COMPRESSIVE STRENGTH AND LEACHABILITY EFFECTS OF TREATED DRILL CUTTINGS AS A PARTIAL REPLACEMENT OF CEMENT IN CONCRETE PRODUCTION

Maxwell Chikwue¹, Reuben Okparanma², Josiah Ayotamuno², Nnaemeka Nwakuba*¹

¹Department of Agricultural and Biosystems Engineering, School of Engineering & Engineering Technology, Federal University of Technology, Owerri, Nigeria.
²Department of Agricultural and Environmental Engineering, Rivers State University, Port Harcourt, Nigeria.

Abstract: This study examines the compressive strengths and leachability effects of treated drill cuttings as a partial replacement of cement in concrete production. Workability tests on various water-binder ratios (w/b) on the fresh concrete showed that an optimum w/b of 0.5 was adequate for the concrete to be workable. Replacement levels of 0, 5, 10, 15, 20, and 25% were used to produce cement-drill cuttings concrete at a 1:1.5:3 mix ratio.

The blended concrete gave a compressive strength in the range of 26.20 N/mm² for 5% to 22.46 N/mm² for 20% replacement levels at 28 days curing time, more than the minimum compressive strength of 20 N/mm² and 25 N/mm² specified for concrete strength class C/20 and C/25, respectively. The strength activity index of 90.56, 98.76, 89.05, 98.05, and 77.64% for 5, 10, 15, and 20% replacement levels at 28 days of curing time was obtained surpassing the minimum 75% specified for normal concrete by the code.

The wet/dry durability effects of the blended concrete at any replacement level passed the structural integrity with less than 5% of the structural integrity of the material lost. The chloride and total polycyclic aromatic hydrocarbons (TPAHs) leachability effects both met the DPRs target values for reusable materials.

*Corresponding Author. E-mail: nnaemeka.nwakuba@futo.edu.ng; ORCID: https://orcid.org/0000-0003-4356-8184
The study has shown that drill cuttings have a good pozzolanic effect on concrete, especially when activated at the temperature of 500°C for 180 minutes. It also shows that treated drill cuttings could replace cement up to 20% by weight to produce concrete of adequate strength using a w/b ratio of 0.5 and mix ratios of 1:1.5:3. The study has also shown that treated drill cuttings replaced with cement to produce concrete which is durable to both wet/dry and leaching effects of chlorides and TPAHs to the environment.

**Keywords**: Waste, leaching, particle size, curing, fineness modulus.

**INTRODUCTION**

The process of drilling oil and gas wells generates two types of waste – drilling fluids and drill cuttings. Drilling wastes are the second largest volume of waste, behind produced water, generated by the exploration and production industry [1]. American production industry (API) estimated that in 1995 about 150 million barrels of drilling waste was generated from Onshore wells in the United States alone [2]. A certain quantity of drilled cuttings cannot be avoided during drilling operations due to several factors such as insufficient setting time, inefficient mechanical separation equipment, the type of formation being drilled and the type of drilling fluid being used. The inability to remove all the drilled solids (cutting) from the fluid system makes them be considered as a continual contaminant of the fluid system.

The quantity of cuttings or drilled solids removes from the hole during operation is tremendous, and often as much as 100,000b/day of cuttings must be carried by mud [3]. Also, Al-Ansary and Al-tabbies [4] reported that about 50,000 - 80,000 tonnes of the wet-weight of oily drill cuttings are produced annually on the UK continental shelf. These drilled cuttings that consist of rock and low-yielding clays incorporated into the mud during drilling are one of the sources of solids in the mud, apart from commercial solids added to the mud and chemically precipitated solids.

Drill cuttings carried by mud (drilling fluid) are usually retrieved at the surface of the platform where they go through some separations from the drilling fluid, this process allows the circulating fluid to re-enter the drilling process. In this case, it would be worth finding ways and means of processing the drill cuttings (a waste) into a useful product and in that case, providing a solution to an environmental problem at the same time.

The oil-based drill cuttings being used as a partial substitute for cement in concrete production were treated by a thermal desorption unit at a temperature of 500°C in 3 hours [5] which is one of the methods of removing oil from the cuttings to reduce the leachability of other contaminants.

