 kN/m² at 0°C and 25°C), but reduced at 45°C (506 kN/m²).

At 4% cement, UCS values remained fairly consistent (595, 591, and 605 kN/m²), showing improved stability of the cement-soil matrix. For 6% cement, UCS values (674, 648, 638 kN/m²) show slightly higher strength at 0°C, with gradual reduction at elevated temperatures. The highest strength was recorded at 8% cement, especially at 0°C (899 kN/m²), compared to 724 and 718 kN/m² at 25°C and 45°C respectively. This confirms that higher cement dosage significantly enhances bonding and densification, that low cement contents improve soil structure through flocculation and early formation of cementitious gels (Amadi, 2014).

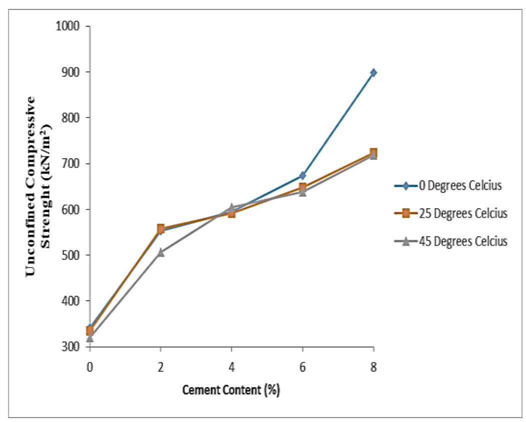

Figure 3a: Variation of UCS for 7 Days Cured Period at Different Temperature and cement Content for BSL

The Unconfined Compressive Strength (UCS) results for the WAS-compacted specimens cured for 7 days at 0°C, 25°C, and 45°C demonstrate At 0% cement, UCS values (386, 400, and 563 kN/m² at 0°C, 25°C, and 45°C

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respectively) At 2% cement, UCS values (631, 628, and 618 kN/m²) remain nearly constant across curing temperatures At 4% cement, UCS values (696, 690, and 685 kN/m²) are very consistent across temperatures, For 6% cement, UCS decreases as curing temperature increases (821, 780, and 721 kN/m²) The highest UCS occurred at 8% cement, with values of 1232 kN/m² at 0°C, 850 kN/m² at 25°C, and 1021 kN/m² at 45°C. Increasing binder dosage improves aggregate formation and reduces environmental sensitivity of stabilized soils (Osinubi et al., 2018).

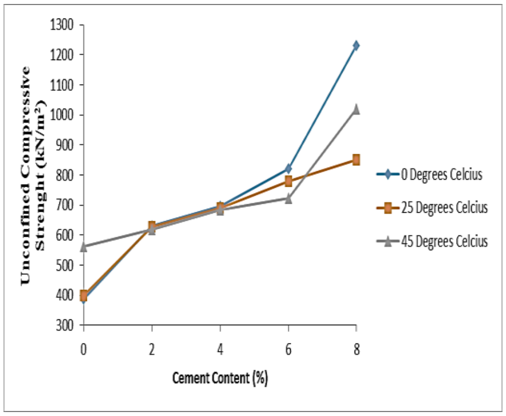

Figure 3b: Variation of UCS for 7 Days Cured Period at Different Temperature and cement Content for WAS

The Unconfined Compressive Strength (UCS) results for the BSH-compacted specimens cured for 7 days at 0°C, 25°C, and 45°C show a pronounced improvement in strength with increasing cement content At 0% cement, UCS values (514, 500, and 602 kN/m² at 0°C, 25°C, and 45°C respectively) With 2% cement, UCS values (792, 754, and 695 kN/m²) decrease gradually as temperature increases At 4% cement, UCS values (824, 797, and 798 kN/m²) remain relatively stable across temperatures, For 6% cement, strength values (1036, 1012, and 1013 kN/m²) are high and nearly uniform across temperatures, The highest UCS values were recorded at 8% cement, with 1443 kN/m² at 0°C, 1541 kN/m² at 25°C, and 1281 kN/m² at 45°C. the reduction at 45°C (1281 kN/m²) may be due to accelerated hydration and internal shrinkage stresses, as also discussed by (Osinubi et al. 2017).

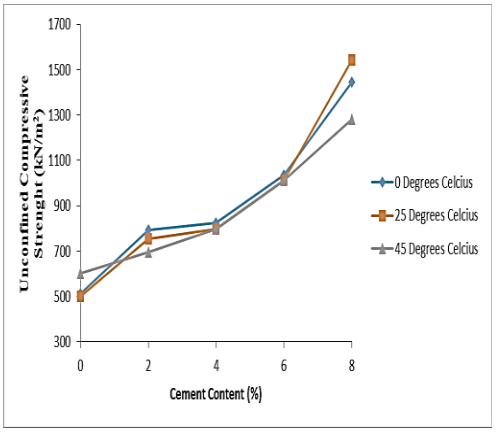

Figure 3c: Variation of UCS for 7 Days Cured Period at Different Temperature and cement Content for BSH

