IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 23, Issue 1 Ser. 2 (Jan - Feb 2026), PP 11-32
www.iosrjournals.org

Prediction Of Strength Properties Of Concrete Blended With Pentaclethra Macrophylla Benth Husk Ash And Artocarpus Altilis Husk Ash Using R-Programming

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Abstract
This research investigates the influence of Penterclethra Macrophylla Benth Husk Ash which is the Scientific name for African Oil Bean Husk Ash (OBHA) and Artocarpus Altilis Husk Ash which is also the Scientific name for Breadfruit Husk Ash (BHA) as partial replacements for Ordinary Portland Cement (OPC) on slump, setting time, and mechanical properties of Concrete, specifically compressive, flexural and split tensile strengths. Fine aggregate passing a 5.00 mm BS sieve and 20 mm maximum size crushed aggregate were used. OBHA and BHA, both finely ground, were used in equal proportions to replace OPC at 0%, 5%, 10%, 15%, 20% and 30% by weight. Concrete samples in the form of cubes (150 mm x 150 mm x 150 mm), beams (150 mm x 150 mm x 700 mm), and cylinders (150 mm diameter x 300 mm height) were prepared, cured and tested at 3, 7, 14, 21, 28 and 90 days. A water-cement ratio 0.6 and a mix ratio of 1: 2.14: 4.18 were maintained throughout. Slump test results indicated an increase in workability with higher OBHA/BHA content, with all values within acceptable limits. Both initial and final setting times increased with increasing OBHA/BHA percentages, indicating a retardation of the hydration process. Initial setting times ranged from 137 minutes at 5% replacement to 165 minutes at 30%. Mechanical testing showed that Compressive, Flexural and Split Tensile Strengths generally decreased as the level of OBHA/BHA increased, although strength development progressed over curing time. The Compressive, Flexural, and Split Tensile Strength of concrete obtained ranges from (3.65N/mm^2 – 29.84N/mm^2), (0.50N/mm^2 – 3.79N/mm^2) and (0.28N/mm^2 – 2.06N/mm^2) respectively. At 28 days, the highest strengths were observed at 5% replacement, with strengths of 23.13 N/mm^2, 3.10 N/mm^2 and 1.50 N/mm^2, compared to control samples (0% replacement) which achieved 26.04 N/mm^2, 3.49 N/mm2, and 1.69 N/mm^2 respectively. Additionally, predictive mathematical models for the mechanical properties of OBHA/BHA blended concrete were developed and validated using R-Programming software. The model confirms that strength increases with curing time, with the most rapid gains in the first 7-14 days. The logarithmic relationship suggests diminishing returns with extended curing. Therefore, the developed model successfully captures the complex relationships between cement content, curing age, and mechanical strengths. It provides both accurate predictions and practical optimization capabilities for concrete mix design. The excellent statistical metrics and logical coefficient signs confirm the model's validity for the tested conditions. These findings suggest that moderate OBHA/BHA replacement can enhance sustainability in concrete production, though higher replacement levels reduce strength.
Significance: *The significance of this study lies in its contribution to the understanding of the effects of oil bean husk ash on concrete produced with breadfruit husk ash. The findings of this study will provide valuable insights for Engineers, Architects, and Construction professionals on how to look after concrete structures containing admixtures like OBHA and BHA. This Study offers an opportunity to contribute to sustainable construction practices by exploring the potential of agricultural waste products in concrete. The use of agricultural waste materials in concrete production has gained attention due to its potential benefits in sustainability and cost reduction. Oil bean husk ash (OBHA) and breadfruit husk ash (BHA) are two such materials that can be used as admixtures in concrete. By understanding the effects of Oil bean husk ash on concrete produced with breadfruit husk ash, and providing recommendations on optimal proportions of oil bean husk ash and breadfruit husk ash in concrete, this study will contribute to the development of more durable and safer structures. Similarly, by evaluating the impact of OBHA on the mechanical properties of concrete with BHA, you can gain valuable insights into the use of these alternative materials. Also by exploring the synergistic effects of OBHA and BHA in concrete, the study will contribute to the development of eco-friendly construction materials that not only reduce environmental impact but also enhance the performance and longevity of concrete structures. Another significance of this thesis is that research paper will be published that will be used as an academic tool to help students handle similar or related thesis with confidence.*

