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Compressive Strength And Water Absorption Effects Of Treated Drill Cuttings As A Partial Replacement Of Cement In Concrete.

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Abstract: *The increasing global demand for concrete, driven by urbanization and infrastructure development, has led to the exploration of sustainable alternatives for concrete production. Worldwide, 30 billion tonnes of concrete are used annually, with Nigeria's cement demand growing by 14% in 2013. This study investigates the potential of using drill cuttings as a partial replacement for cement in concrete, focusing on its impact on strength and water absorption. Drill cuttings, the waste material generated from drilling operations, are traditionally disposed of or treated for recycling. By processing these cuttings into pozzolanic materials, they can replace some cement in concrete, potentially reducing environmental impact and lowering production costs. Pozzolans enhance concrete's durability and strength by reacting with lime to form cementitious compounds. The study evaluates the water absorption ratio of concrete with varying replacement levels of drill cuttings. Results show that higher replacement levels increase water absorption at early curing stages, but long-term curing (90 days) improves concrete's performance by reducing permeability. This research has established that using drill cuttings as a pozzolan can provide an eco-friendly solution to the cement demand issue, enhancing concrete's durability while reducing environmental impact.*

Keywords: Water Absorption, Drill Cuttings, Concrete, Pozzolan, Cement.

1. Introduction

Concrete is one of the most widely used materials in construction, driven by increasing demands for infrastructure and shelter due to global urbanization. The global consumption of concrete has reached approximately 30 billion tonnes annually, three times the amount used four decades ago, with demand outpacing that for steel or wood. In Nigeria, for example, cement demand increased by 14% in 2013, highlighting the growing need for sustainable construction materials (Bangudu, 2013). However, the environmental impact of cement production is a concern, prompting the search for alternative materials. This study explores the potential of using drill cuttings as a partial replacement for cement in concrete, focusing on their impact on strength and water absorption. Drill cuttings, generated from drilling activities in oil, gas, and mining, often pose disposal challenges but can be processed into pozzolans—materials that enhance the strength and durability of concrete. By substituting a portion of cement with processed drill cuttings, this research aims to reduce cement consumption, lower carbon emissions, and improve concrete performance. The use of drill cuttings as pozzolans is expected to offer economic and environmental benefits, contributing to more sustainable construction practices (Mostavi et al., 2015; Mehta, 2022). This study also evaluates how varying replacement levels and curing times affect the material's water absorption capacity, a critical factor in long-term concrete durability.

2. Materials and Methods

In carrying out the study the following materials were used:

i. Drill Cuttings: Pretreated drill cuttings were collected from a waste treatment facility at Onne Rivers State at a treated temperature of 350^0C at 1hour 30mins duration.
ii. Cement: The cement used was Portland Limestone Cement (PLC), grade 32.5R, CEM II type cement bought from accredited distributors in Owerri Imo State.
iii. Fine Aggregates: Natural sand obtained from Otamiri River of maximum nominal size of 3.18mm was used.
iv. Coarse Aggregates: Crushed gravel of maximum nominal size of 19mm obtained from local quarry processing plant at Okigwe Imo State was used.
v. Water: Ordinary portable tap water available in the Agricultural and Biosystems engineering laboratory of Federal University of Technology Owerri was used for the mixing and curing the concrete specimens.

The following specimens were collected and prepared.

The pretreated collected drill cuttings were burnt in an electric furnace carbonite GPC 12/65 at a temperature and time of 500^0C for 3hours. The drill cuttings were grinded using a mechanically operated agate pestle mortar at 2hours period and passed through 63µm sieve in other to obtain a finely divided cuttings.

The binder used in producing concrete was a mixture of cement and drill cuttings obtained at the activation temperature and time of 500ºC and 3hours respectively.

The drill cuttings (DC) was used to replace cement at replacement levels of 5, 7.5, 10, 12.5, and 15% by weight of cement, while normal cement plus 0% drill cuttings was used as control.

