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Flexural and Split Tensile Strength Properties of Oil Bean Husk Ash/Ordinary Portland Cement (OBHA/OPC) Concrete

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ABSTRACT

This research work examined the influence of oil bean husk ash (OBHA) content ─ as ─ supplementary cementitious material (SCM) ─ on the flexural and splitting tensile strengths of concrete. River sand with particles passing 4.75mm BS sieve and crushed aggregate of 20mm maximum size were used while the OBHA used was of particles passing through 212µm BS sieve. OBHA/OPC concrete beams (150mm x 1500mm x 600mm) and cylinder (150mm x 300mm) with 0%, 10%, 15%, 20%, 25% and 30% substitutions of OPC with OBHA were made, cured and tested at the ages of 7, 14, 21 and 28 days for flexural and tensile strengths. The water–cement ratio (w/c) was 0.5 and a mix ratio of 1: 2: 4 were cured. At 28days, the maximum flexural strength was 3.102 N/mm^2 (10% substitution); and the maximum splitting tensile strength was 1.473N/mm^2 (10% substitution). The control samples (0% OBHA substitution) at 28 days gave 3.494N/mm^2 and 1.710 N/mm^2 for flexural and tensile strengths respectively. Flexural and splitting tensile strengths results and curves for OBHA/OPC concrete showed increase in strength as the curing days of concrete increased and also decrease in strength as the OBHA level increased. Flexural strength and splitting tensile strength test results of OPC/OBHA concrete were found to be lower compared to those of normal OPC concrete at 28 days. . The mathematical models that can be used for the prediction of theflexural and splitting tensile strength of OBHA/OPC concrete were also created by the Response Surface Method (RSM) using the Design Expert Software Application. The optimizations were done and the results were validated.

Keywords: Flexural strength, Split tensile strength, Oil bean husk ash and ordinary Portland cement

1. Introduction

The African oil bean (*PentaclethramacrophyllaBenth*) is a tropical tree crop found mostly in the Southern and Middle Belt Regions of Nigeria and in other coastal parts of West and Central Africa (Asoegwu, et al., 2006). It belongs to the *Leguminosae*family and the sub-family of *Mimosoideae*with no known varietal characterization (Keay, 1989). The tree is recognized by peasant farmers in Eastern Nigeria for its soil improvement properties and as a component of the agro-forestry system (Okafor and Fernandez, 1987). Madukasi, et al., (2016) described African Oil bean seed husk as the outer pod that covers a bean seed and also a biomass that is discarded indiscriminately in Eastern part of Nigeria. Oil Bean Husk Ash (OBHA) is an agro-waste generated from Oil Bean Husk. It is obtained from the combustion of oil bean husk residues of oil bean tree. Therefore, Oil bean husk ash whose chemical composition contains a large amount of silica, when used in cement replacement, can help to recover these heavy metals and prevent soil and underground water pollution. Due to much demand of cement (OPC) for the production of concrete and other construction works, experts and researchers in concrete technology had strived over the years to produce or discover alternative conventional building material (binder) that are cheaper and easily accessible**.** The reduction of cement content in concrete can also be achieved by utilization of supplementary cementitious materials such as fly ash, blast furnace slag, natural pozzolans, and biomass ash Sooraj (2013),. Recently, the use of pozzolana materials as concrete ingredient is gaining popularity and one such material is Oil bean husk ash (OBHA). American Society for Testing and Materials (ASTM 618: 2008) describes pozzolana as a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Flexural and tensile strengths are among the most important mechanical properties of concrete (Weilai, et al., 2017). The value of tensile strength of concrete affects its performance in structures and should be appropriately considered in structural designs (Weilai, et al., 2017).Tensile stresses can also be caused by warping, corrosion of steel, drying shrinkage and temperature gradient (Sowmya, 2020). Flexural strength of concrete (modulus of rupture) is an indirect measure of the tensile strength of the unreinforced 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.