These thermally desorbed oil-based drill cuttings can be recycled for use as a major constituent of mixes for making substantially monolithic specialized civil engineering concrete structures of large sites such as roads and drilling pads [1].

This study investigated the compressive strengths and leachability effects of treated drill cuttings as a partial replacement of cement in concrete production. The results showed that the blended concrete can be used to produce concrete class C20 and C25, respectively without any adverse environmental effects.
MATERIAL AND METHODS

The following materials were used in the production of blended concretes:

i. Portland limestone cement 42.5R grade.

ii. Fine aggregate of natural sand obtained from Choba River of maximum nominal size of 3.18mm.

iii. Coarse aggregate gravel obtained from a quarry site at Okigwe, Imo State of a maximum nominal size of 19mm.

iv. Thermally treated oil-based drill cuttings of the nominal size of < 63μm.

v. Potable tap water available in the civil engineering laboratory was used for mixing and curing the concrete.

Preparation of drill cuttings

The oil-based drill cuttings were collected from a waste treatment facility at Onne, Rivers State at a pre-treated temperature and time of 400°C and 90 minutes. To prepare the oil-based drill cuttings as a pozzolanic material, it was treated at an optimum temperature and time of 500°C and 3 hours and ground for 1 hour and then allowed to pass through a 63μm sieve [5]. These treated oil-based drill cuttings were used as a partial substitute for cement at percentage replacement levels 5, 10, 15, 20, and 25% in the production of concrete.

Aggregate characterization

To determine the suitability of the fine and coarse aggregates (sand and gravel) for concrete production, sieve analysis was conducted on the aggregates. The particle size distribution curves for the aggregates were plotted and their corresponding grading properties: nominal size, fineness modulus, coefficient of curvature (C_c), and coefficient of uniformity (C_u) were determined. The characterization of the aggregates was conducted by the standard procedure (BS 1377 parts 1 and 2).

Particles size distribution of aggregates

A set of sieves was arranged beginning (top) with one which was the largest aperture and ending with the pan. The stacked sieves were shaken for about 5 to 10 minutes with a mechanical shaker, and then each set of sieves was weighed. Mass retained, percentage retained and percentage passing was calculated. The percentage passing versus sieve diameter was plotted and relevant parameters such as effective size, uniformity coefficient C_u and coefficient of curvature C_c were calculated.

\[
C_u = \frac{D_{60}}{D_{10}} 
\]

\[
C_c = \frac{D_{30}^2}{D_{10}D_{60}} 
\]

D_60 is the diameter of 30% passing,
D_10 is the diameter at 10% passing,
D_60 is the diameter at 60% passing.
Fineness modulus of samples

The fineness modulus is a single figure which expressed the grading of an aggregate or material. When the sieve analysis is carried out, the fineness modulus is then obtained by adding up all percentages of samples retained on the BS test sieves and dividing the sum by 100.

\[
\text{Fineness Modulus (FM)} = \frac{\text{Cumulative Percentage Retained}}{100}
\]

Concrete mix proportioning

The mix ratio of 1:1.5:3 was used for the study and the water-cement ratio of 0.5. 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.

Weight of cement = Unit weight of concrete x volume of cement.
Weight of sand = Unit weight of concrete x volume of sand.
Weight of gravel = Unit weight of concrete x volume of gravel.
Weight of water = Water – Cement ratio x weight of cement.

<table>
<thead>
<tr>
<th>Constituent Material</th>
<th>0% DC</th>
<th>5% DC</th>
<th>10% DC</th>
<th>15% DC</th>
<th>20% DC</th>
<th>25% DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement, kg</td>
<td>1.5</td>
<td>1.45</td>
<td>1.35</td>
<td>1.275</td>
<td>1.2</td>
<td>1.125</td>
</tr>
<tr>
<td>Drill cutting, kg</td>
<td>0.0</td>
<td>0.075</td>
<td>0.15</td>
<td>0.225</td>
<td>0.3</td>
<td>0.375</td>
</tr>
<tr>
<td>Sand, kg</td>
<td>2.25</td>
<td>2.25</td>
<td>2.25</td>
<td>2.25</td>
<td>2.25</td>
<td>2.25</td>
</tr>
<tr>
<td>Gravel, kg</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>W/C ratio</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Total water, kg</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Workability of cement – drill cuttings concrete