2.1 Aggregate Characterization

To determine the stability of the aggregates (sand and gravel) for concrete production, sieve size analysis was conducted on the aggregates. Particle size distribution curves for the aggregates were plotted and their corresponding grading properties, nominal size, fineness modulus, coefficient of curvature (Cc) and coefficient of uniformity (Cu) were determined. The specific area and particle size (from sieve analysis result) were determined. The characterization of the aggregates was conducted in accordance with the standard procedure: BS 1377 (2016) Parts 1.

2.2 Concrete Mix Proportioning/Mix Design.

The mix ratio of 1:2:4 was used for the study and water-binder ratio of 0.60 BS 8110 specifies the following relationships to develop the mix proportions for the concrete constituents and conditions, since the batching was carried out by weight and this was used to obtain the blended concretes as shown in Table 1.

Weight of cement = unit weight of concrete x volume of cement ….1

Weight of sand = unit weight of concrete x volume of sand ….2

Weight of gravel = unit weight of concrete x volume of gravel ….3

Weight of water = binder ratio x volume of cement ….4

Table 1: Mix Design for Mix Ratio of 1:2:4

Constituent material	0% DC	5% DC	7.5% DC	10% DC	12.5% DC	15% DC
Cement (kg)	1.2	1.14	1.11	1.08	1.05	1.02
Drill cuttings (kg)	0.0	0.06	0.09	0.12	0.15	0.18
Sand (kg)	2.3	2.3	2.3	2.3	2.3	2.3
Gravel (kg)	4.6	4.6	4.6	4.6	4.6	4.6
W/B ratio	0.60	0.60	0.60	0.60	0.60	0.60
Total water (kg)	0.66	0.66	0.66	0.66	0.66	0.66

2.3 Slump/Workability of Blended Cement-Drill Cuttings Concrete.

The workability of a concrete mix gives a measure of the ease with which fresh concrete can be placed and compacted. The main factor affecting workability is the water content of the mix of 1:2:4 (binder: sand: gravel) was used for the experiment at a water-binder 0.60.

2.4 Compressive Strength of the Cement.-Drill Cuttings Concrete

The test was carried out according to BS 1881:116 methods. The concrete cubes of sizes 150x150x150mm prepared using a mix ratio of 1:2:4 at water-binder ratio (w/b) of 0.60, with different percentages of drill cuttings as substitute of cement. Two cubes of each concrete mix were cast and cured for 7, 14, 28, 60, and 90 days before the crushing. The compression testing machine plunger was set under california bearing ratio ring capacity of 50kN and samples crushed at a uniform rate to shear the samples were recorded.

2.5 Strength Activity Index (SAI)

The strength activity indices (SAIs) is a measure of the pozzolanicity of supplementary cementitious material (SCM) and is measured as the strength relative to the control in percentage. For an SCM to be classified as pozzolan, the strength of the blended cement at 7-day and/or 28-day must not be less than 75% of the strength of the normal/concrete.

2.6 Water Absorption Ratio

Water absorption ratio (WAR) helps in understanding how various replacement levels and curing times affect the material's durability, particularly in construction where water absorption can affect how long concrete structures last. The samples were submerged in water at room temperature for duration of the curing ages.

3. Results and Discussion

3.1 Aggregate characterization

The fine and coarse sands used in this study for the concrete production were characterized before use. It was observed that both the fine (sand) and coarse (gravel) distribution curves were within the region classified as sand (fine aggregate) and gravel (coarse aggregate) respectively shown in Table 2 and Figure 1.

Table 2. Particle size distribution analysis of the fine and coarse aggregates.

Sieve Size (mm)	Percentage Retained (%)	Percentage Passing (%)	Sieve Size (mm)	Percentage Passing (%)	Percentage Retained (%)
2.00	0.6	99.4	22.4	85.65	14.35
1.40	1.2	98.8	16	48.60	51.4
0.710	8.5	91.5	13.2	34.81	65.19
0.500	25.2	74.8	9.5	10.09	89.91
0.355	56.5	43.5	4.75	0.58	99.42
0.250	86.9	13.1			
0.180	94.8	5.2			
0.125	97.1	2.9			
0.075	98.9	1.1			

