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EFFECT OF ACID ON STRENGTH OF CONCRETE MADE WITH COCONUT SHELL AS AGGREGATE REPLACEMENT

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ABSTRACT
This paper presents the results of experimental investigation carried out to study the effect of acidic environment on concrete made with coconut shell (CS) as a partial aggregate replacement, in which the natural coarse aggregates were replaced with 0%, 10%, 20% and 30% CSby volume. To study the performance of CS concrete in acidic environment, compressive strength test at 28 days before immersion in acid, weight loss assessment after immersion in acids at interval of 3 days and compressive strength loss assessment after immersion in 3% hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) mediums for 27 days were carried out. The results indicated that Coconut shells maybe viable for use as apartial replacement to aggregate in concrete. But when subjected to strength tests after immersion in both HCl and H_2SO_4 acidic environment they did not perform well, as theircompressive strength and weight decreased with increase in CS replacements. The losses are higher in the H_2SO_4 medium than in HCl medium. The use of coconut shells in concrete should be avoided in aggressive environments.
Keywords: *Coconut shell;coarse aggregate; acid resistance; weight loss; partial replacement.*

INTRODUCTION
Concrete is the leading civil engineering construction material, whose production involves a combination of ingredients like cement, fine aggregates, coarse aggregate, and water. Among all the ingredients, aggregates form the largest part, unfortunately, anoperation associated with aggregate extraction and processing isamajor cause of environmental concerns. The growingdemandfor sustainable development has made researchers to centertheir investigation on the use of waste or recycled materials as a potential construction material (Alengaram *et al.,* 2013). Therefore, there is a growing demand for alternative materials that can be used as coarse aggregates in concrete (Rajeevan and Shamjith, 2015).Various types of waste materials and industrial bye products such as fly ash, bottom ash, recycled aggregate, foundry sand, china clay sand, crumb rubber, glass, coconut shell, palm kennel shell have been investigated for use as a replacement for natural aggregates (Dhir *et al.,* 2004).Using alternative materials asasubstitute for natural aggregates in concrete production makes concrete a sustainable and environmentally friendly construction material.

Various Investigations have been conducted onthepossible use of coconut shell (CS) for partial aggregate replacement in concrete (Prusty and Patro, 2015), (Shraddha *et al.,* 2014), (Rajeevan and Shamjith, 2015), (Kaur and Kaur, 2012). The investigations showed that a potential exists for the use of coconut shells assubtitutes for coarseaggregates in both conventional reinforced concrete and plain cement concrete constructions. Coconuts being naturally available in nature and its shells are non-biodegradable can be used readily inconcrete, which fulfills almost all the qualities of the original form of concrete. However, further research is needed for better understanding of the behavior of coconut shell as aggregate in concreteespecially on durability. The durability of concrete may refer to its ability to resist quality degradation whenexposed to environments that cause deleterious effects on the concrete (Ramli *et al.,* 2013). Therefore the aim of this research is to assess the the durability of concrete containing coconut shell as partial replacement for coarse aggregates in acidic medium.

MATERIALS AND METHODS
Materials
***Cement*:** Ordinary Portland cement produced by Dangotecement company was used in this study.

Fine Aggregates: River sand obtained locallyfrom Wudil, Kano, Nigeria. The fine aggregate was clean and not contaminated by impurities.It was air dried before being used.

Coarse Aggregates: Locally available crushed granite aggregates of nominal size 20 mm were used.

Coconut Shell: The coconut shells used for this research were obtained locally. The coconut shellsweresun-dried for three weeks and crushed manually using a hammer.

Acids: Sulphuric acid (H_2SO_4) and Hydrochloric acid (HCl) used in this study were locally sourced and were not further synthesized.

Mix proportion
In this study, the concrete to achieve a target compressive strength of 25 N/mm^2 at 28 days was designed using the absolute volume mix design method (Neville, 1995). The mix ratio used from the mix design was 1:2:4 for cement, fine and coarse aggregates respectively. The water cement ratio used was 0.5 and the Coarse aggregates were partially replaced with coconut shell by volume (0%, 10%, 20% and 30%) as shown in Table 1.