2.0 Literature review

Jayaraman et al. (2012) studied tensile test of concrete made with lateritic sand and limestone filler as fine aggregates. The limestone filler was varied at intervals of 25% while the laterite was varied from 0% to 100%. They observed that at water/cement ratio of 0.55, the tensile strength ranged from 10.06N/mm^2 to 15.5 N/mm^2 for all the mixtures considered. The concrete was found to be suitable for structural works, while laterite content didn't exceed 50%. Upata and Ephraim (2012) studied the flexural and tensile strength properties of concrete using lateritic soil and quarry dust as fine aggregates. Their results showed flexural strengths of 3.28N/mm^2 for 50% laterite: 50% quarry dust and 2.88N/mm^2 for 25% laterite: 75% quarry dust. Similarly, tensile strengths were 2.91N/mm^2 for 50% laterite: 50% quarry dust and 1.67N/mm^2 for 25% laterite: 75% quarry dust. The results showed that both flexural and tensile strengths increases with increase in laterite content. The results also suggested that concrete containing mixtures of lateritic sand and quarry dust can be reasonably used in structural elements as for normal concrete (concrete with river sand as fine aggregate). Linora et al. (2015) investigated the optimum possibility of replacing cement partially by red mud in concrete. They reported that 15% of cement can be optimally replaced by red mud beyond which compressive strength, split tensile strength, and flexural strength starts to decrease. They also reported that cement replacement by red mud up to 15% yielded characteristic strengths greater than conventional concrete. Nova (2013) reported that the increase in metakaolin content improved the split tensile and flexural strength of the concrete up to 15% replacement. Arivalang (2012), studied split tensile strength properties of basalt fiber concrete member. He discovered that the compressive strength and the split tensile strength of basalt fiber concrete specimen were higher than those used for the control (concrete specimen) at all ages. Also, the strength difference between basalt fiber concrete specimen and the control concrete specimen were high at the beginning age of curing. The concrete attained splitting tensile strength in the range of 123% - 125% at 28days when compared to the control at 28days.Wakchaure et al. (2012), researched on the split tensile test on plain cement concrete with natural sand as fine aggregate and the other with artificial sand. They reported that the tensile strength difference between the two concretes were marginal, the values being 3.78MPa for the natural sand concrete and 3.71MPa for artificial sand concrete. They also stated that the split tensile strength for all specimen, were more than 10% of compressive strength of the concretes.

3.0. Materials and Methods

3.1 Materials

The materials used for this research work are ordinary Portland cement (OPC), oil bean husk ash (OBHA), fine aggregates (River sand), coarse aggregates (Granite/Chippings) and Water. These materials were sourced locally within Imo state, Nigeria.

Dangote 3X is a Portland limestone cement conforming to the Nigerian cement standards NIS 444-1 (2003), EN 197-1 (2000) and EN 197-1 (2011) specifications was used in all the concrete mixtures. Oil bean husk ash was produced from the process of recycling local oil bean husk produced by boiling Oil bean seeds in water for over six hours to separate the brown husk from the fleshy cotyledons. The husk was sourced locally, dried and heated in an improvised oven for over 10 hours at very high temperatures. Sieve analyses of both OBHA and sand were carried out with sieve size No. 4, 10, 40, 100 and 200. In this research, OBHA passing 425 µm sieve was used. 10%, 15%, 20%, 25% and 30% of OBHA will be incorporated as replacement for OPC. The coarse and fine aggregates used were crushed granite and river sand from local quarries. The grading of fine aggregates conformed to BS 882 (1992). Sieve analyses of both fine and coarse aggregates were done in accordance with BS 812: part 103 (1983) and the test sieve selected according to BS 410 (1986). The sieving was performed with a sieve shaker machine. Sieve analysis of sand was carried out with sieve size Nos. 4, 10, 40, 100 and 200. Portable and clean water free from any impurities was used in the course of the project. It conformed to BS 3148 (1980) and BS EN 1008:2002 requirements.

3.2 Methods

3.2.1 Specimen Preparation/Mix design

The concrete mixtures were prepared inside the laboratory using OPC and percentage replacement levels (10%, 15%, 20%, 25% and 30%) of OBHA to OPC. The concrete and mortar constituents were weighed in required proportions and mixed in a concrete mixer. All the concrete and mortar specimens were prepared with a water-cement (w/c) ratio of 0.5. Potable water was used for the mixture and the curing of the specimens (concrete). The ratio of 1:2:4 were kept constant in all the concrete mixtures.