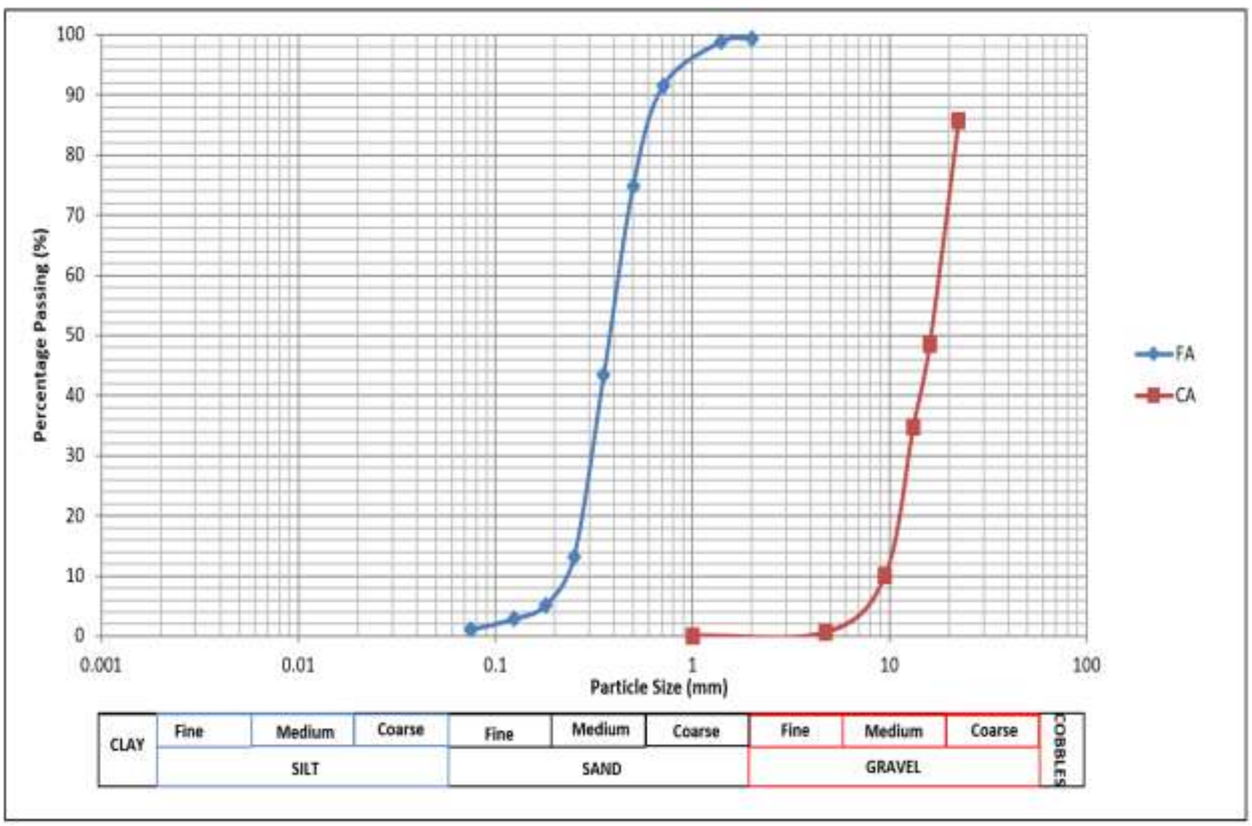

Figure 1. Particle Size Distribution Curves of Sand and Gravel.

Also, more than 90% of the gravel was retained above the 4.75mm sieve size, the upper bound for aggregate, while more than 95% of the sand passes 2.00mm and more than 98% retained at 0.075mm sieve size. Hence, both the sand and the coarse aggregates are within the specific requirements for fine and coarse aggregates in concrete production (BS 1377). The uniformity coefficient (Cu) and curvature coefficient (Cc) for the sand and gravel are 0.16, 0.9 and 2.00, 1.13 respectively which showed that the aggregates are well sorted, while their fineness moduli are 4.69 and 3.20 which are within the acceptable values (ASTM C 125) and works of Salau et al., (2012).

