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Structural Properties of Locally Made Ultrafine Palm Oil Fuel Ash (UPOFA) as Partial Replacement for Cement

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***Abstract*— Locally made Ultra Fine Palm Oil Fuel Ash (UPOFA) was processed from waste Palm Oil Fuel Ash (POFA) locally available in oil mills and was used as partial replacement for cement in the production of High Strength Concrete (HSC) at the replacement levels of 10%, 20%, 30% and 40% for various water binder ratios (w/b) of 0.25, 0.27 and 0.29. The workability of the fresh concrete and the mechanical properties of the hardened concrete were investigated. It was observed that the workability reduced with increase in UPOFA content and increased with water binder ratio. The slump values ranged from 0 to 22mm with the highest value recorded for the control with w/b ratio of 0.29. The 28 days compressive, split tensile and flexural strength and modulus of elasticity of the HSC increased with UPOFA content up to 20%, followed by a drop for higher UPOFA content. The maximum values of these characteristics occurred at UPOFA content of 10% and were respectively 82.40, 4.51, 5.45 and N/mm2 The results are in good agreement with those from earlier studies and international codes and standards.**

***Index Terms*— Ultra Fine Palm Oil, HSC .**

I. INTRODUCTION

Cement is the major binder and one of the most cost critical items used in concrete work and a large volume of energy is consumed in the production of cement. About 880 kg of CO_2 is emitted into the atmosphere per every ton of cement produced due to the burning of fuel and calcination of limestone [2]. The carbon dioxide emitted through the production of cement causes greenhouse effect. Therefore, there is an environmental as well as an economical interest in reducing the amount of cement consumed and one of the ways to do this is to source for alternative binding materials to totally or partially replace cement as a binder in concrete work. Palm oil fuel ash (POFA) has proven to be one of the promising materials that has the potential to replace cement to a certain percentage while retaining the strength and some other qualities of the concrete. POFA is a waste product from palm oil mills. Nigeria is the fifth largest producer of palm oil in the world, producing about 1million metric tons behind countries like Indonesia, Malaysia, Thailand and Columbia [5]

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It is expected that tons of palm oil waste will be produced in Nigeria yearly. This huge amount of POFA is disposed each year as waste with limited utilization in landfills and incineration which could lead to health and environmental problems as well as financial loss. POFA has been found to demonstrate varied usefulness in construction and concrete industries by numerous researchers [1] [8]. Palm oil fuel ash (POFA) has the high potential to be used in concrete construction materials as pozzolans. This is because POFA possesses high content of silica oxide of about 55% meeting the pozzolanic properties criteria to react with calcium hydroxide ($Ca(OH)_2$) from the hydration of cement. The pozzolanic reaction produces calcium silicate hydrates (C-S-H) which is a gel compound that contributes to the strength of the concrete resulting in its enhanced density and durability. Therefore, POFA has the potential to be used as replacement for cement or as filler to produce a strong and durable concrete [1]

It is not sufficient to get rid of POFA by utilizing it in concrete production in the limited amount, but efforts are also required to improve the properties of POFA in order to enhance its usage in high strength concrete production and allow more volume utilization to reduce damage to the environment through its accumulation in fills

In this research work, POFA is used in the production of HSC by locally improving the properties of POFA through filtering, grinding and heat treatment. The product obtained from the treatment of POFA is referred here to ultrafine palm oil fuel ash (UPOFA) because the particles are finer than cement particles after the treatment. This research involves tests to ascertain the influence of ultrafine POFA (UPOFA) on the workability, compressive and some other mechanical properties of the HSC. The study is not only going to help in environmental waste reduction but will also help to reduce construction cost

II. EXPERIMENTAL PROGRAM

This section describes the materials used in the experimental work, their sources, preparation, properties and experimental program. It also describes the various test carried out on the materials to determine their properties. The procedure for concrete mix design, batching, curing and testing of concrete specimen in fresh and hardened state were also given. Materials used in the experimental works include water, cement, ultrafine palm oil fuel ash (UPOFA), fine aggregates, coarse aggregates and super plasticizer or high range water reducing agent (HRWRA) (Master Rheobuild

561). The details are described in the relevant paragraph below.