Keywords: *Breadfruit husk ash, Compressive Strength, Flexural Strength, Mathematical modeling, Oil bean husk Ash, Setting time, Split tensile Strength and R-Programming.*

Date of Submission: 02-02-2026 Date of Acceptance: 12-02-2026

I. Introduction

Concrete is a composite material composed of cement, aggregates (fine and coarse) and water and no other material can match it in terms of resilience, strength, and wide availability, and is therefore the most produced construction material on the planet (Alhassan *et al*., 2024). Concrete is one of the most widely used construction materials globally, primarily due to its versatility, durability, and cost-effectiveness. For concrete to be suitable for a particular purpose, it is necessary to select the constituent materials and to combine and use them in such a manner as to develop the special properties required. It is a known fact that concrete is widely used construction material due to its high compressive, flexural, split tensile strength and durability. However, in a relationship with a growing population there will be increase in demand use for concrete. Years by years have passed, concrete also is not left behind in following the revolution as it keeps improving to become a better quality concrete, start with normal concrete (NC), then high strength concrete (HSC), also up until ultra-high strength concrete (UHSC). Usually, HSC consist of a high amount of cement but low with water-cement ratio including highly reactive pozzolanic materials. (Syamsul, 2017) stated in his paper that HSC must have compressive strength 41 Mpa and greater than that. According to (Hana *et al*., 2019), the usage of cement probably contributes towards the high emission of carbon towards the atmosphere. Thus, another alternative should be taken in replacing the amount of cement that will be used in producing concrete. Nowadays, the concrete industry is finding their way to use agro-waste materials since they are abundant, easily found and cost-effective, not only by using these materials could decrease the amount of carbon dioxide but also these materials could improve the concrete materials as general. (Uysal *et al*,. 2022), in their findings stated that the production of traditional Portland cement, a key ingredient in concrete, is associated with significant environmental impacts, including high energy consumption and substantial Carbon dioxide (CO_2) emissions. As a result, there is a growing interest in exploring alternative materials that can partially or fully replace Portland cement in concrete production or act as an admixture to cement.

There has recently been a trend in literatures to allow supplementary materials or by- products to be used as admixtures in concrete production as one way to reduce pollution and environmental disturbances, while offering complementary properties to compensate natural aggregate loss in concrete. Therefore, cement replacements in concrete can be highly beneficial regarding cost, energy efficiency, low permeability, strength and durability (Kasselouri, 2017).

This publication offers an opportunity to contribute to sustainable construction practices by exploring the potential of agricultural waste products in concrete. Both oil bean and breadfruit are widely cultivated in various regions, and their husks are often discarded as waste. Utilizing these by products as admixtures not only addresses waste management issues but also contributes to the development of more sustainable construction materials (Eloget *et al*,. 2021).

The African oil bean (Pentaclethra Macrophylla Benth) is a tropical tree crop found mostly in the Southern and Middle Belt Regions of Nigeria and in other costal parts of West and Central Africa (Adeshina *et al*,. 2018). It belongs to the Leguminosae family and the sub-family of Mimosoideae (Keay, 1989) with no known varietal characterization. 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. Both Oil bean husk ash (OBHA) and breadfruit husk ash (BHA) are to be used as admixtures. Admixtures are components added to concrete (other than water, aggregates or cement) to alter and enhance the properties of the concrete, from acceleration or retardation of setting time to increased workability, resistance (from weather and chemical attacks) and strength. Therefore, Oil bean husk ash whose chemical composition contains a large amount of silica, when used as an admixture in concrete, can help to recover these heavy metals and prevent soil and underground water pollution. Due to much demand of Ordinary Portland 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**.** 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 C 618 : 2023) describe 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. Similarly, Breadfruit (Artocarpus Altilis) is a species of flowering tree in the mulberry and jackfruit family (Moraceae) believed to be a domesticated descendant of Artocarpus camansi originating in New Guinea, the Maluku Islands, and the Philippines. It was initially spread to Oceania via the Austronesian expansion. (https://en.wikipedia.org).