The concrete investigated was of mix ratio 1:1.5:3 (binder: sand: gravel) with varied water-binder ratios of 0.40:1, 0.45:1, 0.5:1, 0.55:1, 0.60:1, 0.65:1, and 0.70:1. To determine the optimum water-binder ratio that could produce workable blended concrete, slump test was conducted in accordance with BS 1881(102).

Compressive strengths of the cement – drill cuttings concrete

The test was carried out according to BS 1881:116 method. The concrete cubes of sizes 150 x 150x 150mm were prepared using the predetermined optimum water-binder ratio (w/b), with different percentages of drill cutting as a substitute for cement. Three cubes for each concrete mix were cast and cured for 7,28,56,90 and 120 days before crushing. The compression testing machine plunger was set under a CBR ring capacity of 50kN and the were samples crushed at a uniform rate of 1mm/min. The readings of the maximum force required to shear the samples were recorded.
Strength activity index (SAI)

The strength activity index (SAI) is a measure of the pozzolanic of supplementary cementation 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 days and/or 28 days must not be less than 75% of the strength of normal concrete [6].

Wet/Dry durability test of the cement-drill cuttings concrete

This test was to evaluate the resistance of the cement drill cuttings concrete material to the natural weathering stresses of repeated wetting and drying cycles. The test was performed in accordance with ASTM D-4843 methods. The cured (28 days) test samples were subjected to ten test cycles. Each cycle consisted of a period of five hours submerged under water and 42 hours in an oven under low drying conditions (71°C). The change in volume, moisture content and weight loss were determined after each cycle. After the ten cycles, the total sample weight loss was determined.

Toxicity characteristics/leaching procedure test (TCLP) of the cement-drill cuttings concrete

The solidified matrix of the concrete was crushed to a particle size of proximately 1mm in diameter, and 5g of the crushed/ground samples were homogenized in reagent water. The pH of the medium was determined using a digital pH meter (HANNA Model pH-211) and the obtained value was used to select the extraction fluid for the leachate extraction. The crushed samples (100g) were then extracted for 18 hours at 30rpm at 22°C with the extraction fluid. After the agitation period, the mixtures were filtered and the filtrate was taken as the TCLP extract which was used to determine the chlorides and total polycyclic aromatic hydrocarbons (TPAHS) leachates from all the replacement levels of the cement-drill cuttings concrete produced. The chlorides and the TPAHs TCLP extracts were tested according to APHA 2520B and APHA 6440C, respectively.
Plate 2. Demolded cubes ready for curing

Plate 3. Blended concrete in curing tank

Plate 4. Blended concretes at different replacement levels after curing ready for crushing

Plate 5. Weighing of the concrete before crushing

Plate 6. Crushing the concrete for compressive strength measurement
RESULTS AND DISCUSSION

Aggregates characterization

For the gradation characteristics of the aggregates, the results of the sieve analysis are presented as the particle-size distribution curves as shown in Table 2 and Figure 1. It was observed that both the sand and gravel distribution curves were within the region classified as sand (fine aggregate) and gravel (coarse aggregate), respectively.