Materials

Portland Limestone Cement (PLC) with the strength class 42.5N according to the British standard (BS EN196-0; 2010) was used for the research work. Raw Palm oil fuel ash (POFA) was obtained from a palm oil mill at Isiokpo near to Port Harcourt in Rivers State of Nigeria. The POFA obtained are raw and mixed with some black carbon materials. The raw POFA was sieved to remove the big charcoals, fibres, kernels and other solid materials which were not burnt completely. It was then oven dried at about 100 °C. The moisture free POFA was passed through a 300-μm sieve to remove coarser particles. The resulting product was subjected to a heat treatment at about 450ºC for 60 mins by cooking to remove smaller unburnt carbon that passed through the initial sieving process. This has been reported to be effective in removing the excessive unburnt carbon in POFA [3]. The heat treated POFA was ground to a sufficient fineness using a local grinding machine. The ground POFA still did not meet the fineness required. It was sieved to obtain the treated ultrafine POFA (UPOFA). This improves the pozzolanic reaction of the materials. Fineness test was determined by dry sieving as per IS: 4031 (Part 1) – 1996. The principle of this is to determine the proportion of UPOFA whose grain size is larger than specified mesh size. Fineness test was carried out on the U-POFA to determine the particle size distribution of the materials.

Fine aggregates used was natural sand most particles passing through 5.0 mm BS 410 test sieve and containing no bigger material. (BS 882:1992). Coarse aggregate used was crushed granite with maximum size of 12mm (BS 882:1992).

Clean potable water which satisfies drinking standard and conforming to BS EN 1008: 2002 was used for mixing and curing of concrete samples.

Master Rheobuild 561 was used as high range water reducing agent (HRWRA) to improve the workability of the concrete and reduce the water binder ratio

Plate 1: Unfiltered POFA

Plate 2: Filtered POFA

Plate 3: Heating Process

Plate 4: Filtering Process

Mixing Proportion

The proportioning used for all concrete mixes was derived from mix design carried out with reference to ACI 211.1-91 2002, BS 5328-I-1997, BS 1881-102 and BS 1881-108 for three water cement ratios of 0.25, 0.27 and 0.29. For the control mix of the high strength concrete (HSC), 100% cement was utilized and tagged CU00 while for other mixes UPOFA were used as a partial replacement for cement by mass at 10%, 20%, 30% and 40% and tagged CU10, CU20, CU30 and CU40 respectively while other materials for the concrete work remains the same for various water cement ratio as obtained in the concrete mix design. A, B and C were used for W/B ratios of 0.25, 0.27 and 0.29 respectively.

Below is a table that shows the mix proportion with the specimen nomenclature.

Table 3.1. Concrete mix proportions

	Concrete mix ratio for 0.25, 0.27 and 0.29 Water cement ratio (SP as % from cementitious material weight)					
	Binder					
Ref	**Cem**	**UPOFA**	**Fine**	**Coarse**	**W/C**	**SP**
CU00	1	0	1.2	1.94	0.2	0.
CU10	0.	0.1	1.2	1.94	0.2	0.
CU20	0.	0.2	1.2	1.94	0.2	0.
CU30	0.	0.3	1.2	1.94	0.2	0.
CU40	0.	0.4	1.2	1.94	0.2	0.
CU00	1	0	1.2	1.94	0.2	0.
CU10	0.	0.1	1.2	1.94	0.2	0.
CU20	0.	0.2	1.2	1.94	0.2	0.
CU30	0.	0.3	1.2	1.94	0.2	0.
CU40	0.	0.4	1.2	1.94	0.2	0.
CU00	1	0	1.2	1.94	0.2	0.
CU10	0.	0.1	1.2	1.94	0.2	0.
CU20	0.	0.2	1.2	1.94	0.2	0.
CU30	0.	0.3	1.2	1.94	0.2	0.
CU40	0.	0.4	1.2	1.94	0.2	0.

Concrete Batching and Production

Concrete batching was done by weight of cement, UPOFA, sand and granite. It was design to give a compressive strength of 75MPa at 28 days wet curing.