Table 1: Quantities of materials

Replacement %	Cement (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Coconut shell (kg)	Water (kg)
0	10.93	43.69	21.74	0	5.465
10	10.93	39.32	21.74	1.68	5.465
20	10.93	32.77	21.74	3.36	5.465
30	10.93	21.84	21.74	5.40	5.465

Methods

To ascertain the effects of acids on the performance of CS concrete, the following tests were carried out: Tests on the constituent materials (fine aggregate, coarse aggregate, and coconut shell),which include specific gravity; particle size distribution tests; compressive strength test at 28 days before immersion in acids (hydrochloric acid (HCl) and sulphuric acid (H_2SO_4)); weight loss assessment after immersion in acids (HCl and H_2SO_4) at interval of 3 days for 27 days and compressive strength loss test after immersion in acids for 27 days.

Specific gravity test

The specific gravity test was carried out on the coconut shell, fine and coarse aggregates in accordance with BS 812 (BS812-2:, 1995).

Particle size distribution test

The particle size distribution testgwas carried out on the coconut shell, fine and coarse aggregates in accordance to (BS.EN933-1:, 1997).

Compressive strength test

Compressive strength tests were conducted on concrete containing 0%, 10%, 20% and 30% CS as replacement for coarse aggregates by volume. The tests were performed on concrete cube specimens of size 150 x 150 x 150 mm. These cubes were prepared and cured in water in accordance with (BS1881-111:, 1983) and tested at 28 days in accordance with (BS1881-116:, 1983). Furthermore, density tests were also conducted atthe 28th day.

Weight loss assessment and compressive strength test after immersion in acids

Weight loss assessment and compressive strength test were conducted on concrete containing CS aggregates at 0%, 10%, 20% and 30% proportion by volume. The tests were performed on the concrete cube specimens. These cubes were prepared and cured in water for 28 days, after which three cubes from each mixture were immersed in 3% hydrochloric acid (HCl) and sulphuric acid (H_2SO_4) mediums and another three corresponding cubes were immersed in water. In order to minimize evaporation, these specimens were kept covered throughout the testing period. The weight of each specimen was taken at the interval of 3 days for 27 days duration. At the end of 27 days acid immersion, the specimens were tested for compressive strength.

Acid resistance was then evaluated by determining the weight loss (WL) and compressive strength loss (SL) of the specimens using Equation (1) and (2):

$$WL(\%) = \frac{w_1 - w_2}{w_1}\ x\ 100 \quad (1)$$

Where: w_1 and w_2 are the weights of the specimens (in kilograms) before and after immersion

$$SL(\%) = \frac{f_{c1} - f_{c2}}{f_{c1}}\ x\ 100 \quad (2)$$

Where: f_{c1} represents 28 days compressive strength of control specimens and f_{c2} is the compressive strength of the specimen after exposure to 3.5% (by volume) hydrochloric acid (HCL) and sulphuric acid (H_2SO_4) solutions for 27 days.

RESULTS AND DISCUSSION

Material properties of coconut shell, fine and coarse aggregates

The specific gravity of coconut shell, fine and coarse aggregates were determined and shown in Figure 1. The specific gravity of coconut shell (1.39) is 50.2% lower than that of natural coarse aggregate (2.79) and 48.51% lower than that of fine aggregates (2.70). The result is in conformity with what was reported in some earlier works ((Kamal and Singh, 2015) and (Shraddha *et al.*, 2014)). Figure 2 shows a well distributed particle size for coconut shell, fine and coarse aggregates.