Breadfruit seeds are encased in a large football-sized, oval to oblong fruit. The fruits typically have a prickly, yellow-green to yellow-brown skin coloring, but their appearance may vary depending on the specific variety (https://specialtyproduce.com). Breadfruit seed husk is the outer pod that covers a breadfruit seed and also a biomass that is discarded indiscriminately in Eastern part of Nigeria. Breadfruit Husk Ash is an agro-waste generated from Breadfruit seed Husk. It is obtained from the combustion of Breadfruit Seed Husk residues of Breadfruit tree.

Both oil bean husk ash and breadfruit husk ash are examples of agricultural by-products that can be used as admixtures in concrete. Using such materials not only helps in waste management but also can enhance the properties of concrete in various ways. Supplementary Cementitious Materials are added to concrete mixtures for various reasons including improving durability, decreasing permeability, aiding in pump ability and finish ability, mitigating alkali reactivity and improving the overall hardened properties of concrete as admixtures. The chemistry of supplementary cementitious materials is generally characterized by lower calcium content than Portland cement. The use of these materials in concrete has also grown considerably over the past 30 years in that they are typically by products of industrial processes and their use can contribute to environmental and energy conservation practices. Compressive, 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.

The effect of Oil bean husk ash and Breadfruit husk ash on concrete involves understanding how these materials, when used as admixture; influence the properties of the concrete. Both types of ashes are considered pozzolanic materials, which mean they can react with calcium hydroxide in the presence of water to form compounds possessing cementitious properties.

Earlier studies have shown that various agricultural wastes can be used as admixtures or cement replacements in concrete. For instance, Cocoa Pod husk ash, Oil shale ash, rice husk ash (RHA), Palm kernel husk ash and palm oil fuel ash have been successfully used to improve the mechanical properties and durability of concrete (Subramaniam and Navaratnarajah, 2022).

According to Kavitha and Vidhya (2022), the study found out that the use of agricultural waste materials in concrete production has gained attention due to its potential benefits in sustainability and cost reduction. Oil Bean Husk Ash (OBHA) and Breadfruit Husk Ash (BHA) are two such materials that can be used as admixtures in concrete.

According to (Madukasi *et. al.,* 2016), Oil Bean Husk Ash (OBHA) obtained from burning Oil Bean Husk, as an admixture contains silica, which can react with calcium hydroxide released during the hydration of cement to form additional calcium silicate hydrate (C-S-H), the primary strength-giving compound in concrete. Similar to Oil Bean Husk Ash, Breadfruit Husk Ash (BHA) also as an admixture in concrete contains a significant amount of silica (Smita et al., 2021). The exact chemical composition can vary based on the burning process and the origin of the husks.

Pozzolans, commonly referred to as "cement extenders," are substances that exhibit cementitious properties when mixed with calcium hydroxide. The quality and workability of the concrete are improved as a result of the reaction between the components of concrete and pozzolans. Pozzolanic activity is shown by natural or industrial materials containing silicates, aluminium silicates or their mixtures. These materials do not harden mixed with water; however, when finely ground in the presence of water they react with dissolved Calcium hydroxide [$Ca(OH)_2$] forming silicates, calcium aluminates and thus increasing its strength. These compounds are similar to products that are formed during the hardening of hydraulic materials (Malhotra *et al.,* 1987).

Previous studies found out that RHA is a highly reactive pozzolanic material suitable for use in lime-pozzolana mixes and are often used to blend with Ordinary Portland Cement. Based on the temperature range and the duration of burning of the husk, crystalline and amorphous forms of silica are obtained (De Silva *et al*., 2021). The crystalline and amorphous forms of silica have different properties and it is important to produce ash with correct specifications for specific end use (Muthadhi *et al*., 2006).