The mixing was done by the use of rotating concrete mixer in the laboratory in accordance with the American Concrete Institute (ACI 544)

recommendation. After the mixing with designed water binder ratio and the addition of super plasticizer, slump tests were conducted on every

mix and the slump values recorded. The concrete was placed in an oiled concrete moulds and compacted with a table vibrator available in the laboratory. The concrete samples were allowed in the moulds for twenty-four hours after which they were removed from the moulds and placed in a curing water tank for 28 days. At 3, 7, 14 and 28days, the cubes were tested for compressive strength and on the 28 days, the flexural strength test and splitting tensile strength test were carried out on the concrete test specimen

Plate 5: Process photograph of Mixing and Vibration Instrumentation and Testing

Particle size distribution test and fineness modulus test were carried out on the aggregates and binders respectively to ascertain their suitability for use in structural concrete production. For the slump test, a slump cone, non-porous base plate, measuring scale and a temping rod were used to carry out the test in accordance with BS 1881 Part 102: 1990 and ASTM C 143 -90.

Compressive strength test was carried out by universal testing machine (UTM). The load was applied steadily and without shock such that the stress is increased at a steady rate until no greater load can be sustained. The maximum load applied to the cube at failure divided by area of specimen gives the compressive strength of concrete in conformity with BS1881–116 (1983). The compressive strength was then calculated by using the formula below:

$f_{cu} = P/A$. Where f_{cu} is the compressive strength, P is the crushing force and A is the area of cube.

Split tensile strength was carried out on 150 mm diameter by 300 mm long cylinder.

The tensile splitting strength f_{ct} in MPa is given by the equation:

$$f_{ct} = \frac{2F}{\pi \, x \, L \, x \, d}$$

Where F is the maximum load (in N), L is the average measured length (in mm), d is the average diameter (in mm)

The test was conducted as specified in BS1881-117.

Flexural strength is the theoretical maximum tensile stress reached at the bottom fibre of a test beam and the test was carried out on 150 mm x 150 mm x 500 mm long moulded concrete beams.

The flexural strength f_d (in MPa) is given by the equation:

$$f_d = \frac{450\,F}{d_1 \ x \ d_2^2}$$ Where

F is the maximum load (in N) d1 & d2 are the width and depth of the specimen respectively (in mm). The test was carried out in accordance to BS1881 part 118.

Plate 6: Process Photograph of Test Procedures

III. RESULTS AND DISCUSIIONS

The experimental results obtained from various laboratory tests in this study are discussed below.

These include the physical properties of the aggregates, the slump result and the mechanical properties of the hardened concrete. The results of the physical properties of aggregates are presented in table 3.1.

From the table, the results revealed that the aggregates exhibit good coefficient of uniformity

and curvature and satisfied ASHTTO classification of Cu>4 and 1<Cc<3 for the aggregates to be used for structural concrete application. From the fineness test result, the values of residue retained in 90-micron sieve are given as 8.42% and 5.84% of the total weight of sample for cement and UPOFA respectively. This is within the stipulated value of not greater than 10% in ASTM C 184 and IS: 4031 for binders to be used in concrete work.

Table 3.1 Physical properties of Aggregates

Properties	Coarse Agg	Fine Agg
Specific Gravity	2.65	2.7
Bulk Density (Kg/m^3)	2113.5	1625
Coefficient of Curvature (Cc)	2.2	1.1
Coefficient of Uniformity (Cu)	5.0	4.2
Fineness modulus	6.92	2.81

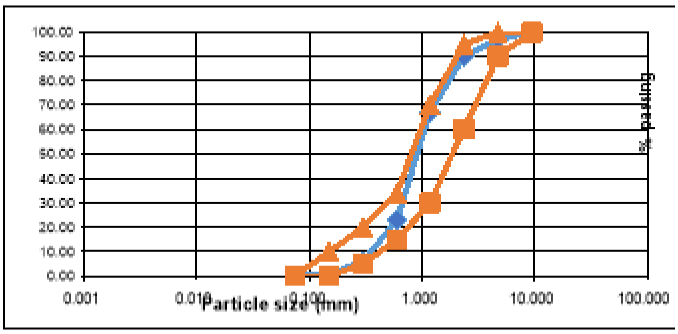

Fig 3.1: Particle Size Distribution for Fine Aggregates.