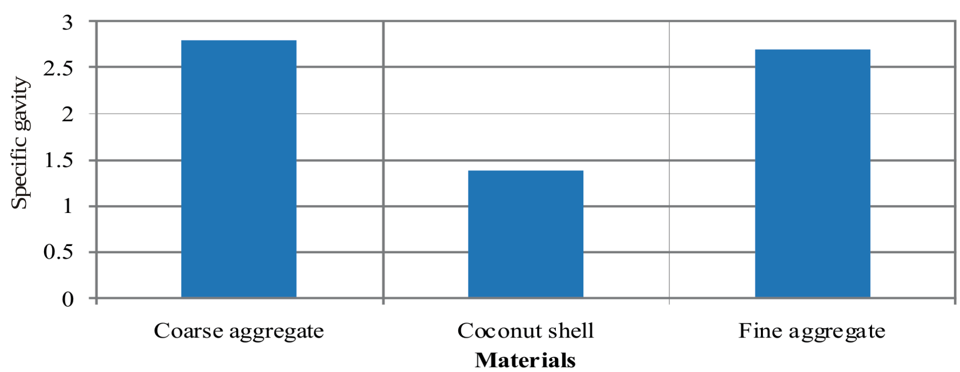

Figure 1: Specific gravity of coconut shell, fine and coarse aggregates

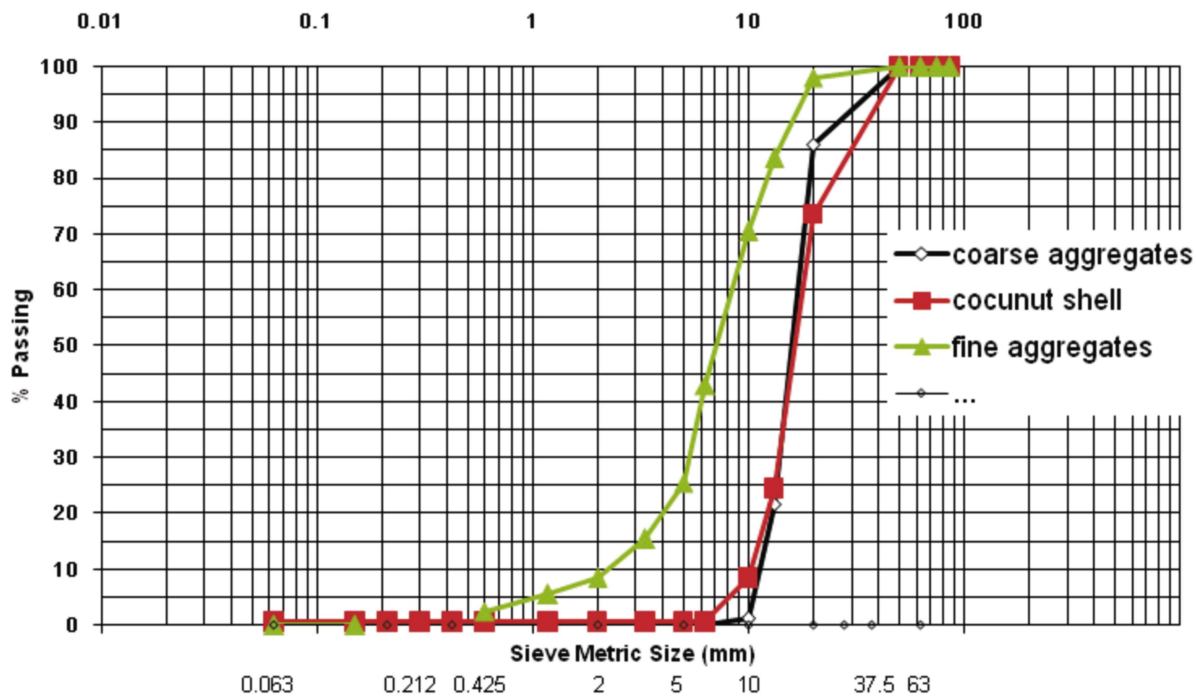

Figure 2: Particle size distributions of coconut shell, fine and coarse aggregates