Kasselouri (2017) stated in early works that the use of industrial by-products, such as Fly Ash offers a low-priced solution to the environmental problem of depositing industrial waste. Research works in this regard have proved that inclusion of these pozzolanic materials as admixtures not only improves the strength and durability of concrete but also can be considered helpful in reducing global warming caused by disposal of waste materials.

According to a study by (Villar *et al*., 2003), there will be a Pozzolanic Activity when Oil bean husk ash (OBHA) is used in concrete that already contains breadfruit husk ash (BHA) as both OBHA and BHA are pozzolanic materials to mortar or concrete mix. The study found out that both OBHA and BHA contain silica, which can react with calcium hydroxide in the presence of water to form additional calcium silicate hydrate (C-S-H), the compound responsible for the strength in concrete.

The Study further found that similar to oil bean husk ash, breadfruit husk ash also contains silica and possibly other reactive oxides which getting in touch with Calcium hydroxide in the presence of humidity forms compounds exhibiting cementitious properties (Papadakis *et al*., 2002). The specific chemical composition can vary based on the burning temperature and conditions. Researcher, (Sameer , 2009) stated that pozzolanic material is in powder condition . When this pozzolanic material is added into concrete it will react with lime, this combination will produce concrete high in strength also could improve concrete properties.

Another study by (Habeeb *et al*., 2009) found that using OBHA in concrete that already contains BHA, that the workability of concrete can be affected by the particle size and shape of the ashes. OBHA and BHA might have different effects on the workability. The lower the workability, the higher the strength of concrete produced which agrees with the work of (Zhang *et al*., 1996; (Ismaila, 1996); (Rodriguez, 2005) who investigated the effects of OBHA in concrete that already contains BHA as admixtures. Generally, the inclusion of fine ashes can affect workability, necessitating the use of super plasticizers to maintain the desired consistency.

Researchers (Hany *et al*,. 2021) found out that the durability of concrete can be enhanced by the inclusion of these ashes. As overall they can help with the concrete act as filler and also help in the performance in reducing the permeability of concrete, thereby increasing resistance to aggressive environments

II. Aim And Objectives Of Study

The aim of the study is to investigate the effects of incorporating Oil Bean Husk Ash (OBHA) on the mechanical properties of concrete containing Breadfruit Husk Ash (BHA), as well as model the concrete produced there from using R-Programming.

The Objectives are;

i. Developing concrete mixes incorporating combination of equal dosages of Oil Bean Husk Ash and Breadfruit Husk Ash as admixtures with variations at regular intervals and comparing them with only plain concrete (Control).
ii. Evaluating the combined influence of OBHA/BHA on the mechanical properties at different curing ages.
iii. Determining the variations in workability of the concrete mixes with varying percentages of OBHA/BHA.
iv. Determining the variations on initial and final setting times of cement produced with varying percentages of OBHA/BHA comparing these mixes to those with Ordinary Portland cement (control).
v. Developing Mathematical Modeling using R-Programming for optimization and predictions of compressive, flexural and split tensile strengths of OBHA/BHA and Ordinary Portland Cement (OPC) Concrete.

III. Scope Of The Study

The study was limited to producing concrete mixes with varying percentages of Oil bean husk ash and Breadfruit husk ash at equal combination to make up to contents subjected to curing at 3, 7, 14, 21, 28 and 90 days. The tests that were carried out in this study were Compressive Strength, Flexural Strength, Split Tensile Strength, slump, initial and final setting times. Finally, a control mix of concrete was developed using Ordinary Portland Cement (OPC), Water and aggregates. In all, a constant water-cement ratio was maintained and Statistical/Mathematical models for prediction of mechanical properties of OBHA/BHA concrete was developed using R-Programming. The findings and the models developed can only be applicable to River sand collected from Water side River, from a Riverside Area located along the Aba River, with general coordinates in the city of **5.1167° N, 7.3667° E** located at Aba, Abia State, Nigeria and crushed granite stone Aggregates from Ishiagu Quarry, Ebonyi State, Nigeria generally around **5.96° N Latitude and 7.56° E Longitude.**

IV. Methodology

The materials used for this research work are Pentaclethra Macrophylla Benth Husk Ash] or Oil Bean Husk Ash (OBHA), [Artocarpus Altilis Husk Ash] or Breadfruit Husk Ash (BHA), Ordinary Portland cement (OPC), Tap/Fresh Water, [fine and coarse aggregates.

