International Journal of Scientific Research and Engineering Development-– Volume 8 Issue 1, Jan-Feb 2025
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

An Investigation into the Sulphate Resistance of Mortar Containing Coconut Fibre Ash (CFA)

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Abstract:

An investigation was carried out into the sulphate resistance of mortar containing coconut fuel ash (CFA) as partial replacement for cement. CFA was used to partially replace Portland cement by 0, 10, 20, 30, 40 and 50% by weight of binder to prepare CFA mortars. The durability of POFA Mortar Bars at various mixes towards sulphate attack was investigated by immersing mortar bars in magnesium sulphate solution and tested for mass change after 1, 5, 9, 13 and 15 weeks of immersion. Results revealed that CFA mortar bar, with 10% CFA exhibited the best resistance towards sulphate attack. It is recommended that the application of CFA in the right dosage would enhance the sulphate resistance of concrete and mortars.

Keywords — **Sulphate Resistance, Concrete, Mortar, Coconut Fibre Ash**

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I. INTRODUCTION

Concrete is a material made from aggregates, cement, water and sometimes admixtures. In ordinary form, concrete contains about 12% cement, 8% water and 80% aggregates by mass. Aggregates and water are from natural resources, only cement must be produced in fabrics, processes which pollute the environment. According to [1], carbon emissions from both electricity and fossil fuels in cement production can range from 304 to 490 kg CO_2 per tonne of cement. Additionally, a report from the [2] notes that the production of aerated concrete emits approximately 480 kg CO_2 per m³.
Because the cement industry is responsible for 5-7% of worldwide emission of CO_2, (which means 1.6 billion tons of carbon dioxide into the atmosphere), in preparing concrete, the cement dosage can be reduced by using mineral additions, a strategy that also can contribute to environment protection by preserving the energy and consume the huge quantities of wastes.

The building material industry is a domain of interest for using waste and researchers have tried to produce new construction materials incorporating wastes. The new generation of building materials is developing on other theories in concordance with the sustainability of the environment.

According to [3], for concrete production, the reduction of cement content in concrete can be achieved by utilization of supplementary cementitious materials such as fly ash, blast furnace slag, natural pozzolans, and biomass ash.

Coconut shell and husk consist agricultural wastes and are available in plentiful quantities throughout tropical countries worldwide like Nigeria, Brazil and Ghana. In many countries, coconut shell is subjected to open burning which contributes significantly to CO_2 and methane emissions. Coconut shell is widely used for making charcoal. The traditional pit method of production has a charcoal yield of 25–30% of the dry weight of shells used. The charcoal produced by this method is of variable quality and often contaminated with extraneous matter and soil. The smoke evolved from pit method is not only a nuisance but also a health hazard.

Coconut husk has a high amount of lignin and cellulose, and that is why it has a high calorific value of 18.62MJ/kg. The chemical composition of coconut husks consists of cellulose, lignin, pyroligneous acid, gas, charcoal, tar, tannin, and potassium. The predominant use of coconut husks is in direct combustion to make charcoal, otherwise husks are simply thrown away.

II. LITERATURE REVIEW

Over the past few decades, numerous studies have explored the use of agro-waste ashes as partial replacements for cement in concrete production. found that concrete incorporating a specific percentage of Palm Oil Fuel Ash (POFA) achieved strength comparable to or greater than that of Ordinary Portland Cement (OPC) concrete. No significant reduction in strength was observed for replacements of up to 30% POFA.

The study by [4] reviewed the application of Palm Oil Fuel Ash (POFA) in concrete and concluded that its use as a partial cement replacement is typically limited to 0–30% by weight of the total cementitious material. Similarly, [5] evaluated the physical and mechanical properties of cement mortar partially replaced with bamboo ash. Their tests, including fineness, soundness, drying shrinkage, air entrainment, water absorption, consistency, setting time, and chemical composition, revealed that bamboo ash is not suitable as a pozzolanic material.

[6] investigated high-volume Palm Oil Fuel Ash (POFA) concrete and observed that, similar to other pozzolanic materials, it exhibited a slower strength gain at early ages. In their study, they found that concrete mixtures with higher POFA content showed reduced early-age strength development compared to conventional concrete. However, the strength continued to develop over time, indicating the pozzolanic activity of POFA contributing to later-age strength. This behavior is typical of pozzolanic materials, which often contribute to strength development at later stages due to their secondary hydration reactions.