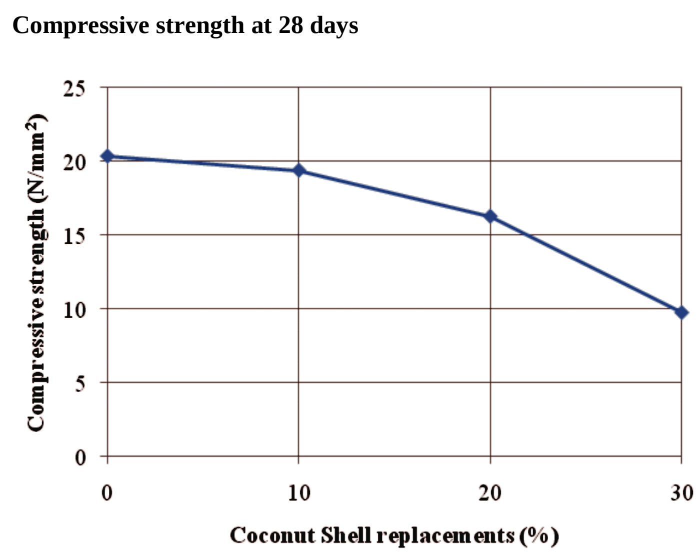

Figure 3: Coconut shell concrete compressive strength at 28 days

Figure 3 shows the result of the compressive strength of concrete partially replaced with coconut shell as aggregates at 28 days before immersion in acids. From the result, there was a 4.7% decrease in compressive strength between 0% CS replacement (20.37 N/mm^2) and 10% CS replacements (19.41 N/mm^2). The decrease continued, with 20% CS replacement (16.3 N/mm^2) having 19.9% decrease and 30% CS replacements (9.78 N/mm^2) having 52% decrease. Generally, the compressive strength decreases with increase in percentage replacement of coconut shell as aggregates. This is in agreement with earlier studies ((Shraddha *et al.*, 2014), (Kamal and Singh, 2015), (Kambli and Sandhya, 2014) and (Osei, 2013)) sand is attributed to the weaker bond between CS and cement mortar, The bond between mortar and CS is weaker than that of natural aggregates.

Figure 4 shows the variation of concrete cubes density with varying CS replacement. There isadecrease in density as the CS replacementincreases; this can be attributed to the lower specific gravity of the CS.

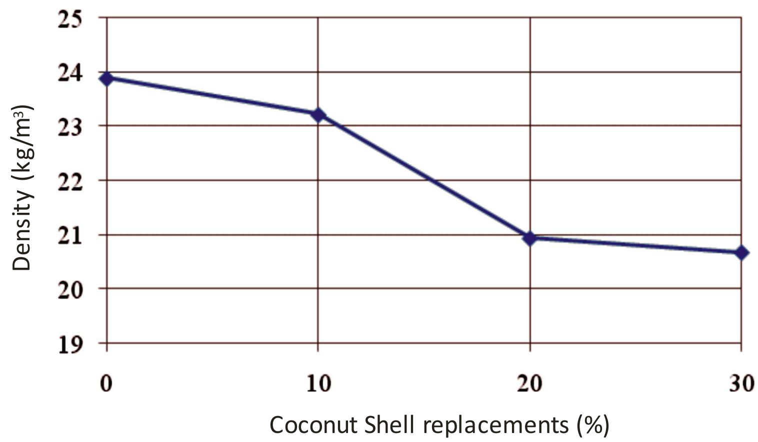

Figure 4: Coconut shell concrete cube density at 28 days weight loss

The behavior of concrete whose aggregates were partially replaced withcoconut shell in acids was investigated. The weight of the specimens when immersed in 3% HCl and 3% H_2SO_4 acid for 27 days were determined and the resultsare shown in Tables 2 and 3. Deteriorations were observed due to leaching of both hydrated and anhydrate cement compounds as well as calcareous soluble calcium compounds. It was also observed that sulfuric acid has more deteriorating effect on all the cubes than hydrochloric acid.

Table 2: Results of weights (kg) for concrete cubes immersed in HCl for 27 days

		Average masses of concrete cubes (kg)			
S/No.	**Days**	**0% coconut shell**	**10% coconut shell**	**20% coconut shell**	**30% coconut shell**
1	0	8.22	7.988	7.46	7.34
2	3	8.155	7.79	7.39	7.318
3	6	8.05	7.67	7.3	7.225
4	12	8.043	7.5	7.24	7.142
5	15	8	7.41	7.17	7.079
6	18	7.95	7.39	7.14	7.073
7	21	7.9	7.34	7.12	7.052
8	24	7.89	7.32	7.1	7.042
9	27	7.89	7.31	7.081	7.031

Table 3: Results of weights (kg) for concrete cubes immersed in H_2SO_4 for 27 days