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

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>% Passing</th>
<th>% Retained</th>
<th>Sieve size (mm)</th>
<th>% Passing</th>
<th>% Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00</td>
<td>99.4</td>
<td>0.6</td>
<td>22.4</td>
<td>85.64</td>
<td>14.36</td>
</tr>
<tr>
<td>1.40</td>
<td>98.8</td>
<td>1.2</td>
<td>16</td>
<td>48.60</td>
<td>51.4</td>
</tr>
<tr>
<td>0.710</td>
<td>91.5</td>
<td>8.5</td>
<td>13.2</td>
<td>34.81</td>
<td>65.19</td>
</tr>
<tr>
<td>0.500</td>
<td>74.8</td>
<td>25.2</td>
<td>9.5</td>
<td>10.09</td>
<td>89.91</td>
</tr>
<tr>
<td>0.355</td>
<td>43.5</td>
<td>56.5</td>
<td>4.75</td>
<td>0.58</td>
<td>99.42</td>
</tr>
<tr>
<td>0.250</td>
<td>13.1</td>
<td>86.9</td>
<td>0.180</td>
<td>5.2</td>
<td>94.8</td>
</tr>
<tr>
<td>0.125</td>
<td>2.9</td>
<td>97.1</td>
<td>0.075</td>
<td>1.1</td>
<td>98.9</td>
</tr>
</tbody>
</table>

Figure 1. Particle size distribution curves of the sand and gravel.

Also, more than 90 per cent of the gravel was retained above the 4.75mm sieve size, the upper bound for aggregate to be categorized as fine aggregate, while more than 95% of the sand passes 2.00mm and more than 98% retained on 0.075mm sieve size. Hence, both the sand and the gravel are within the specified requirements for fine and coarse aggregates in concrete production (BS 1377). The uniformity coefficient $C_u$ and coefficient of curvature $C_c$ 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 C125).
Workability of cement-drill cuttings concrete

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

Table 3. Effect of water-binder ratio (w:b) on the slump of the blended cement-drill cuttings concrete.

<table>
<thead>
<tr>
<th>Drill Cuttings Content (%)</th>
<th>Slump Value (mm)</th>
<th>Water-binder ratio (w/b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.40</td>
</tr>
<tr>
<td>0</td>
<td>73</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>60</td>
<td>160</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>25</td>
<td>15</td>
<td>40</td>
</tr>
</tbody>
</table>

The results show that for all mixes apart from w:b of 0.70:1, for normal, 5, 20 and 25% drill cutting, w:b of 0.65:1 for 10% drill cuttings and also w:b of 0.60:1 for 15% drill cuttings concretes that have collapse slump all other mixes were of a true slump. However, concrete mixes containing 0% and 5% drill cuttings at 0.4:1 water-binder (w:b) ratio were viscous and stiff due to inadequacy of water, and so could not have slump value. As the w:b ratio increases from 0.40:1 to 0.70:1 at an interval of 0.05, the slump increases accordingly for an equal percentage of drill cuttings replacement in the mix. For example, at 10% drill cuttings, the slump increases from 20mm to 190mm. However, at 5, 10, and 15% drill cuttings replacements, the slump increased with an increase in the number of drill cuttings for the same water-binder ratio. This trend indicates that less water is required to maintain the same consistency as the drill cuttings content increases up to 15%, but more water is required to maintain the same consistency as the drill cuttings content increases from 20 to 25% replacement.

Figure 2. Effect of w/b ratio on the slump of blended cement-drill cuttings concrete
Also, at a water-binder ratio of 0.4:1 with 10%, 15%, 20% and 25% drill cuttings content, the slump values were 20, 30, 5 and 15mm respectively and the slumps were of true slumps. But at 0% and 5%, the mix becomes harsh with zero slumps at 0.40:1 of w:b. The results show that drill cuttings at 5%, 20% and 25% replacements appear to absorb more water than Portland limestone cement in the mix while 10% and 15% drill cuttings absorb less water than the Portland limestone cement. Water-binder ratios from 0.45:1 to 0.55:1 were adequate to produce a workable mix with a true slump for all the replacement levels of drill cuttings used for the mixes, while at w:b of 0.60:1 at 15% drill cuttings, 10% drill cuttings at 0.65:1 w:b and 0, 20, and 25% drill cuttings at 0.7:1 w:b the slump values were more than 200mm with collapse slumps.