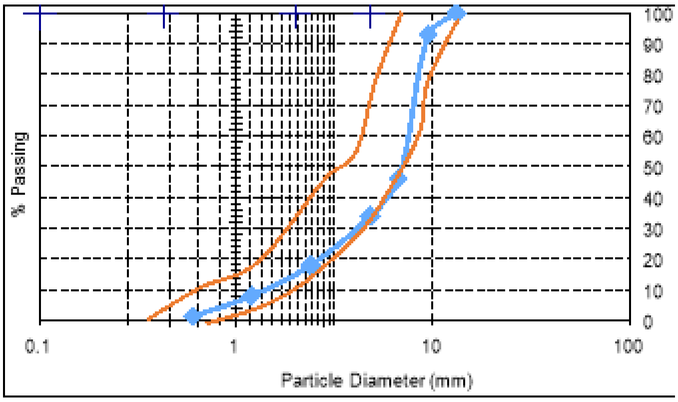

Fig 3.2: Particle Size Distribution for Coarse Aggregates

Workability of High Strength Concrete Containing UPOFA

Concrete slump test was used to determine the workability of the concrete mix. The result of workability of the concrete for 0%, 10%, 20%, 30% and 40% of UPOFA content were tested for

various w/b ratios of 0.25, 0.27 and 0.29. Slump test was carried out on fifteen concrete samples and the result is presented in Table 3.2.

. Table 3.2: Result of Slump experimental test for Various % UPOFA Content and W/B Ratios

S/no	Spec Ref.	UPOFA % in Conc.	W/B Ratio	Height Slump Cone (mm)	Height of collapse (mm)	Slump (mm)
1	CU00A	0	0.25	300	290	10.0
2	CU10A	10	0.25	300	295	5.0
3	CU20A	20	0.25	300	300	0.0
4	CU30A	30	0.25	300	300	0.0
5	CU40A	40	0.25	300	300	0.0
6	CU00B	0	0.27	300	280	20.0
7	CU10B	10	0.27	300	288	14.0
8	CU20B	20	0.27	300	292	8.0
9	CU30B	30	0.27	300	300	0.0
10	CU40B	40	0.27	300	300	0.0
11	CU00C	0	0.29	300	276	22.0
12	CU10C	10	0.29	300	284	12.0
13	CU20C	20	0.29	300	290	8.0
14	CU30C	30	0.29	300	295	5.0
15	CU40C	40	0.29	300	300	0.0

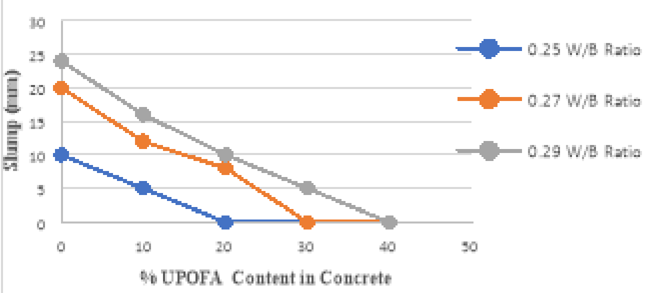

Fig 3.3: Variation of Workability with Percentage UPOFA for Various W/B Ratios

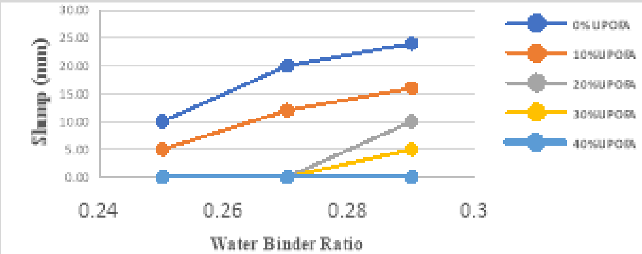

Fig 3.4: Variation of Workability with Water Binder Ratio for Various UPOFA Content.