		Average masses of concrete cubes (kg)			
s/n	Days	0% coconut shell	10% coconut shell	20% coconut shell	30% coconut shell
1	0	8.22	7.988	7.46	7.34
2	3	8.12	7.83	7.41	7.19
3	6	7.77	7.6	7.21	7.12
4	12	7.57	7.4	6.99	6.89
5	15	7.45	7.25	6.76	6.6
6	18	7.26	7.16	6.58	6.33
7	21	7.17	7	6.39	6.25
8	24	7.11	6.87	6.34	6.2
9	27	7.09	6.85	6.21	6.19

Based on the result in Table 2 the rate of weight loss due to the immersion in acid is calculated using Equation (1) and the result presented in Figure 5.

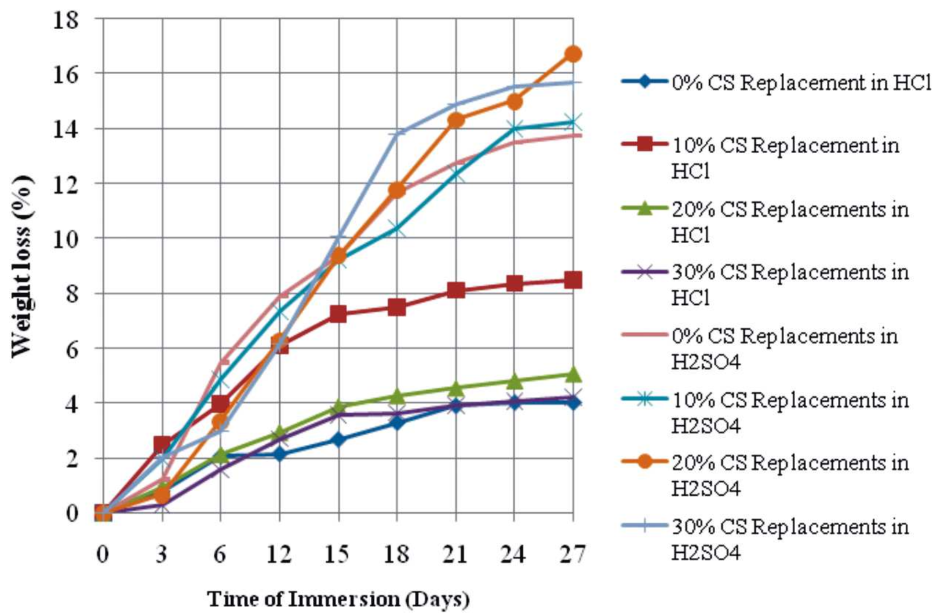

Figure 5: Rate of weight loss of CS concrete immersed in HCl and H_2SO_4 over time

It can be observed from Figure 5 that the weight loss is higher in the H_2SO_4medium than in HCl medium. It can also be deduced that the higher the CS replacement the higher the weight loss. The weight loss is an indication of resistance to acidic attack, the higher the percentage loss the lower the resistance.

The loss of weight of concrete cubes in the H_2SO_4 medium is due to ettringite formation (Chen and Lui, 2005), sulphuric acid attacks on Ca(OH) and the formation of $CaSO_4$ which is leached out of concrete easily. The calcium silicate hydrate reacts with H_2SO_4 to form a fragile silica gel which is destroyed by external physical forces. The calcium sulphate formed bytheinitial reaction can proceed to react with calcium aluminate phase in cement to form voluminous calcium sulphoaluminate (ettringite) which can cause expansion, cracking, loss of weight, loss of strength and disintegration of concrete. The chemical reaction involved in

H_2SO_4 attack on cement concrete can be represented as follows (Allahverdi and ŠKVÁRA, 2000; Chaudhary *et al.*, 2001; Ghernouti and Rabehi, 2012; Rao and Madhavia, 2013):

$$Ca(OH)_2 + 2H_2SO_4 \rightarrow CaSO_4.2H_2O \quad (3)$$

$$3CaSO_4 + 3CaO \cdot Al_2O_3 \cdot 6H_2O + 25H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O \quad (4)$$