Slump test is sensitive to change in consistency corresponding to slumps between 10 and 200mm and the test is not considered suitable beyond these extremes. Also, a mix having a slump between 60-130mm is considered to be plastic and required either mechanical or hand compaction [7]. This behavior suggests that 0.45:1, 0.55:1 water-binder ratio (w:b) could be considered. To avoid being on the lower extreme of 10mm (slump value for 20% drill cutting at 0.45:1 water-binder ratio) and on the higher extreme of 200mm (slump value for 15% drill cuttings at 0.50:1 water-binder ratio), the water-binder ratio of 0.50:1 should be considered appropriate, water binder ratio above 0.55:1 could lead to segregation and excessive bleeding of concrete in which water or water-rich cement rises to the surface of the concrete to produce a weak surface layer or be trapped under the aggregate particles [8].

**Compressive strengths of drill cuttings-cement blended 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 Portland limestone cement. Figure 3, shows the compressive strengths of blended drill cutting samples containing different percentages of drill cuttings after 7, 28, 56, 90, and 120 days of curing.

![Figure 3. Compressive strength of concrete samples containing different percentages of drill cuttings after 7, 28, 56, 90, and 120 days of curing.](image-url)
When compared to the control sample (0%) replacement, the compressive strength of cement–drill cutting concrete increased as the curing age increased irrespective of the content of the drill cuttings replaced in the samples. At the early age of 28 days of the concretes the compressive strength decreased as drill cuttings content increased. For normal concrete 0% drill cuttings, the compressive strength at 28 days is 28.93N/mm² while that of 5,10,15,20 and 25% are 26.20, 28.57, 25.77, 22.46 and 19.15N/mm² respectively, representing a decrease of 9.44, 11.24, 10.92, 22.36 and 33.81% respectively. But at a later curing age of 56, 90 and 120 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 strengths are below that of normal concrete at 120 days. At 120 days, normal concrete has a strength of 40.23N/mm² about 28.09% higher than 28 days strength. Similar findings were reported by [9, 10] for cement–drill cuttings concrete at replacement levels of 5, 20 and 35%.

The increase in strength was also observed in blended concretes at 120 days of curing with 5,10,15,20 and 25% replacement levels, with compressive strengths of 35.33, 37.23, 33.96, 28.27 and 22.58N/mm² at increases of 25.84, 23.26, 24.12, 20.55 and 15.19% respectively. This strength increase of cement-drill cuttings blended concrete indicates that the treated drill cuttings have the potential to contribute to late strength gain. This characteristic suggests that the treated drill cuttings possess pozzolanic properties. The results are comparable to the works of [11] and [14].

**Strength activity index (SAI)**

The strength activity indices (SAIs) of the cement drill cuttings blended concrete are presented in Table 4. At 7 days, all the drill cuttings replacement levels (contents) blended-cement concrete met the minimum SAI permissible limit (75%), but at 28 days of curing age, the SAIs for 5,10,15 and 20% are 90.56, 98.76, 89.08 and 77.64% respectively, which is greater than the minimum recommended by (ASTM, 1999) thus suggesting pozzolanic activity occurring during this period. As the level 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 strength increase with age.

<table>
<thead>
<tr>
<th>Drill cuttings contents (%)</th>
<th>7</th>
<th>28</th>
<th>56</th>
<th>90</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
<td>SAI</td>
<td>CS</td>
<td>SAI</td>
<td>CS</td>
</tr>
<tr>
<td>0</td>
<td>22.00</td>
<td>100</td>
<td>28.93</td>
<td>100</td>
<td>29.41</td>
</tr>
<tr>
<td>5</td>
<td>21.38</td>
<td>97.18</td>
<td>26.20</td>
<td>90.56</td>
<td>32.62</td>
</tr>
<tr>
<td>10</td>
<td>25.47</td>
<td>115.77</td>
<td>28.57</td>
<td>98.76</td>
<td>32.69</td>
</tr>
<tr>
<td>15</td>
<td>24.40</td>
<td>110.91</td>
<td>25.77</td>
<td>89.08</td>
<td>27.60</td>
</tr>
<tr>
<td>20</td>
<td>21.16</td>
<td>96.18</td>
<td>22.46</td>
<td>77.64</td>
<td>24.20</td>
</tr>
<tr>
<td>25</td>
<td>17.91</td>
<td>81.41</td>
<td>19.15</td>
<td>66.19</td>
<td>20.8</td>
</tr>
</tbody>
</table>

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 of the blended cement concrete at 28 days of curing at replacement levels of 0, 5, 10, 15, 20 and 25% as shown in Table 3 were produced at a mix ratio of 1:1.5:3 (binder: sand: gravel) at a water-binder ratio of 0.5:1.