From Fig 3.3 it was observed that as the percentage of UPOFA increased in the HSC the slump decreased. This is due to the fact that UPOFA requires more water to make it workable than ordinary cement. Also, as the water binder ratio was increased, the slump value also increased, this is due to the fact that UPOFA requires more water to make it workable than ordinary cement. Also, as the water binder ratio was increased, the slump value also increased, this is due to the introduction of more water into the concrete production. The laboratory observations yielded highest measured slump values of 10, 20 and 22 mm for the high strength concrete at w/b of 0.25, 0.27 and 0.29 respectively for 0% UPOFA content considered in this study

Average Compressive Strength Test Result of High Strength Concrete containing UPOFA

The result obtained from compressive strength test carried out on the 180 cubes of concrete specimen are presented in Table 3.3. The cubes were cast from high strength concrete mixes having W/B ratios of 0.25, 0.27, 0.29 and UPOFA content of 0 to 40% varied in steps of 10%.

Compressive strength is the maximum compressive stress that, under a gradually applied load, a given solid material can sustain without fracture. Compressive strength is calculated by dividing the maximum load by the original cross-sectional area of a specimen in a compression test. Out of many test applied to the concrete, this is the utmost important which gives an idea about all the characteristics of concrete.

Table 3.3: Average Experimental Values of Compressive Strength (N/mm^2) for Various Durations of Wet Curing, UPOFA Content and W/B Ratios

S/no	Ref.	W/B Ratio	UPOFA %	Duration of Wet Curing (Days) 3	7	14	28
1	CU00	0.25	0	33.1	53.5	62.4	78.2
2	CU10	0.25	10	32.2	51.3	63.5	82.4

3	CU20	0.25	20	30.9	50.5	62.8	79.6
4	CU30	0.25	30	29.4	48.8	53.3	68.0
5	CU40	0.25	40	21.0	35.2	47.3	52.0
6	CU00	0.27	0	32.2	52.5	60.6	76.2
7	CU10	0.27	10	31.8	51.0	62.4	79.6
8	CU20	0.27	20	30.4	49.2	61.5	77.2
9	CU30	0.27	30	26.8	44.7	48.2	64.3
10	CU40	0.27	40	18.3	30.0	41.1	48.0
11	CU00	0.29	0	31.9	51.3	59.2	75.1
12	CU10	0.29	10	30.8	49.6	60.5	78.8
13	CU20	0.29	20	30.3	48.2	59.8	76.0
14	CU30	0.29	30	24.4	38.6	43.9	58.1
15	CU40	0.29	40	16.2	27.3	32.4	46.2

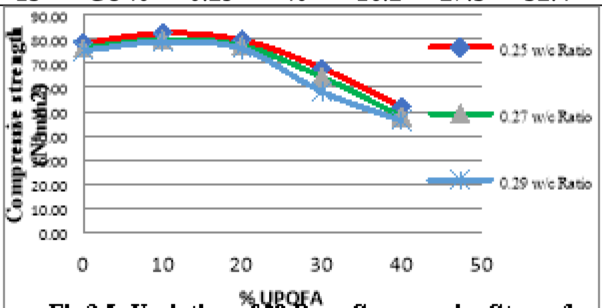

Fig 3.5: Variation of 28 Days Compressive Strength with % UPOFA Replacement for Various Water Binder Ratios

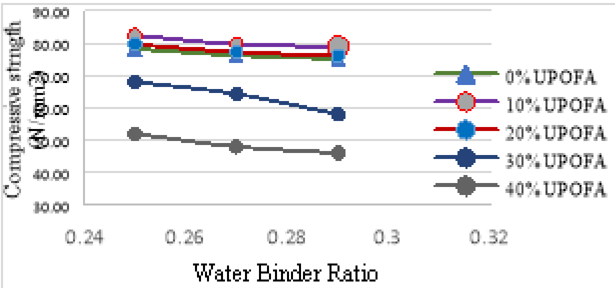

Fig 3.6: Variation of 28 Days Compressive Strength with Water Binder Ratio for Various % UPOFA Replacement.