3.2 Workability of Blended Cement-Drill Cuttings Concrete.

The results of the slump test conducted on the concrete containing different proportions of drill cuttings as replacement for cement at different water-binder ratio as presented in Table 3

Table 3: Effect of Water-Binder Ratio (w/b) on Slump of the Blended Cement-Drill Cuttings Concrete.

Drill Cuttings Content (%)	Slump Value (mm) Water-Binder Ratio (w/b)		
	0.5	0.55	0.60
0	24.5	42	68
5	5	6.5	24
7.5	5	13.5	15.3
10	6	8.5	17
12.5	1.7	1.7	22
15	12	14	17

The workability of a concrete mix gives a measure of the ease with which fresh concrete can be placed and compacted. The concrete should flow readily into the form and go around and cover the reinforcement, the mix should retain its consistency and the aggregates should not segregate. A mix with high workability is needed where sections are thin and/or reinforcement is complicated and congested. The main factor affecting workability is the water content of the mix. The results show that as the W/B ratio increases from 0.5:1 to 0.60:1 at an interval of 0.05, the slump increases accordingly for equal percentage of drill cuttings replacement in the mix. For example, at 5% drill cuttings, the slump increases from 5mm to 24mm. However, at 5, 7, 5, 10, 12.5 and 15% drill cuttings replacements the slump increased with increase in amount of drill cuttings for the same water binder ratio.

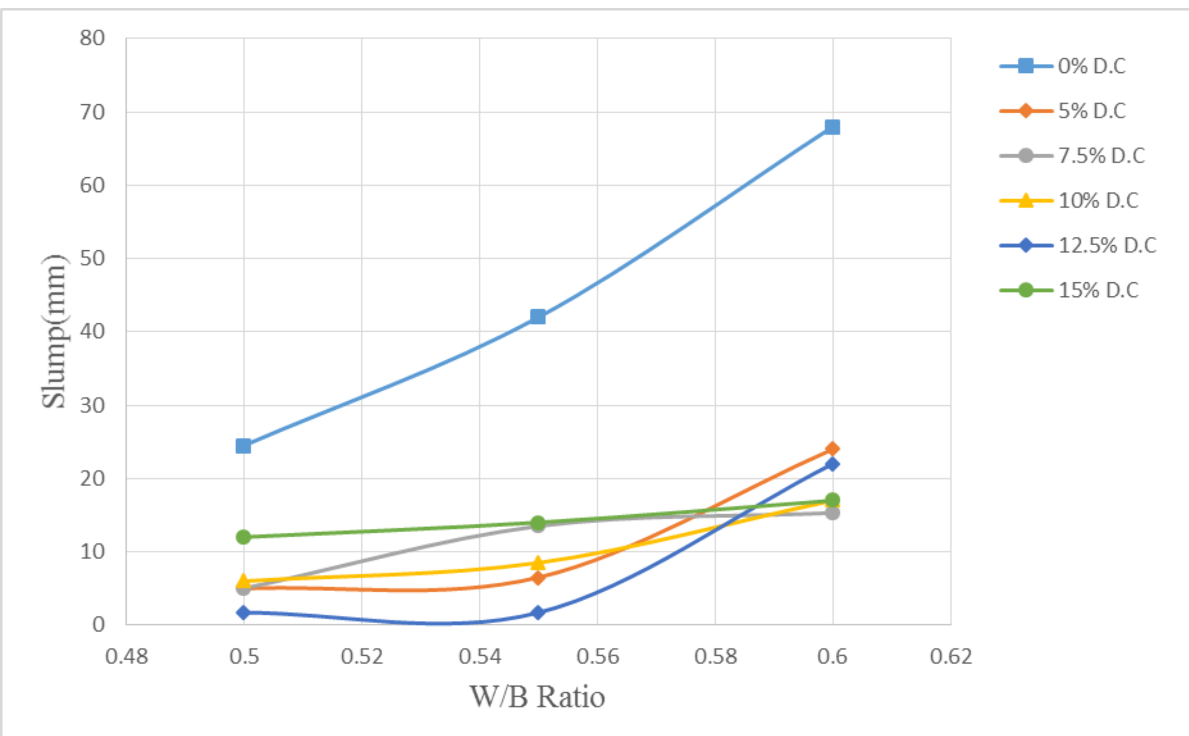

Figure 2: Effect of W/B Ratio on Slump of Blended Cement Drill Cuttings Concrete.