3.2.2 Batching, Casting Compaction and Curing of Concrete

Batching of the components of the concrete was by weight and mixing was done with the help of concrete mixer. Required proportion of OPC and OBHA were mixed with the fine aggregate, coarse aggregate and water at required proportions. Water was added gradually and the concrete was mixed thoroughly to ensure homogeneity. The oiled plastic moulds, free from any foreign material were arranged close to the platform. The concrete was simultaneously filled in the moulds approximately 150mm thick and each layer was compacted using tamping rod. The surplus on the mould were stripped off and leveled by hand trowel. The specimens were packed neatly to maintain proper hydration of the cement. (BS.1881-103:1983 and BS. 1881-103: 1993). Two different types of concrete specimen were produced in the laboratory. These included; 150mm x 150mm x 600mm concrete prototype beam specimen prescribed according to BS 1881-118 (1983) and 150mm x 300mm cylindrical concrete specimen prescribed according to BS EN 12390-6:2009. After casting, placing, compacting and finishing operation, all specimens were covered with a plastic sheet till demoulding. The specimens were demolded after 24 hours and immersed in water in a water tank for 7, 14, 21 and 28 days. This was done in accordance with BS 1881: Part 111, (1983). Once the desired curing period was completed, the specimens were taken out from the curing tank and prepared for test program.

3.3 Tests

3.3.1 Chemical Composition

Chemical composition analysis for OBHA was done to determine the amount of silica, Ca, K, Mg, Na, Al, Fe. Loss on Ignition was done as per standard method.

3.3.2 Flexural Strength Test

Modulus of rupture of concrete is determined by the Flexural Strength Test using a simple beam. This was done in accordance with BS. 18811 Part 118: (1983). The flexural tensile strength or modulus of rupture, f_b can also be calculated as follows:

$$f_b = \frac{PL}{bd^2} \qquad (3.1)$$

Where, P is maximum applied load in kg,

bis average width of specimen at the point of fracture

dis average depth of specimen at the point of fracture

3.3.3 Splitting Tensile Strength Test

This test method measures the splitting tensile strength of concrete by the application of a compressive force on a cylindrical concrete specimen placed with its axis horizontal between the platens of a testing machine, (BS.1881- 117: 1983). The splitting tensile strength, T can be calculated as follows:

$$T = \frac{2P}{\pi dl} \quad (3.2)$$

Where, P is maximum load at failure, d is average diameter of cylinder and l is the average length of the concrete specimen.

4.0. Results and Discussion

4.1Results

4.1.1: Chemical Composition of Oil Bean Husk Ash (OBHA) Result

The results of the chemical composition test conducted on the oil bean husk ash and ordinary Portland cement are displayed in Table 4.1

Table 4.1: Chemical Composition of Oil Bean Husk Ash (OBHA)

Oxide	Symbols	Percentage Composition (%)	OPC (BS 12 Ranges)
Silica(SiO_2)	SiO_2	5.23	17-25
Ferrous oxide (Fe_2O_3)	Fe_2O_3	7.68	0.5-6.0
Aluminum oxide	Al_2O_3	3.17	3-8
Calcium oxide	CaO	39.89	60-67
Magnesium oxide	MgO	22.76	0.1-4.0
Sulfur trioxide	SO_3	1.00	1.0-2.0
Potassium oxide	K_2O	0.03	
Lead (ii) oxide	PbO	20.23	

The results show that OBHA has the combined percentage of (SiO_2 + Al_2O_3 + Fe_2O_3) of 16.08%.The CaO content (39.89%) in OBHA shows that it has some self-cementing properties.

4.1.2: Experimental Result of The Flexural strength Tests

The experimental result of the flexural strength tests of OBHA concrete cubes are shown in table 4.2. The 28-day flexural strength of 100% OPC (0% OBHA) concrete is 3.494 N/mm^2 and it is the maximum flexural strength. The 7-day compressive strength of 70% OPC (30% OBHA) concrete is 0.840 N/mm^2 and it is the minimum flexural strength.