Meanwhile, Obilade (2018) conducted an experimental study on the acid resistance of concrete containing sugarcane straw ash (SCSA). SCSA was used to partially replace Portland cement by weight of binder in order to produce SCSA concrete.

[8] carried out experimental research on the strength performance of concrete using Portland Pozzolana Cement and Sugarcane Bagasse Ash (SCBA). Their findings indicated that finely ground SCBA can effectively replace cement, contributing to higher compressive strength than conventional concrete when the cement quantity remains unchanged.

[9] examined the chloride and sulfate resistance of concrete and mortar containing POFA as a partial cement replacement. POFA was substituted for Portland cement at 0%, 10%, 20%, 30%, 40%, and 50% by weight of binder to produce POFA concrete. Their results showed that a 10% POFA replacement provided the best resistance to chloride ingress.

In the present study, the durability of CFA mortar bars under sulfate attack was assessed by immersing them in a magnesium sulfate solution. The mortar bars were tested for mass change after 1, 5, 9, 13, and 15 weeks of immersion to evaluate their resistance.

III. MATERIALS & METHODS

A. Materials

1) Cement

The type of cement selected for this research work is ordinary Portland cement (OPC). There are various brands available in the Nigerian Building material Markets such as Dangote, BUA, Unicem, Elepahnt Cement (Which is of two grades: 42.5 for Supaset and 32 for ordinary one). Elephant Supaset is a Portland Limestone Cement conforming to the Nigerian cement standards NIS 444-1: 2003 & EN 197-1:2011 specifications will be used in all the four concrete and mortar mixtures.

2) Coconut Fiber Ash (CFA)

Coconut Fiber Ash is produced from the process of recycling local Coconut Husk and shells extracted from coconut fruits. The fiber and husk are dried and heated in an improvised over for over 10 hours at a temperature below 600 ^{0}C. In this research, CFA passing 425 µm sieve is used. 10%, 15% and 20% of (CFA) will be incorporated as replacement for OPC.

3) Aggregates

The coarse and fine aggregates used are crushed granite and river sand, respectively from local quarries. The grading of fine aggregates was conforming to BS 882 (1992).

Sieve analysis of both CFA and sand was carried out with sieve size No. 4, 10, 40, 100 and 200. The ratio of 1:2:4were kept constant in all the concrete mixtures. Moreover, all the concrete and mortar specimens were prepared with a w/cm ratio of 0.4 and potable water was used for mixing and curing the specimens.

*4) **Water***

The water used for the study was obtained from a free-flowing stream. The water was clean and free from any visible impurities. It conformed to BS EN 1008:2002 requirements.

B. Specimen preparation

The Chloride resistance of CFA concretes at various mixes towards chloride attack was investigated using 100 x 100 x 100 mm concrete cubes with varying percentages of CFA replacing Ordinary Portland Cement (OPC) from 0% to 50% prepared and cured after 24 hours from casting for 14 days. They were then stored in drying room for 28 days. After the conditioning period, they were placed inside 3 per cent Sodium Chloride (NaCl) solution. The concrete cubes were brought out and tested for mass change after 2, 4, 6, 8 and 10 weeks of immersion. After each interval, the concrete cubes were placed in fresh sodium chloride solution until the subsequent measurement.

*C. **Mix proportions of concrete specimens***

The proportioning by weight was used in this research. The cement-aggregates ratio used in this work is 1:2:4. CFA were used to replace OPC at dosage levels of 10%, 20%, 30% , 40% and 50% replacement by weight of binder. The mix proportions to be used are calculated below:

$$No.\,of\ Cubes\ per\ Batch = 18$$
$$(i.e.\ Eighteen\ cubes\ for\ ages\ 2, 4, 6\ and\ 8\ weeks\ tests)$$

Batch implies Control Mix (0% CFA Replacement),

10% CFA Replacement

20% CFA Replacement

30% CFA Replacement

40% CFA Replacement and

50% CFA Replacement

$$Size\ of\ each\ Cube = 100\ mm \times 100\ mm \times 100\ mm$$

$$Volume\ of\ one\ Cube = 100^3 = 1 \times 10^{-3} m$$

$$Volume\ of\ 18\ cubes = 18 \times 1 \times 10^{-3} = 0.018\ m^3$$

To account for wastage, it was factored by 1.2

$$Volume\ of\ the\ Batch = 0.018 \times 1.2 = 0.022\ m^3$$

$$The\ ratio\ to\ be\ used\ in\ this\ research\ is\ 1:2:4 = cement: Sand: Coarse\ Aggregate$$