This trend indicates that less water is required to maintain the same consistency as the drill cuttings content increases to 15% replacement at 0.60:1 water-binder ratio in Figure 2 and Table 3.

Water-binder ratios from 0.5:1 at 10% and 12.5% and 0.55:1 at 7.5% 10%, 12.5% and 15% and 0.60:1 at all its replacement levels of drill cuttings were adequate to produce workable mix with true slump.

Slump test is sensitive to changes in consistency corresponding to slump between 10 and 200mm and the test is not considered suitable beyond these extremes. Also, mix having slump between 60-130mm is considered being plastic and requires either mechanical or hand compaction (Domane, 2003). This behaviour suggests that 0.60:1 water-binder ratios (w/b) could be considered appropriate in the concrete production at different replacement levels of 0%, 5%, 7.5%, 10%, 12.5% and 15%% respectively in this research.

3.3 Compressive Strength of Drill Cuttings Blended Cement Concrete.

To evaluate the effects of drill cuttings on the compressive strength of blended concrete samples, various percentages of drill cuttings were used to replace cement, Figure 3shows the compressive strength of concrete samples containing different percentage of drill cutting after 7, 14, 28, 60, and 90 days of curing.

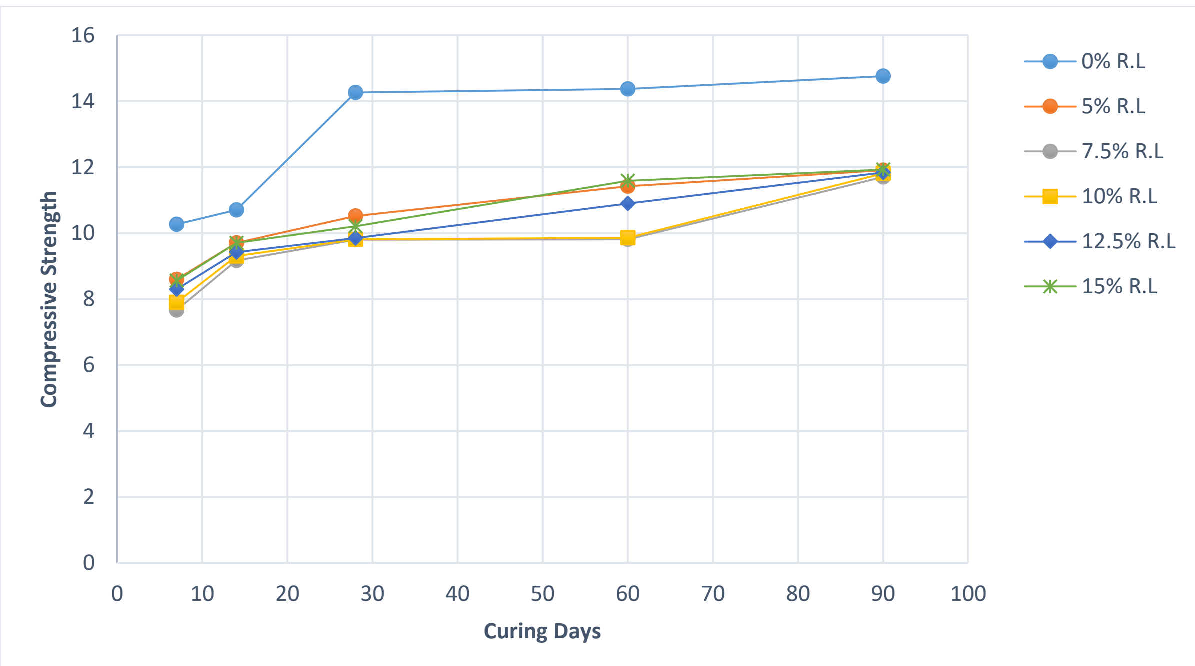

Figure 3; Compressive Strength of Concrete Sample Containing Different Percentage of Drill Cuttings after 7, 14, 28, 60 and 90 Days of Curing.