Table 4.2. The Flexural Strength Test Results

Amount of Cement (%)	Amount of OBHA (%)	Design Strength (N/mm^2)			
		7 Days	14 Days	21 Days	28 Days
100	0	1.759	2.871	3.187	3.494

90	10	1.280	2.341	2.601	3.102
85	15	1.179	2.111	2.323	2.784
80	20	1.020	1.915	2.121	2.552
75	25	0.968	1.856	2.101	2.343
70	30	0.840	1.752	1.860	2.230

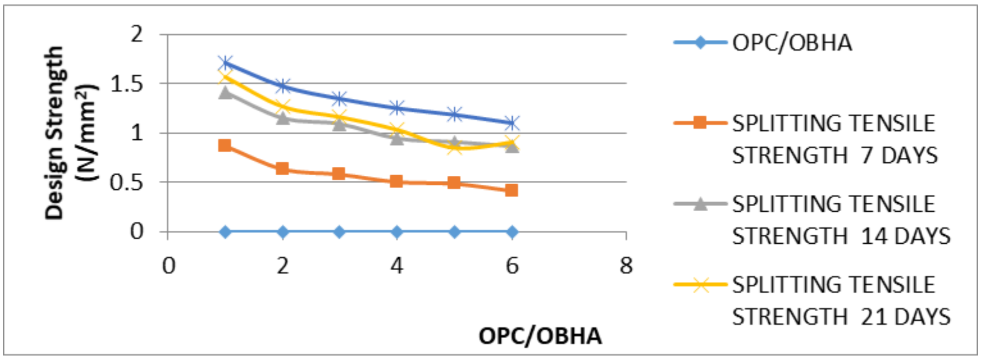

Figure 4.1: Flexural strength development of concrete mixes.

The flexural strength curve for OPC/OBHA concrete shows increase in strength as the curing days of concrete increase and decrease in strength as the OBHA level increases.

4.1.3: Experimental Result of The Splitting Tensile Strength Test

The experimental result of the splitting tensile strength tests of OBHA concrete cubes are shown in table 4.3. The 28-day splitting tensile strength of 100% OPC (0% OBHA) concrete is 1.710 N/mm^2 and it is the maximum splitting tensile strength. The 7-day splitting tensile strength of 70% OPC (30% OBHA) concrete is 0.410 N/mm^2 and it is the minimum splitting tensile strength.

Table 4.3: The Splitting Tensile Strength Test Results

Amount of Cement (%)	**Amount of OBHA (%)**	**Design Strength (N/mm^2)**			
		7 Days	14 Days	21 Days	28 days
100	0	0.862	1.412	1.570	1.710
90	10	0.630	1.148	1.270	1.473
85	15	0.576	1.087	1.164	1.346
80	20	0.500	0.938	1.034	1.250
75	25	0.482	0.902	0.985	1.184
70	30	0.41	0.859	0.910	1.100

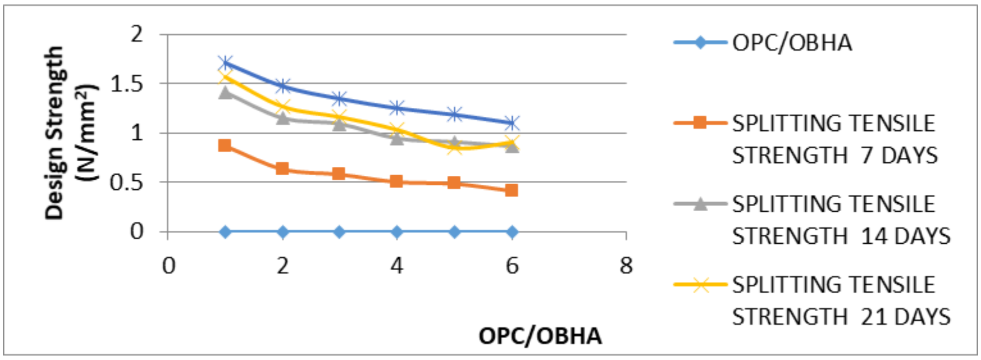

Figure 4.2: Splitting tensile strength development of concrete mixes.

4.2 Statistical/Mathematical Model Analyses

4.2.1 Statistical/Mathematical Model Analyses for the Flexural Strength of Cement/OBHA Concrete Using Design Expert Software.