14 Days Curing

The 14-day UCS results for BSL, WAS, and BSH compactive efforts clearly show significant strength development with curing time, cement content, compactive energy, and temperature. At 0% cement, values (404, 435, 334 kN/m²) show minor variation with temperature At 2–4% cement, strength increases moderately, especially at 25°C (621 and 656 kN/m² respectively), suggesting that moderate curing temperature enhances hydration A remarkable increase occurs at 6% cement, particularly at 25°C and 45°C (995 and 952 kN/m²), The highest strength is recorded at 8% cement, especially at 25°C (1780 kN/m²), which is nearly double the value at 0°C. This suggests that 25°C provides optimal curing conditions for cement hydration and formation of calcium silicate hydrate (C–S–H), as also emphasized by (Consoli, 2014),

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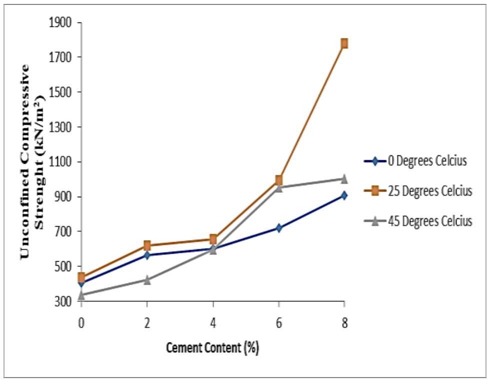

Figure 4a: Variation of UCS for 14 Days Cured period at Different Temperature and cement Content for BSL

The WAS compactive effort shows stronger performance than BSL at equivalent cement percentages. At 0% cement, strength increases with temperature (415, 500, 560 kN/m²) At 2–4% cement, significant strength improvement occurs at 25°C (711 and 884 kN/m² respectively), confirming favorable curing conditions at moderate temperature At 6% cement, UCS peaks at 1015 kN/m² (25°C), but drops at 45°C (634 kN/m²), suggesting that excessive temperature may cause shrinkage or rapid evaporation that disrupts hydration. At 8% cement, the maximum UCS of 1926 kN/m² at 25°C is observed, showing exceptional strength development. (Horpibulsuk, 2012),

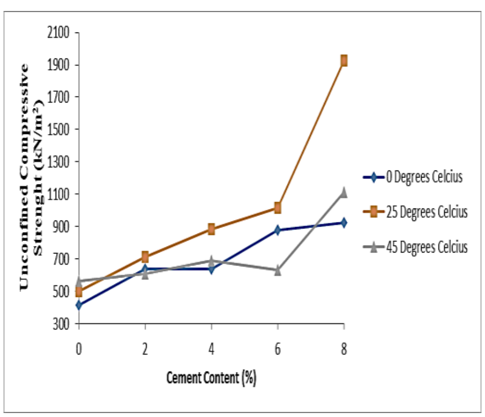

Figure 4b: Variation of UCS for 14 Days Cured period at Different Temperature and cement Content for WAS

BSH specimens exhibit the highest overall strength among the three compactive efforts, confirming the importance of higher compactive energy. At 0% cement, strength increases significantly at 25°C (714 kN/m²), suggesting strong densification due to high compaction energy. At 4–6% cement, UCS values are high, particularly at 25°C (995 and 1174 kN/m²), indicating effective hydration under optimal temperature. At 8% cement, the highest overall strength of the entire study is recorded: 1817 kN/m² (0°C), 2002 kN/m² (25°C) and 1236 kN/m² (45°C) The peak value of 2002 kN/m² at 25°C demonstrates that high compactive effort combined with adequate cement dosage and moderate curing temperature produces maximum structural performance. Sherwood (1993) emphasized that compactive energy significantly improves particle interlocking and binder efficiency, while Fatahi (2013) confirmed that higher compaction and binder dosage produce denser microstructure and improved stiffness.

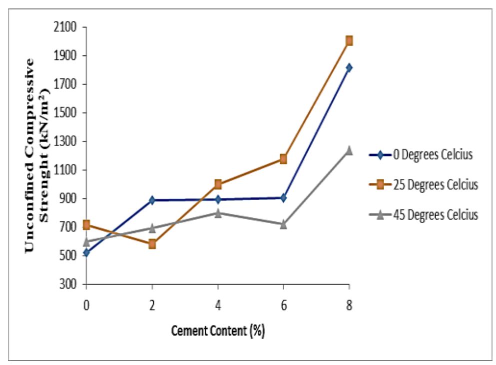

Figure **Error! No text of specified style in document.**c: Variation of UCS for 14 Days Cured period at Different Temperature and cement Content for BSH

CONCLUSION

This study investigated the influence of cement content, compactive effort (BSL, WAS and BSH), curing temperature (0°C, 25°C and 45°C), and curing duration (7 days and 14 days on the engineering properties of lateritic soil. Compaction characteristics revealed that Maximum Dry Density (MDD) increased with increasing cement content but increased with compactive effort (BSL

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< WAS < BSH). Optimum Moisture Content (OMC) increased with cement addition due to higher water demand for hydration and cation exchange reactions.

For Unconfined Compressive Strength (UCS), strength increased consistently with cement content for all compactive efforts and curing temperatures. At 7 days curing, compactive effort significantly influenced UCS, while curing temperature was not significant. BSH produced the highest strength values, followed by WAS, confirming that higher compactive energy enhances soil-cement bonding. At 14 days curing, strength gain was substantial across all mixtures. Although BSH recorded the highest numerical values (up to 2002 kN/m² at 8% cement and 25°C), which showed that compactive effort and temperature were not significant at this stage. This indicates that extended curing allowed hydration reactions to dominate strength development, minimizing temperature and compaction effects (Sani et al 2020b).

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