Similarly, deterioration of concrete due to hydrochloric acid can be characterized by the following reactions (Reddy *et al.*, 2012; Sivakumar *et al.*, 2014):

$$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O \quad (5)$$

$$CaCl_2 + 3\,CaO.Al_2O_3 + 10H_2O \rightarrow 3CaO.Al_2O_3.CaCl_2.10H_2 \quad (6)$$

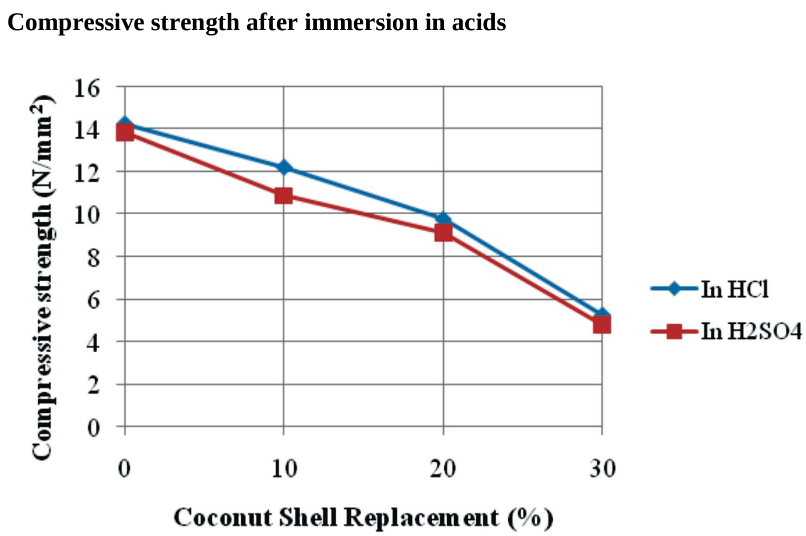

Figure 6: CSConcrete compressive strength after immersion in acids for 27 days

Figure 6 shows the result of the compressive strength of concrete containingaggregatespartially replaced with coconut shellafter immersion in 3% HCl and H_2SO_4 for 27 days. It is evident that all specimens exposed to an acidic environment, exhibit reduction in compressive strength having lower ability to resist load in contrast to the specimens before immersion in acids (as shown in Figure 3). After 27 days, a 0% CS replacement loses 30% strength in HCl and 32% strength in H_2SO_4. For 10% CS replacements the strength loss is 37% and 44% in HCl and H_2SO_4 respectively. While for 20% CS replacementsthe strength loss is 40% and 44% in HCl and H_2SO_4 respectively. And for 30% CS replacementsthe strength loss is 46% and 51% in HCl and H_2SO_4 respectively. The reduction in compressive strength can be attributed to the deterioration of the concrete due to acid attack on the matrix structure of the concrete as exhibited by Equations (3), (4) and (5).

The control specimen (0% replacement) has the highest compressive strength in both HCl and H_2SO_4. The compressive strength decreases with increase in coconut shell percentage replacements. Similarly, compressive strength loss is higher in H_2SO_4 than in HCl. All specimens containing coconut shell did not perform well in the acidic medium and therefore do not have good durability inanaggressive environment.

CONCLUSIONS

Based on the test results and discussions, the following conclusion can be drawn:

- Coconut shells maybe viable for use asapartial replacement for aggregates in concrete. The lower the percentage replacement the better as there isareduction in compressive strength and density as the percentage replacement increases.
- Weight loss was observed in all the specimens when they were exposed to 3% HCl and H_2SO_4 acids for 27 days. The weight loss is higher in the H_2SO_4 medium than in HCl medium. It can also be deduced that the higher the CS replacement the higher the weight loss and generally, specimens containing 10% CS replacement show a better performance than other replacement levels.The control specimen (0% replacement) has the highest compressive strength in both HCl and H_2SO_4. The compressive strength decreases with increase in coconut shell percentage replacements. Similarly, compressive strength loss is higher in H_2SO_4 than in HCl. All specimens containing coconut shell did not perform well in the acidic medium and therefore do not have good durability inanaggressive environment.
- It is recommended that the use of coconut shells in concrete should be avoided in aggressive environments.

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