Table 4.4: Analysis of Variance Table forFlexural Strength of OPC/OBHA Concrete

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	11.73	9	1.30	463.42	< 0.0001	Significant
A-Cement/OBHA	0.37	1	0.37	130.58	< 0.0001	
B-Time(Days)	0.094	1	0.094	33.33	< 0.0001	
AB	0.073	1	0.073	25.81	0.0002	
A^2	0.093	1	0.093	32.95	< 0.0001	
B^2	0.51	1	0.51	181.74	< 0.0001	
A^2B	4.330E-003	1	4.330E-003	1.54	0.2352	
AB^2	6.118E-003	1	6.118E-003	2.17	0.1624	
A^3	1.038E-004	1	1.038E-004	0.037	0.8504	
B^3	0.24	1	0.24	86.95	< 0.0001	
Residual	0.039	14	2.814E-003			
Cor Total	11.77	23				

The analysis of variance model for flexural strength done with 95% confidence is displayed in Table 4.4. A P-Valueof <0.0001 indicates the model is significant. The F-value of 463.42 implies that the model is significant. There is only a 0.01% chance that an F-value of this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicate that the model terms are significant. In this case, A, B, AB, $A^{\wedge 2}$, $B^{\wedge 2}$, $B^{\wedge 3}$ are significant model terms.

4.2.3: Mathematical Model for Flexural Strength of OPC/OBHA Concrete

Equation 4.1 is the mathematical model for the optimization of the flexural strength of OPC/OBHA concrete in terms of coded factors

Mathematical Model for the Flexural Strength, FST result of the OPC/OBHA concrete: $+2.29 + 0.62A + 0.31B + 0.11AB + 0.15A^2 - 0.33B^2 - 0.043A^2B - 0.055AB^2 - 0.11A^3 + 0.51B^3$

(4.1)

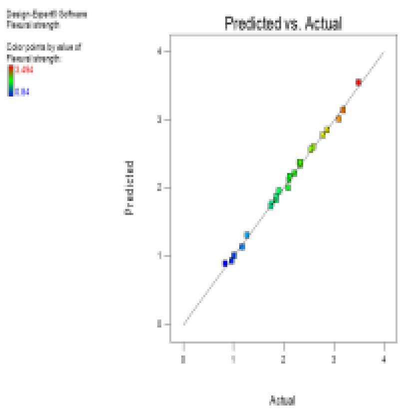

Figure 4.3A: Graph of Predicted vs Actual

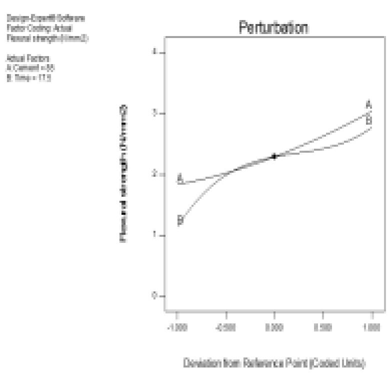

Figure 4.3B: Perturbation plot

Figure 4.3A is the graph of Predicted vs Actual Flexural Strength of OPC/OBHA concrete whilefigure 4.3B is the Perturbation plot on flexural strength response with reference point of 0.00

Figure 4.3A shows a strong correlation between the predicted details and actual/experimental details. The maximum flexural strength of OPC/OBHA concrete value is 3.494kN/m^2 while the minimum value is 0.84 kN/m^2. The perturbation graph (Figure 4.3B) shows that any increase of cement in concrete increases the flexural strength (FST) and increase in curing time (days) increases the flexural strength of OPC/OBHA concrete.