The compressive strength results shows that all the blended concretes met the minimum compressive strength of C/20 concrete grade which can be used for plain concrete construction works [15]. Also, the compressive strength results from Table 3 at the same mix ratio and the water-binder ratio at cement drill cutting concrete replacement levels of 5, 10 and 15% only, met the minimum compressive strength C/25 concrete grade which can be used for construction of reinforced load-bearing building structural members such as columns, beams and slabs in mild exposure condition [15].

**Wet/dry durability effects on the blended cement-drill cuttings concrete**

The wet/dry durability was used to evaluate the ability of both plain concrete (0% drill cuttings), with blended cement-drill cuttings concrete at replacement levels of 5, 10, 15, 20, and 25% at 1:1.5:3 mix design and 0.5:1 water-binder ratio to resist weathering by the natural environment after 28 days curing, it entails simulation of the harsh environment and subject the concretes to those conditions. The results in Table 4 show that the wet and dry durability effect of all the concrete ranged between 99.79 – 99.83%.

<table>
<thead>
<tr>
<th>S/No.</th>
<th>Replacement levels (%)</th>
<th>Mean moisture content (%)</th>
<th>Wet and Dry durability effect (%)</th>
<th>Standard ≤ 5% DPR, 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.17</td>
<td>99.83</td>
<td>0.17</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>0.17</td>
<td>99.83</td>
<td>0.17</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>0.17</td>
<td>99.83</td>
<td>0.17</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>0.17</td>
<td>99.83</td>
<td>0.17</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>0.18</td>
<td>99.82</td>
<td>0.18</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>0.21</td>
<td>99.79</td>
<td>0.21</td>
</tr>
</tbody>
</table>

The least wet and dry durability effect was observed for the blended concrete at a 25% replacement level. It is worthy of note that all the concrete samples favorably satisfied the stipulated 10 dipping cycle criteria, with less than 5% of material lost, thus passing the stipulated standard (DPR, 2002). This also agreed with the works of [16], [17] which showed a concrete durability factor of 98.3% (1.7%) after 10 cycles of wet and dry conditions.

**Leachability effects on the blended cement-drill cuttings concrete**

The toxicity characteristics leaching procedures test was used to access the leaching effects of the blended cement-drill cuttings concretes at different replacement levels of 5, 10, 15, 20 and 25% at 1:1.5:3 mix design and 0.5:1 water-binder ratio after 28 days of curing. This is necessary since high concentrations of chlorides and total polycyclic aromatic hydrocarbons if released into the environment as a result of leaching from any material can pose a great danger to human and animal lives and an early deterioration of
structures and monuments, so the leachability test results of chlorides from Table 5 shows that all the replacement levels met the DPR’s intervention value of 5000mg/l for reusable materials.

Table 5. Toxicity characteristics leaching procedure test for blended concrete for different replacement levels at 28 days curing time.

<table>
<thead>
<tr>
<th>S/N.</th>
<th>Replacement levels (%)</th>
<th>Chloride (mg/l)</th>
<th>TPAHs (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>60</td>
<td>0.033</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>30</td>
<td>0.125</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>120</td>
<td>0.077</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>140</td>
<td>0.064</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>90</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Also, the leachability test results of total polycyclic aromatic hydrocarbons (TPAHs) from Table 5 show that all the replacement levels met the DPR’s target value of 1mg/l and intervention value of 40mg/l for reusable materials. Also, previous works of [1], [16], [18] – [22] have shown that blended-cement concretes with pozzolanic materials (treated drill cuttings) are particularly effective for stabilization.

CONCLUSIONS

Drill cuttings when treated at a heating temperature and time of 500°C and 3 hours at a concrete mix ratio of 1:1.5: at 0.5:1 water-binder ratio can be used in plain concrete construction i.e., concrete class C/20 at replacement levels of 5, 10, 15, 20 and 25%. Also, the drill cuttings at the same treatment levels at the same concrete mix ratio and water-binder ratio can be used in constructing reinforced load-bearing building structural members (beams, slabs and columns). i.e., concrete class C/25 at replacement levels of 5, 10 and 15%.