From the table of average experimental values of compressive strength (N/mm^2) for various durations of wet curing, UPOFA content and w/b ratios, as the curing days increased, compressive strength increased. As the % of the UPOFA increased, the compressive strength of the HSC initially reduced below the control at 3 and 7 days wet curing. After 14 and 28 days wet curing, the compressive strength increased with an average of 104.92 and 101.41% of the control for 10 and 20% UPOFA respectively for 28 days curing for the w/b ratios. This indicates initial slow strength gain in HSC containing UPOFA. It was observed that the compressive strength at 28 days for the control with 0% specimen, 10% and 20% UPOFA met the target strength of 75MPa for all the w/b ratios. Above 20% replacement, target strength was not achieved. The maximum was the 28 days strength of 10% UPOFA content of 0.25 w/b ratio that yielded 105.3% of the control. From Fig 3.6, as the water binder ratio increased the strength reduced. The reduction in the concrete strength may be due to increased water binder ratio that increases more void in the concrete

Flexural Strength (Modulus of Rupture) of High Strength Concrete Containing UPOFA.

Flexural strength of unreinforced concrete also known as modulus of rupture is an indirect measure of tensile strength of concrete. It is a measure of the maximum stress on the tension face of an unreinforced concrete beam or slab at the point of failure in bending. The average flexural strength values for the tested beams are shown in Table 3.4.

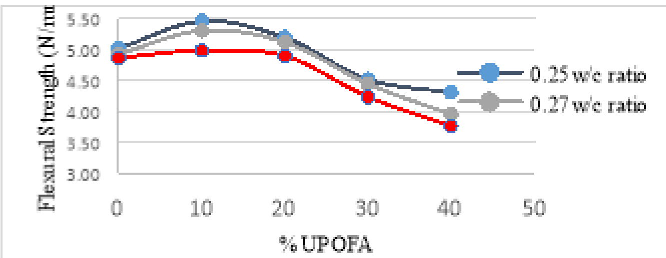

Fig 3.7: Variation of Flexural Strength with % UPOFA for Various W/B Ratio after 28 Days Wet Curing

UPOFA content was due to the interfacial transition From Fig 4.8, it was observed that as the % UPOFA increases from 0% to 20% at 10% incremental, the flexural strength increased for w/b ratios of 0.25, 0.27 and 0.29 for 28 days curing. The highest obtained are 108.78, 107.72 & 103.75% of the control at 10% UPOFA content. At more than 20% UPOFA the flexural strength dropped. The decrease in the flexural strength with the increase of the zone between the aggregate and the binding paste that's not strong enough to resist the shear force that was applied during the flexural strength test. [6]

From the variation of flexural strength with water binder ratio in Fig 3.8, it was also observed that as the water binder ratio increased, the flexural strength reduced for all percentages UPOFA content for the 28 days curing.

Table 3.4: Experimental Test Result of Flexural Strength (Modulus of Rupture) (N/mm^2) for Various % UPOFA Contents and W/B Ratios after 28 Days Wet Curing.

S/no	Ref.	UPOFA % in Conc.	W/B Ratio	Ultimate Load	Flexural strength test (N/mm^2)
1	CU00A	0	0.25	11.13	5.01
2	CU10A	10	0.25	12.11	5.45
3	CU20A	20	0.25	11.53	5.19
4	CU30A	30	0.25	10.02	4.51
5	CU40A	40	0.25	9.56	4.30
6	CU00B	0	0.27	10.93	4.92
7	CU10B	10	0.27	11.78	5.30
8	CU20B	20	0.27	11.36	5.11
9	CU30B	30	0.27	9.87	4.44
10	CU40B	40	0.27	8.78	3.95
11	CU00C	0	0.29	10.80	4.80