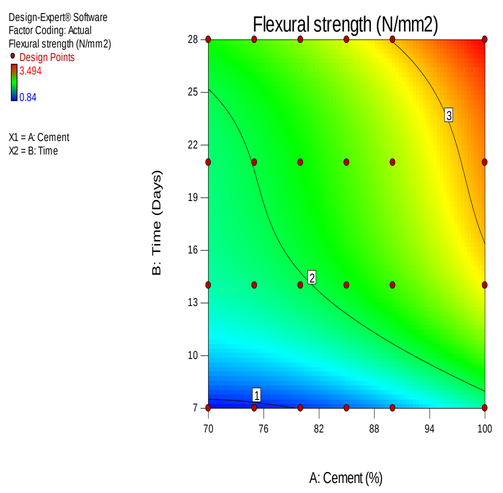

Figure 4.4A: 2Dimensional Contour of OPC/OBHA

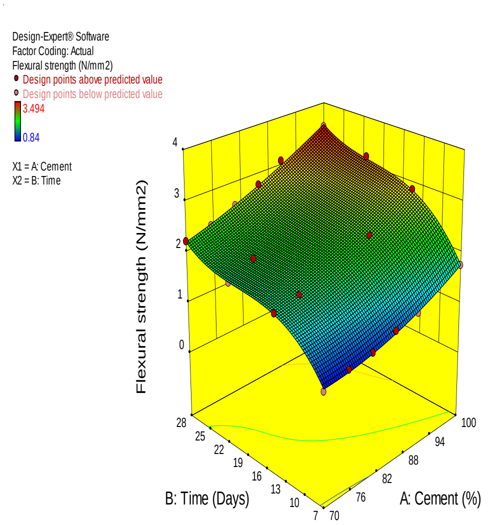

Figure 4.4B: 3Dimensional Contour of OPC/OBHA

Figure 4.4A and B are 2&3Dimensional Contour of factors (OPC/OBHA) on flexural strength test response. The figures shows the contour is elliptical which indicates interactions between the two factors on the model.

4.2.4: Optimization of the Flexural Strength Test Result

Table 4.5: Optimization Criteria

Factor and Response	Limits		Criterion	Goal
	Lower	Upper		
Oil Bean Husk Ash (OBHA) %	10%	30%	In range	In range
Cement (OPC) %	70%	90%	In range	In range
Time (Days)	7	28	In range	In range
Flexural Strength (KN/m^2)	0.84	3.102	Maximize	Minimize

Table 4.18 shows the optimization factors and response limits corresponding to required goals. Each factor and response was given a criteria that was within the design space as represented in the range. Figure 4.11A, 4.11B and 4.11C are representations of the optimized result as output by the Design Expert software.

4.2.5 Optimization Output For Maximizing the Flexural Strength.

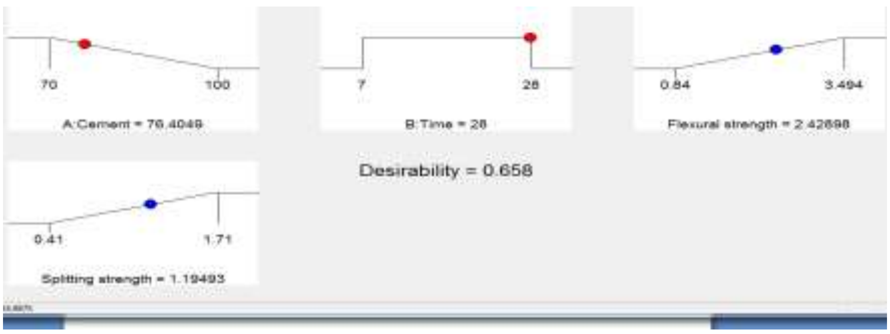

Figure 4.5: The solutions of the optimization for maximum FST factor of 0.658,

Figure 4.5 show the solutions of the optimization for maximum FST factor of 0.658. The output optimization result is considered in terms of its average after 28days of curing. The Output Optimization Result = 2.429 kN/m^2

4.2.6:Validation of Optimized Flexural Strength TestResult

Validation of test was achieved from the average output values in figure 4.11 A, B and C. The predicted and actual test results were compared in Table 4.19. The differences are negligible.

Table 4.6: Validation of Test

S/n	**OPC/OBHA (%)**	**Time (Days)**	**FST**	
			Predicted	**Actual**
Trial 1	**76.40/23.60**	**28**	**2.429**	**2.430**

The maximum validation result for flexural strength of 10% OBHA replacement with cement in concrete for 28days curing is 2.434 kN/m^2

4.2.7: Statistical/Mathematical Model Analysis for Splitting Tensile Strength of Cement/OBHA Concrete Using Response User Method in Design Expert Software.

4.2.8Analysis of Variance for Splitting Strength of OPC/OBHA Concrete

The analysis of variance model for splitting tensile strength done with 95% confidence is shown in Table 4.21. The P-Valueof <0.0001 indicates the model is significant.

Table 4.7:Analysis of Variance Table (Partial Sum of Squares).