When compared to the control sample (0%) replacement, the compressive strength of cement-drill cuttings blended concrete increased as the curing age increased irrespective of the content of the drill cuttings replaced in the mixture. At the early age of the 7 days of the concrete, the compressive strength decreased as drill cutting content increased (Figure 3). For the normal (control) concrete 0% drill cuttings, the compressive strength at 28 days is 14.27N/mm^2 while that of 5, 7.5, 10, 12.5 and 15% levels are 10.52, 9.8, 9.81, 9.85 and 10.20N/mm^2 respectively, representing increases of 26.28, 31.32, 31.25, 30.97 and 28.52% respectively. But at later curing age of 60 and 90 days the strength development increased with concrete containing different levels of drill cuttings compared to the normal concrete at 7 and 28 days, but all the blended concrete strength are below that of normal concrete at 90 days. At 90 days, normal concrete has strength of 14.76N/mm^2 about 3.22 higher than 28-day strength.

Similar findings were reported by Ehsan, et al (2015) and Al-Ansary & Al-Tabba (2007) for cement-drill cuttings concrete at a replacement levels of 5, 20 and 35%. This strength increase of cement-drill cuttings blended concrete indicates that the treated drill cuttings have potential to contribute to late strength gain. This characteristics suggest that the treated drill cuttings possess pozzolanic

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properties. The results obtained are comparable to works of Tsivilis, et al (2002), Gurumoorthy (2014), Kumur & Karishna (2014) and Hoque et al (2014).

3.4 Strength Activity Index (SAI).

The strength activity indices (SAIs) of cement drill cuttings blended concrete are presented in Table 4. The strength activity indices (SAIs) is a measure of the pozzolanicity of supplementary cementitious material (SCM) and is measured as the strength relative to the control in percentage. For an SCM to be classified as pozzolan, the strength of the blended cement at 7-day and/or 28-day must not be less than 75% of the strength of the normal/concrete (ASTM C 618-99).

Table 4: Compressive Strength (CS) (N/mm^2) and Strength Activity Index (SAI) of Blended Cement-Drill Cuttings Concrete.

	Curing Ages									
	7		14		28		60		90	
Drill cuttings contents (%)	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**
0	10.27	100	10.70	100	14.27	100	14.37	100	14.76	100
5	8.6	83.74	9.57	89.44	10.52	73.72	11.42	79.47	11.91	80.69
7.5	7.67	74.68	9.17	85.70	9.80	68.68	9.81	68.27	11.70	79.27
10	7.9	76.92	9.31	87.01	9.81	68.75	9.86	68.62	11.81	80.01
12.5	8.3	80.82	9.42	88.04	9.85	69.03	10.90	75.85	11.84	80.22
15	8.56	83.35	9.70	89.69	10.21	71.55	11.84	82.39	11.93	80.83

The strength activity indices (SAIs) of the cement-drilling cuttings blended, concrete are presented in Table 4. and it shows that at 7-day all the drill cuttings replacement levels (contents) blended-cement concrete met the minimum SAI permissible limit (75%), but at 28-day curing age, none of the replacement levels (content) met the minimum recommended by (ASTM, 1999) but still can be suggested to have the pozzolanic properties since it met the minimum SAI permissible limit of 75% at 7-day curing age. This agrees with the works of Okparanma et al (2020) and Salau, et al (2012).

As the development of calcium-silicate-hydrate (C-S-H) gel is a phase responsible for strength gaining, it is likely that with suitable substitution of cement with drill cuttings, formation of this phase is initially inhibited and then allowed to develop at a later age resulting in the strength increase with age.