12	CU10C	10	0.29	11.07	4.98
13	CU20C	20	0.29	10.87	4.89
14	CU30C	30	0.29	9.40	4.23
15	CU40C	40	0.29	8.36	3.76

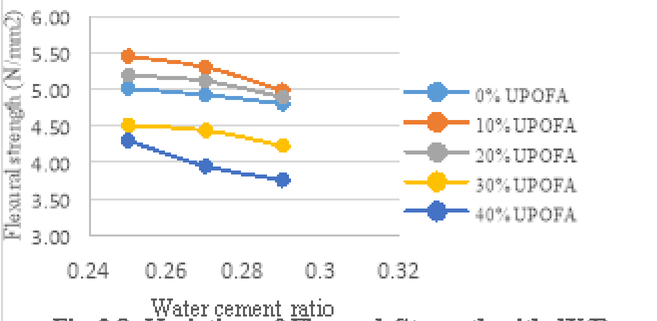

Fig 3.8: Variation of Flexural Strength with W/B Ratio for Various % UPOFA Content at 28 Days Wet Curing

Split Tensile Strength of High Strength Concrete Containing UPOFA.

Split tensile strength is a measure of the ability of material to resist a force that tends to pull it apart. It is expressed as the minimum tensile stress needed to split the material apart. The experimental results obtained from the split tensile strength test carried out on the cylinders specimens are presented in Table 3.5

Table 3.5: Experimental Test Result of Splitting Tensile Strength (N/mm^2) for Various % UPOFA Contents and W/B Ratios after 28 Days Wet Curing.

S/ no	Ref.	UPO FA % in Conc.	W/ B Ratio	Splitting Load	Split Tensile strength (N/mm2)
1	CU0	0	0.2	306.9	4.34
2	CU1	10	0.2	318.9	4.51
3	CU2	20	0.2	310.4	4.39
4	CU3	30	0.2	283.5	4.01
5	CU4	40	0.2	267.3	3.78
6	CU0	0	0.2	302.6	4.28
7	CU1	10	0.2	314.6	4.45
8	CU2	20	0.2	304.0	4.30
9	CU3	30	0.2	268.7	3.80
1	CU4	40	0.2	259.5	3.67
1	CU0	0	0.2	297.7	4.21
1	CU1	10	0.2	305.4	4.32
1	CU2	20	0.2	301.2	4.26
1	CU3	30	0.2	265.1	3.75
1	CU4	40	0.2	251.7	3.56

tensile strength of conventional concrete that ranges

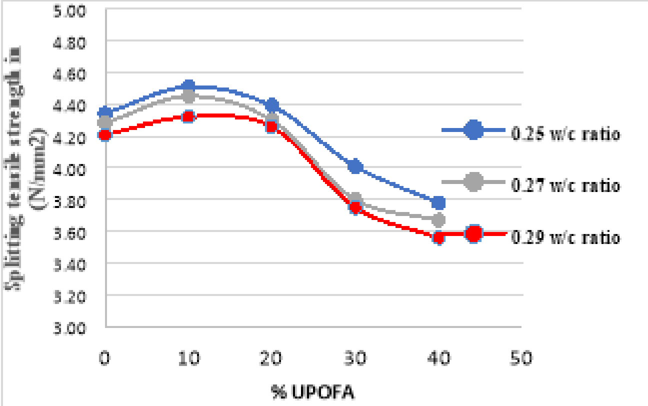

Fig 3.9: Variation of Splitting Tensile Strength Versus % UPOFA Content for Various W/B Ratio at 28 Days Wet Curing

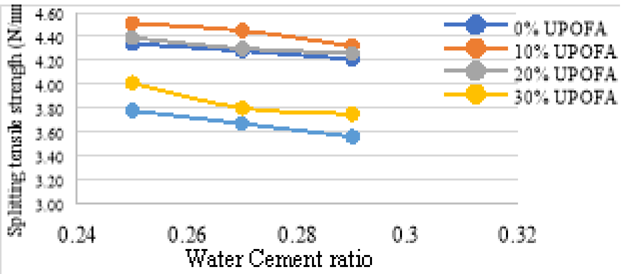

Fig 3.10: Variation of Splitting Tensile Strength Versus Various W/B Ratios at 28 Days Wet Curing

From Fig 3.9, it was observed that as the percentage of UPOFA increased to 10 and 20% UPOFA, the split tensile strength increased for various W/B ratio with average values of 103.5 and 100.94% of the control for 10 and 20% UPOFA content. This is similar to the result obtained for the compressive strength of the UPOFA concrete. Above 20% replacement, the split tensile strength reduced below the control.