$$Volume\ of\ Cement = \frac{1}{7} \times 0.022 = 0.0031\ m^3$$

$$Standard\ Weight\ of\ Concrete = 2400\ kg/m^3$$

Therefore:

$$Weight\ of\ cement\ in\ one\ Batch = 2400 \times 0.0031 = 7.55kg$$

$Similarly$:

$$Volume\ of\ sand = \frac{2}{7} \times 0.022\ m^3 = 0.0063\ m^3$$

$$Weight\ of\ sand = 2400 \times 0.0063 = 15\ kg$$

$$Volume\ of\ Coarse\ Aggregate = \frac{4}{7} \times 0.022 m^3 = 0.0126\ m^3$$

$$Weight\ of\ sand = 2400 \times 0.0126 = 30.2\ kg$$

The water to binder ratio adopted in the course of this research was 0.5 and this was used to calculate the amount or weight of water required per batch

$$Weight\ of\ water = 0.5 \times weight\ of\ bimder\ (Cement) = 0.5 \times 7.55 = 3.78\ kg$$

D. Casting and Compaction of Concrete

The oiled plastic molds, free from any foreign material were arranged close to the platform. The concrete was simultaneously filled in the molds approximately 100mm thick and each layer was compacted on compacted table using tamping rod. The surplus on the mold was stripped off and leveled by hand trowel. The specimens were packed neatly to maintain proper hydration of the cement.

E. Curing

After casting, placing, compacting and finishing operation, all specimens were covered with a plastic sheet till demolding. The specimens were remolded after 24 hours and immersed in water in a water tank for 14 days. They were then stored in the drying room for 28 days. After the conditioning period, they were placed inside 3 per cent Sodium Chloride (NaCl) solution.

F. Tests

The effect of CFA dosage on mortar and concrete specimens was assessed by measuring the following mechanical and durability properties:

1) **Chemical Composition**

Chemical composition analysis for PA: to determine the mineralogical analysis of PA, chemical composition analysis for PA was determined for silica, Ca, K, Mg, Na, Al, Fe. Loss on Ignition was done as per standard method.

2) **Workability**

The slump test and compacting factor test was conducted on the fresh concrete to determine their ease of mixing, placement and compaction. The slump test was used to test the workability of the concrete. A slump cone mold of diameters 200 mm and 100mm, and height 300mm was filled with concrete in three layers of equal volume. Each layer was compacted with 25 strokes of a tamping rod. The slump cone mold was lifted vertically and the change in height of concrete was measured to the nearest millimeter of 1mm.

The Compacting Factor apparatus was also used to determine the compacting factor values of the fresh concrete in accordance with BS 1881: Part 103 (1983).

3) Chloride Resistance

The concrete cubes were brought out and tested for mass change after 2, 4, 6, 8 and 10 weeks of immersion. After each interval, the concrete cubes were placed in fresh sodium chloride solution until the subsequent measurement.

4) **Sulphate Resistance Test**

The durability of CFA Mortar Bars at various mixes towards sulphate attack was investigated by testing mortar bars following the procedures outlined in ASTM C 1012-04. The variations in the mass of mortar bars (25 x 25 x 25 mm sizes) after exposure to sulphate solutions were observed. The mortar bars were made using 1 part of cement to 2.75 parts of sand by mass. A water-cement ratio by mass of 0.485 was used. Six sets

of mortar bars were produced by replacing OPC with CFA at 0, 10, 20, 30, 40 and 50% levels. The specimens were demolded after 24 hours and thereafter placed inside magnesium sulphate solution. Each liter of sulphate solution was prepared by dissolving 42.35g of Magnesium Sulphate ($MgSO_4$) in 900ml of distilled water to obtain 1.0litre of solution. The mortar bars were brought out and tested for mass change after 1, 5, 9, 13 and 15 weeks of immersion. After each interval, the mortar bars were placed in fresh sulphate solution until the subsequent measurement.

IV. RESULTS & DISCUSSION

A. Experimental Mix Design

The result of the concrete mix design are shown in table I

Table I: Concrete Mix Design

Constituent Materials	0% CFA (Control)	10 % CFA	20 % CFA	30 % CFA
Cement (kg)	37.0	33.3	29.6	25.9
CFA (kg)	0.0	3.70	7.40	11.1
Fine Aggregate (kg)	74.0	74.0	74.0	74.0
Coarse Aggregates (kg)	148.0	148.0	148.0	148.0
Water/Cement Ratio	0.6	0.6	0.6	0.6
Total Water (kg)	22.2	22.2	22.2	22.2

B. *Compressive strength*

The compressive strength development in OPC, 10% CFA, 15% CFA and 20% CFA mortar specimens with curing period is shown in table 4.1.