Both the drill cuttings-cement concrete class C/20 and C/25 produced from the heated temperature and time have a strength activity index greater than 75% as stipulated by (ASTM, 1999). The wet and dry durability effects of the drill cuttings-cement concrete class C/20 and C/25 produced for all the replacement levels (5-25%) passed the wet and dry durability effects with less than 5 per cent of the blended concrete matrix lost, after exposure to harsh environmental condition. Also, these blended concrete classes at different replacement levels (5-25%) at 28 days of curing, passed the toxicity characteristics leaching effects of both the chloride and total polycyclic aromatic hydrocarbons (TPAHs) target values for reusable materials, thus the treated drill cuttings can be said in compliance with environmental guidelines on chlorides and TPAHs for sustainable reuse as construction materials.

REFERENCES

IZDRŽLJIVOST NA PRITISAK I UTICAJ NA PROPUSTLJIVOST TRETIRANIH OTVORA BUŠOTINA KOD DELIMIČNE ZAMENE CEMENTA U PROIZVODNJI BETONA

Maxwell Chikwue¹, Reuben Okparanma², Josiah Ayotamuno², Nnaemeka Nwakuba¹

¹Department of Agricultural and Biosystems Engineering, School of Engineering & Engineering Technology, Federal University of Technology, Owerri, Nigeria.
²Department of Agricultural and Environmental Engineering, Rivers State University, Port Harcourt, Nigeria.

Sadržaj: U ovoj studiji ispitane su vrednosti sila na pritisak i efekat curenja (propustljivosti) tretiranih otvora (bušotina) kod delimične zamene cementa u proizvodnji betona. Test ispitivanja obradivosti na različitim odnosima veziva vode (w/b) na svežem betonu su pokazala da je optimalna vrednost w/b=0,5 bila adekvatna da beton bude obradiv. Nivoi zamene od 0, 5, 10, 15, 20 i 25% su korišćeni za proizvodnju betona u mešavini 1:1 i 5:3. Mešani beton je dao vrednosti otpora na pritisak u opsegu od 26,20 N/mm² za 5% do 22,46 N/mm² za 20% nivoa zamene cementa tokom vremena očvršćavanja od 28 dana, više od minimalne vrednosti otpora na pritisak vrednosti od 20N/mm² i 25N/mm² specificirane za klase čvrstoće betona C20 i C25, respektivno.

Indeks aktivnosti čvrstoće od 90,56; 98,76; 89,05; 98,05 i 77,64% za nivoe zamene od 5, 10, 15 i 20% na 28 dana vremena očvršćavanja dobijen je premašujući minimalnih 75% propisanih standardom za normalan beton.

Efekti izdržljivosti mešanog betona na mokro/suvo na bilo kom nivou zamene prevazišli su strukturalni integritet sa manje od 5% izgubljenog strukturalnog integriteta materijala.

Efekti uticaja hlorida i ukupnih policikličnih aromatičnih ugljovodonika (TPAHs) su ispunili ciljne vrednosti DPR za materijale za višekratnu upotrebu.

Studija je pokazala da bušotine imaju dobar pucolanski efekat na beton, posebno kada se aktiviraju na temperaturi od 500°C u trajanju od 180 minuta.

Takođe ispitivanje pokazuje da se u obrađenoj bušotini može zameniti cement do 20% po težini da bi se proizveo beton adekvatne čvrstoće koristeći odnos veziva vode (w/b) od 0,5 i odnos mešanja od 1:1 i 5:3.
Istraživanje/studija takođe pokazuje da su obradjeni otvori bušotina kod zameni sa cementom, stvorili beton otporan na suve i vlažne efekte propuštanja hlorida i TPAH jedinjenja u životnu sredinu.

**Ključne reči:** Otpad, ispiranje, veličina čestica, očvršćavanje, modul finoće.

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