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob> F**	
Model	2.79	9	0.31	788.36	< 0.0001	Significant
A-Cement/OBHA	0.091	1	0.091	231.66	< 0.0001	
B-Time	0.015	1	0.015	38.55	< 0.0001	
AB	0.013	1	0.013	33.21	< 0.0001	
A^2	0.022	1	0.022	56.98	< 0.0001	
B^2	0.13	1	0.13	339.35	< 0.0001	
A^2B	1.070E-004	1	1.070E-004	0.27	0.6101	
AB^2	5.091E-003	1	5.091E-003	12.95	0.0029	
A^3	1.534E-005	1	1.534E-005	0.039	0.8463	
B^3	0.067	1	0.067	171.14	< 0.0001	
Residual	5.506E-003	14	3.933E-004			
Cor Total	2.80	23				

The F-value of 788.36 implies that the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicate that the model terms are significant. In this case A, B, AB, A^2, B^2, AB^2, B^3 are significant model terms. Values greater than 0.1000 indicate that the model terms are not significant.

4.2.9 Mathematical Model for Splitting Tensile Strength (STS) of OPC/OBHA Concrete

The equation in terms of coded factors can be used to make predictions about a response for a given level for each factor.

The Mathematical Model for the Splitting Tensile Strength, STS result of OPC/OBHA concrete: $+1.13 +0.31A +0.13B +0.048AB +0.074A^2 - 0.17B^2 -6.814E\text{-}003A^2B -0.050AB^2 +4.109E\text{-}003A^3 +0.27B^3$(4.8)

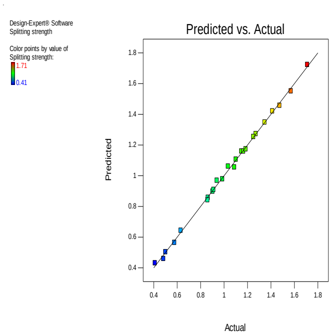

Figure 4.6A: Graph of the predicted vs actual

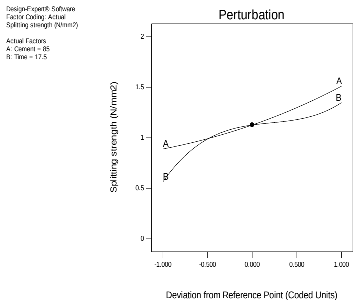

Figure 4.6B: Perturbation plot

Figure 4.6 A and B are the graph of the predicted vs actual splitting tensile strength (STS) of OPC/OBHA concrete and the Perturbation plot on splitting tensile strength response with reference point of 0.00 on STS respectively**.** Figure 4.6A shows that there is a strong correlation between the predicted details and actual/experimental details. The maximum splitting tensile strength of OPC/OBHA concrete value is 1.714kN/m^2 while the minimum value is 0.41 kN/m^2 and figure 4.12B shows that increase in OBHA causes decrease in splitting tensile strength (STS) and increase in curing time (days) increases splitting tensile strength of OBHA concrete.

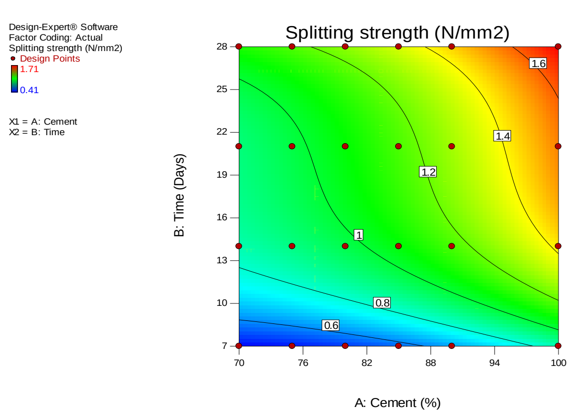

Figure. 4.7 A

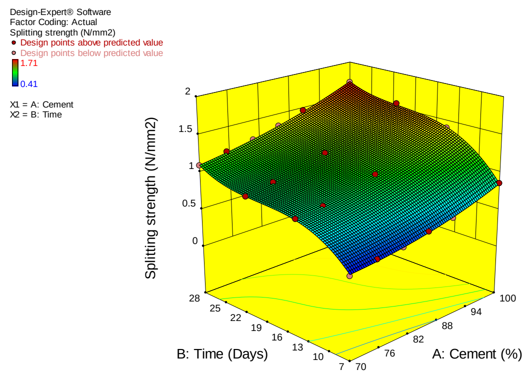

Figure. 4.7 B

Figure. 4.7 A and B are 2 and 3Dimensional contour plot of factors OPC/OBHA on splitting tensile strength test response

From Figure 4.7A and 4.7B, the contour is elliptical which indicates that there are interactions between the two factors on the model.