Table 2: The Compressive Strength Test Results

Amount of Cement (%)	Amount of CFA (%)	Design Strength (N/mm^2)			
		7	14	21	28

		Days	Days	Days	Days
100	0	19.45	19.41	19.46	19.51
90	10	16.56	16.00	15.82	16.54
85	20	13.17	12.02	11.41	13.00
80	30	8.70	9.04	10.06	12.05

C. ***Slump cone test***

A high-quality concrete is one which has appropriate workability in the fresh condition. Basically, the greater the measured height of slump, the improved the workability will be, indicating that the concrete flows easily but at the same time is free from segregation the slump achieved at the rate of 50mm to 90 mm for the different mix of CFA and OPC. This type of slump is suitable for normal reinforced concrete placed with vibration [10]

It is found that workability of concrete increases by increasing the percentage of replacement of CFA in concrete.

Table 3: Slump Test Results

Amount of Cement (%)	Amount of CFA (%)	Slump (mm)
100	0	**53.6**
90	10	**61.1**
85	20	**74.0**
80	30	**80.0**

D. ***Particle Sieve Analysis of CFA***

The results of the particle sieve analysis conducted on Coconut Fuel Ash (CFA) are displayed on table 4. The results are represented on the particle seize distribution curve shown on figure 1

Table 4: Sieve analysis result table for CFA

Sieve Size (mm)	Percentage Passing
0.6	69.80
0.425	49.70
0.3	30.10
0.212	17.66
0.15	12.55
0.075	8.290
0.063	4.120

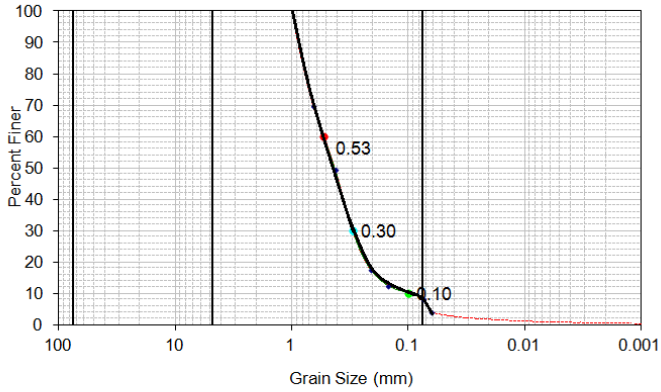

Figure 1: Particle size distribution curve for CFA

E. **Specific Gravity Test**

The specific gravity test was conducted using the relative density bottle method. The result of the test is presented in table 5 to 7

Table 5: Specific Gravity of CFA

Sample Weight (g)	Test A (g)	Test B (g)	Test C (g)
W1	16.62	24.10	20.05
W2	35.42	43.05	40.23
W3	78.58	83.59	79.46
W4	70.97	74.34	71.13
G_S	1.68	1.91	1.70
G_S	1.763		

$$G_s = \frac{(W_2 - W_1)}{\{(W_4 - W_1) - (W_3 - W_2)\}}$$

$$Average = G_s = \frac{1.68 + 1.91 + 1.70}{3}$$

$$G_s = 1.763$$

Table 6: Specific Gravity of Cement

Sample Weight (g)	Test A (g)	Test B (g)	Test C (g)
W1	16.62	24.10	20.05
W2	40.71	48.76	42.03
W3	86.29	90.15	85.51
W4	70.97	74.54	71.13
G_S	2.76	2.72	2.89
G_S	2.79		

$$Average = G_s = \frac{2.76 + 2.72 + 2.89}{2}$$

$$G_s = 2.79$$

Table 7: Specific Gravity of Sand

Sample Weight (g)	Test A (g)	Test B (g)	Test C (g)
W1	16.62	24.10	20.05
W2	63.44	69.37	65.35
W3	99.30	101.80	99.17
W4	70.97	74.54	71.13
G_S	2.53	2.51	2.62
G_S	2.55		

$$Average = G_s = \frac{1.91 + 1.96}{2}$$

$$G_s = 2.55$$

F. ***Density of Concrete Cubes***

The density of the concrete cubes for OPC, 10% CFA, 20% CFA and 30% CFA where determined after curing in the water tank for 7, 14, 21 and 28th days by measuring the mass and dividing the value by the volume of one cube (150mm x 150mm x 150mm). The results are shown in table 4.6