Concrete grades or strength classes denote the compressive strength of concrete which is taken as the 28 day crushing strength of concrete cubes (BS EN 2004). The compressive strength of the blended cement concrete at 28 day curing at a replacement levels of 0, 5, 7.5, 10, 12.5 and 15% as shown in Table 4. were produced at a mix ratio of 1:2:4 (binder: sand: gravel) at water-binder ratio of 0.60:1. The compressive strength result shows that only the replacement levels at 5 and 15% of the blended concrete met the minimum compressive strength of C/10 concrete grade which can be used for plain concrete construction works (Mosley et al, 2007) and also agrees with the works of Adewole et al (2015)

3.5 Water Absorption Ratio.

The comprehensive Table of the water absorption ratio (WAR) over various curing periods (7, 14, 28, 60, and 90 days) is shown in Table 5. This involves the weights of the material in dry and wet states.

Table 5 Water Absorption Ratio of the Blended-Cement Concrete Mix at 7-90 Day Curing Time at Different Replacement Levels.

Sample%/Days	7	14	28	60	90
0	1.18	3.37	2.38	4.71	2.41
5	2.38	3.57	6.41	5.41	2.44
7.5	6.41	4.71	1.19	6.02	2.33
10	3.61	3.53	3.66	6.98	1.23
12.5	4.71	4.19	3.66	7.41	1.78
15	5.62	2.50	5.81	8.99	2.33

It is very helpful in understanding how various replacement levels and curing times affect the material's durability, particularly in construction where water absorption can affect how long concrete structures last. As shown in Table 5: The water absorption ratio (WAR) data from the Table 5 presents a clear pattern of how replacement levels (RL) and curing time impact the material's water absorption over time.

At 7 days, the WAR values range between 1.18 and 5.62, and a distinct trend of increasing WAR with higher replacement levels is noted. This suggests that the incorporation of replacement materials (such as supplementary cementitious materials) increases the porosity or the material's capacity to absorb water at early stages of curing. The higher WAR values at higher replacement levels may reflect the ongoing hydration process, as the added materials have yet to fully contribute to reducing porosity. By 14 days, the WAR values are in a similar range (2.50 to 4.19), with only slight changes from the 7-day data. This relative stability implies that the curing process during this period does not significantly alter the material's capacity for water absorption, though slight increases could be due to continued hydration that influences the pore structure. At 28 days, the WAR values show a slightly expanded range (1.19 to 5.81), continuing the pattern of higher WAR with higher replacement levels. This suggests that while hydration progresses, the increase in WAR persists, likely because the pores formed by the replacement materials are still not fully sealed. The 60-day results (WAR values 4.71 to 8.99) show a noticeable rise, especially at higher replacement levels, indicating that the longer curing time has allowed for more pronounced effects of the replacement materials on water absorption. However, at 90 days, WAR values significantly drop to between 1.78 and 2.44. This decline suggests that the hydration process is leading to pore refinement, reducing permeability as voids are filled over time, thus lowering the material's water absorption capacity.

4 Conclusions

The treatment of drill cuttings at 5000°C for 180 minutes successfully produced a material with a combined silica, alumina, and ferrite content of 70.1%, which meets the required threshold for pozzolanic properties. This indicates that the treated drill cuttings can be effectively utilized in concrete production.

At a concrete mix ratio of 1:2:4 with a water-binder ratio of 0.60:1, the treated drill cuttings can be incorporated as a cement replacement in plain concrete construction. The addition of 5% and 15% treated drill cuttings as a replacement for cement did not negatively affect the compressive strength of the concrete at 28 days of curing, making it suitable for producing concrete with a class rating of C/10. Furthermore, the strength activity index at these replacement levels exceeded 75%, indicating that the treated drill cuttings exhibit good pozzolanic activity and contribute positively to the concrete's performance.

The observed increase in the water absorption ratio (WAR) with rising replacement levels suggests that higher amounts of treated drill cuttings may increase the porosity of the concrete, leading to greater water absorption. This trend is consistent with the usual behavior of materials containing pozzolanic properties. However, this shows a significant decrease in WAR after a 90-day curing period, indicating that further chemical changes in the material occur over time, leading to reduced porosity. Thus, curing for 90 days appears to be an optimal period for achieving lower water absorption and enhanced durability in concrete mixes containing treated drill cuttings.

In summary, using treated drill cuttings as a cement replacement in concrete is feasible, and extended curing times can further enhance the material's performance, particularly in terms of water absorption and durability.

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