Comparing the compressive test result with the split tensile strength result of the experimental work, the split tensile strength ranged from 5.48 – 7.85% of the compressive strength result for the target strength of 75MPa of the HSC. This is similar to the same result obtained by Sarita Sigla (2012), the results showed a split tensile strength between 5:89-7.24% of the compressive strength result for a target strength of 80MPa. This is different from the split from 8-14% of the compressive strength. [4]

From Fig 3.10, it was observed that as W/B ratio increased, the split tensile strength also decreased for all the % UPOFA content, this is similar to the compressive strength result obtained. It can be associated to the increase in void in concrete that is introduced by presence of more water in concrete.

IV. CONCLUSION AND RECOMMENDATIONS

Conclusion

1) The addition of UPOFA to concrete affects its workability. The slump decreased with increase in the percentage of UPOFA content for all the W/B ratios of 0.25, 0.27 and 0.29 considered. On the other hand, as the water binder ratio was increased, the slump also increased. The Slump ranged from 0 to 22mm. 22mm being the highest slump recorded for 0% UPOFA in 0.29 W/B ratio.

2) The compressive strength, split tensile strength and flexural strength of the high strength concrete increased with UPOFA content up to 20% followed by a drop in the strength values for higher UPOFA content. The maximum values of these characteristics occurred at 10% UPOFA content and W/B ratio of 0.25 with values of 82.40 MPa, 4.51 N/mm^2 and 5.45 N/mm^2 for compressive strength, split tensile strength and flexural strength respectively. This constituted a slight increase of 5.04, 4.4 and 8.8 percent of the control mix with 0% UPOFA content. These results are in close agreement with those from similar studies.

Recommendations

1. High strength concrete mixes with UPOFA content up to 20% developed in this study and water binder ratio in the range of 0.25 – 0.29 are recommended for specification for practical application

2. Further researches are recommended to investigate the durability and long term responses, effect of other range of water binder ratios, effect of different types of curing methods, and effect of various types of HRWRA on high strength concrete with partial replacement of cement with the UPOFA developed in this study.

REFERENCES

[1] Awal, A. S. M and Hussin, M. W. (1997). Some Aspects of Durability Performances of Concrete Incorporating Palm Oil Fuel Ash. Proceedings of Fifth International Conference on Structural Failure, Durability and Retrofitting. Singapore, pp 215-216

[2] Böhringer, C., Finus, M., & Vogt, C. (2002). Controlling global warming: Perspectives from economics, game theory and public choice. Cheltenham: Edward Elgar.

[3] Chandara, C., (2011). Study on pozzolanic reaction and fluidity of blended cement containing treated palm oil fuel ash as mineral admixture, Materials and Mineral Resources Engineering. PhD Thesis University Sains Malaysia. p. 188

[4] Kosmatka, S. H., (2002) Design and Control of Concrete Mixtures, 5th Edition, Cement Association of Canada, Ottawa

[5] Iskandar, M. J., Baharum, A., Anuar, F. H., & Othaman, R. (2018). Palm oil industry in South East Asia and the effluent treatment technology, A review. Environmental Technology & Innovation, 9, 169-185. doi:10.1016/j.eti.2017.11.003

[6] Mohammad (2015) Feasibility study of ground POFA as partial cement replacement materials in Oil Palm Shell Lightweight Concrete (OPSLC). Advances in Materials Science and Engineering Volume 2014, Article ID 610274,

[7] Sarita Singla (2012). Mechanical Properties of High Strength High Performance. Concrete. Proc. of Int. Conf. on Advances in Civil Engineering 2012.

[8] Sukuntapree, S., Namarak, C., and Jaturapitakkul, C. (2002). "Use of calcium carbide residue and palm oil fuel ash in concrete." Proc., 2002 Annual Conf. of the Engineering, Bangkok, Thailand, 191–199 (in Thai).