Table 8: Density of Concrete cubes

($x10^3$ kg/m^2)	7 days	14 days	21 days	28 days
0% CFA	2.44	2.44	2.62	2.65
10% CFA	2.28	2.42	2.46	2.47
20% CFA	2.32	2.31	2.35	2.38
30% CFA	2.19	2.30	2.28	2.31

G. ***Chemical Composition of Coconut Fibre Ash (CFA)***

Table 2 shows the oxide composition of CFA. The CaO content (39.89%) in CFA also shows that it has some self-cementing properties.

Table 9: Chemical Composition of Coconut Fibre Ash (CFA)

Oxide	Percentage Composition (%)	OPC (BS 12 Ranges)
SiO_2	5.23	17-25
Fe_2O_3	7.68	0.5-6.0
Al_2O_3	3.17	3-8
CaO	39.89	60-67
MgO	22.76	0.1-4.0
SO_3	1.00	1.0-2.0
K_2O	0.03	
PbO	20.23	

H. ***Resistance of OBHA Mortar Bars towards Sulphate attack***

The results of the reaction of CFA mortar bar specimens with Magnesium sulphate (MgSO4) solution are presented in Table 10. The details of the percentage change in mass of mortar bar specimens at each period of exposure in sulphate solution is plotted in Figure 2. All the mortar bars experienced gain in mass as a result of the expansion of the mortar bars. After 15 weeks immersion in magnesium sulphate solution, the percentage increase in masses of 0%, 10%, 20%, 30%, 40% and 50% of CFA mortars were 9.4%, 8.9%, 9.8%, 12.1% 12.4% and 14.4% respectively. It can be seen that after 15 weeks exposure to sulphate solution, the gain in masses of the control mortar bars were higher than the gain in masses of the 10% CFA mortar bars. The 50% CFA mortar bars experienced the biggest expansion as revealed by the percentage gain in mass of 14.4% after 15 weeks exposure to MgSO4 solution. Thus, the inclusion of CFA of not more than 10% improved the resistance of the mortar bars towards sulphate attack. The formation of C-S-H gel made the mortar bars to be denser and more resistant towards sulphate attack.

Table 10 Reaction of CFA Mortar with Magnesium Sulphate

Percentage CFA (%)	Effect of $MgSO_4$ on	Duration of Immersion in Magnesium Sulphate (Weeks)					
		0	1	5	9	13	15
0	Mass (g)	433.9	469.5	472.5	473.0	473.0	474.7
	Change (g)		31.6	36.9	39.5	39.5	40.8
	% Change		8.2	8.9	9.0	9.0	9.4
10	Mass (g)	434.6	468.5	471.1	472.0	472.4	473.3
	Change (g)		33.9	36.5	37.4	37.8	38.7
	% Change		7.8	8.4	8.6	8.7	8.9
20	Mass (g)	404.2	439.8	442.2	443.4	443.4	443.8
	Change (g)		35.6	38.0	39.2	39.2	39.6
	% Change		8.8	9.4	9.7	9.7	9.8
30	Mass (g)	362.9	401.4	403.9	405.0	405.1	406.8
	Change (g)		38.5	41.0	42.1	42.2	43.9
	% Change		10.6	11.3	11.6	11.6	12.1

40	**Mass (g)**	347.8	386.4	389.5	389.9	390.6	390.9
	Change (g)		38.6	41.7	42.1	42.8	43.1
	% Change		11.1	12.0	12.1	12.3	12.4
50	**Mass (g)**	345.5	390.6	394.1	394.8	396.1	397.9
	Change (g)		45.2	48.7	49.4	50.7	52.5
	% Change		12.3	13.3	13.5	13.9	14.4

Table 11: Effect of Magnesium Sulphate on CFA Concrete

	0% CFA	10 % CFA	20 % CFA	30% CFA	40% CFA	50% CFA
0 Weeks						
1 Weeks	8.2	7.8	8.8	10.6	11.1	12.3
5 Weeks	8.8	8.4	9.4	11.3	12.0	13.3
9 Weeks	9.0	8.6	9.7	11.6	12.1	13.5
13 Weeks	9.0	8.7	9.7	11.6	12.3	13.9
15 Weeks	9.4	8..9	8.8	12.1	12.4	14.4