4.2.10: Optimization of the Splitting Tensile Strength.

Table 22 shows the optimization factors and responses limits corresponding to required goals. Each factor and response is given a criteria that is within the design space as represented in range. Figure 17A, 17B and 17C are representations of the optimized results as output by the Design Expert software.

Table 4.8: Optimization Criteria

Factor and Response	Limits		Criterion	Goal
	Lower	Upper		
Oil Bean Husk Ash (OBHA) %	10%	30%	In range	In range
Cement (OPC) %	70%	90%	In range	In range
Time (Days)	7	28	In range	In range
Splitting Tensile Strength. (kN/m^2)	0.41	1.473	Maximize	Maximize

4.10.11: Optimization Output for Maximizing the Splitting Tensile Strength

The optimization outputs are shown in Figures 4.17

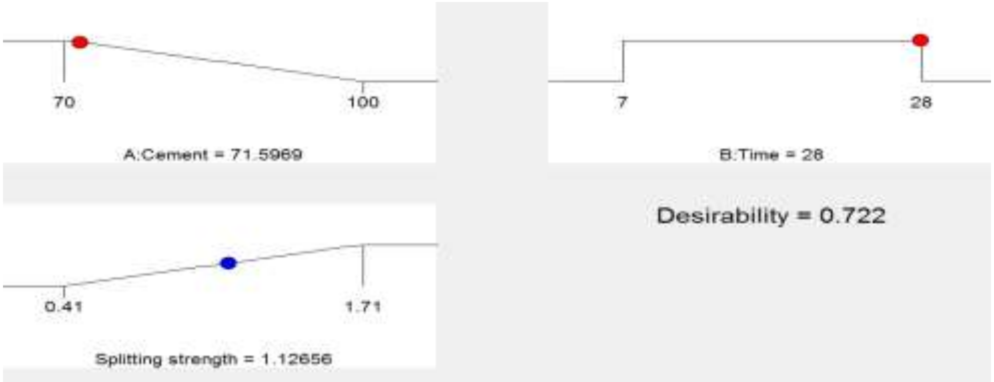

Figure 4.8: The Outputs for Splitting Tensile Strength of OPC/OBHA Concrete.

Figures 4.8 show the outputs for maximum STS factor of 0.722. The optimization result is considered after 28days of curing. The optimization result of splitting tensilestrength = 1.12656N/mm^2

4.10.12: Validation of Optimized Splitting Tensile Strength Result

The validation of the splitting tensile strength test result is achieved from the average output values of Figure 4.17 A and B. The predicted and the actual values are compared in Table 4.23

Table 4.9 Validation of Test

S/n	OPC/OBHA (%)	Time (Days)	Splitting Tensile Strength	
			Predicted	Actual
Trial 1	**71.60/28.40**	**28**	**1.127**	**1.129**

The validation result for the splitting tensile strengthof OBHA/OPC concrete after 28days of curing is 1.129kN/m^2 (Actual).

5.0 CONCLUSION

The study investigated the effects of OBHA on the splitting tensile and flexural strength development of OPC/OBHA concreteand its potentialas a supplementary cementitious material in a developing country like Nigeria.

The flexural and splitting tensile strength curves for OPC/OBHA concrete showed increase in strength as the curing days of concrete increased and also decrease in strength as the OBHA level increased. Flexural and splitting tensile strength results of OPC/OBHA concrete were found to be lower compared to those of normal OPC concrete at 28 days. Experimental results obtained from the work suggested that 20% replacement of OBHA could be the optimum level for the production of quality concrete as the strength of the OPC/OBHA concrete reduced gradually beyond this replacement level. Concrete with 30% OBHA could be used in practice for non- structural works such as mass concreting where strength is not a very important factor. The mathematical model created showed a good relationship between OPC/OBHA concrete. The optimization gave good results which were used for validation in the laboratory.

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