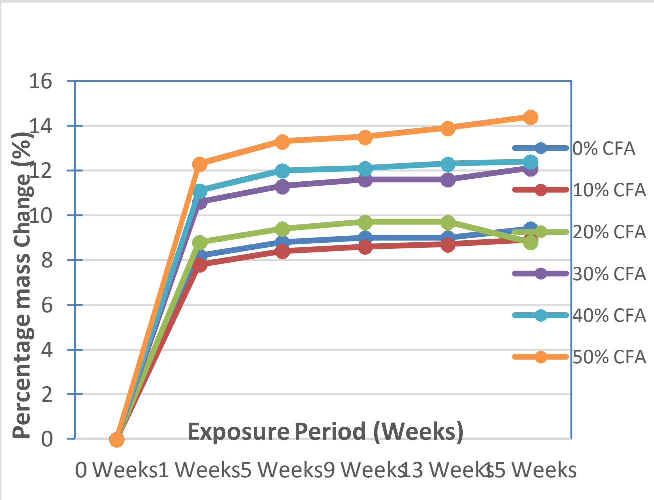

Figure 2: Effect of Magnesium Sulphate on CFA Concrete

V. CONCLUSION

i.) The use of CFA as a partial replacement for cement exhibits a lower water absorption rate and slower setting time of concrete.

ii.) Concrete strengths increase with curing age and decreases with increasing percentage of CFA replacement in concrete.

iii.) The CFA concrete with 10% by weight replacement of cement had the best resistance towards sulphate ingress as it experienced the least percentage gain in mass upon immersion in sodium chloride solution.

iv.) The use of CFA will reduce the volume of cement used in light weight concrete, thereby reducing the cost of concrete production.

v.) The use of CFA will minimize the environmental issues arising from the disposal of Coconut Fibre Wastes.

REFERENCES

[1] Kajaste, R., & Luttinen, S. (2015). *Environmental impacts and costs of concrete production and demolition* (pp. 27–45). MDPI. https://doi.org/10.3390/2076-3298/5/2/27

[2] Danish Technological Institute. (2019). *Life cycle assessment of building materials: Concrete and aerated concrete*. Danish Technological Institute. https://orbit.dtu.dk/files/241813498/BYG_R_439_1_.pdf

[3] Karim et al. (2011) found that concrete incorporating a specific percentage of Palm Oil Fuel Ash (POFA) achieved strength comparable to or greater than that of Ordinary Portland Cement (OPC) concrete.

[4] Safiuddin, M., Salam, M. A., & Jumaat, M. Z. (2010). Utilization of palm oil fuel ash in concrete: A review. *Journal of Civil Engineering and Management, 16*(1), 1-12. https://doi.org/10.3846/jcem.2010.01

[5] Mujedu et al (2018): Evaluation of Physical and Mechanical Properties of Partially Replaced Bamboo Ash Cement Mortar, The International Journal of Engineering and Science (IJES), ISSN (e):2319 –1813ISSN (p):23-19 –1805

[6] Awal, A. S. M. A., Hussin, M. W., & Ismail, M. (2011). A short-term investigation on high-volume palm oil fuel ash (POFA) concrete. *Journal of Engineering Science and Technology, 6*(6), 720-732.

[7] Obilade, I. O. (2018). Acid resistance of concrete containing sugarcane straw ash (SCSA) as partial replacement of cement. *Journal of Materials Science and Construction, 5*(3), 45-52.

[8] Nawkhare et al (2018): Experimental Study On Use of SCBA in Concrete by Partially Replacement of Cement,The International Journal of Engineering and Science (IJES), ISSN (e):2319 –1813 ISSN (p):23-19 –1805

[9] Obilade, I. O., & Olutoge, F. A. (2018). An investigation into the chloride and sulphate resistance of concrete and mortar containing palm oil fuel ash as partial cement replacement. *The International Journal of Engineering and Science*, *7*(9), 16–19.

[10] Lyons, A. (2007). *Materials for Architects and Builders* (4th ed.). Butterworth-Heinemann.

[11] Sooraj (2013): Effect of Palm Oil Fuel Ash (POFA) on Strength Properties of Concrete, International Journal of Scientific and Research Publications, Volume 3, Issue 6, June 1

[12] Shetty .M.S (2004): Concrete Technology (Theory and Practice), S. Chand & Company LTD, Ram Nagar, New Delhi - 110 055.