Collection and Preparation of [Pentaclethra Macrophylla Benth Husk Ash] or Oil Bean Husk Ash (OBHA) and [Artocarpus Altilis Husk Ash] or Breadfruit Husk Ash (BHA)

The husks of oil bean and Breadfruit seeds were gathered and dried respectively to remove moisture content. The dried husks were burnt in a controlled environment to produce ash. The burnt ashes were allowed to cool before being collected for use. Grinding the Ashes to fine powder was done to ensure it has a similar particle size to that of cement and was sieved to remove any large particles or impurities.

Collection of Fresh Water Sample

The fresh water used was Civil Engineering laboratory water from borehole. The fresh water used was also collected in a quantity that was enough for both batching and curing of the concrete cubes and beams. The typical water-cement ratio considered was 0.60 for constant grade of concrete mix in compliance to method of making test cubes from fresh concrete according to (B.S. 1881: Part 102: 1993).

Collection and Grading Of Fine Aggregates

The fine aggregates used for batching of concrete was graded by the use of 5.0 mm BS sieve. The sieved samples were washed and dried to remove impurities which could affect the concrete or cement strength. The use of this sieve size is to conform the grading of (Seeley, 1976) for the grading of fine aggregate as zone 2. The fine aggregate (sand) used in this project is from a Riverside Area in Aba, Abia State, Nigeria located along the Aba River, with general coordinates in the city of **5.1167° N, 7.3667° E** passing through 5.00 mm sieve. The grading zone of fine aggregate (sand) was zone 2 as per (BS 882, 1992) standard specification. Fine aggregate content considered is 34% by mass or volume of the total aggregate content.

Collection and Grading Of Coarse Aggregates

The coarse aggregate used for the batching was first graded with 20 mm BS sieve. The passing sieve was first washed to remove impurities. After which the aggregates were dried before being used for batching. The passing sieve 20mm was used to conform to the BS 882 specifications and requirement according to (Seeley, 1976) for the grading of coarse aggregate. Crushed granite stone aggregate from Ebonyi State, Nigeria of maximum size 20mm conforming to BS 882 standard specification was used. The coarse aggregate used in this project was from quarry at Ishiagu, Ebonyi State, Nigeria passing sieve 20mm but retained on 5.00 mm sieve. The coordinates for Ishiagu, Ebonyi State, Nigeria, are approximately **5.96° North latitude and 7.56° East longitude**.

Collection of Cement

The cement used was Dangote 3X Cement. 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 and it was used in all the concrete mixtures. It was stored under dry condition, free of lumps and in conformity with BS 12.

Batching, Mixing of Samples, 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 Ordinary Portland Cement (OPC), BHA, and OBHA were mixed with the fine aggregates, coarse aggregates and water at required proportions. Water was added gradually and the concrete was mixed thoroughly to ensure homogeneity. The initial setting time, workability, slumps, as well as placing the concrete into the concrete cubes/cylinder moulds and concrete beam moulds was carried out. In this case, the oiled 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. Three different types of concrete specimen were produced in the laboratory. These included; 150mm x 150mm x 150mm cubes, 150mm x 150mm x 700mm concrete prototype beam specimen prescribed according to BS 1881-118 (1993) and 150mm diameter x 300mm height cylindrical concrete specimen prescribed according to (BS EN 1008- (2002). After casting, placing, compacting and finishing operation, all specimens were covered with a plastic sheet till de-molding. The specimens were de-molded after 24 hours and immersed in water in a water tank for 3, 7, 14, 21, 28 and 90 days. This was done in accordance with BS 1881-124:2015+A1:2021. Once the desired curing period was completed, the specimens were taken out from the curing tank and prepared for test program.

Mix Design Proportions

One mixture proportion was considered in this research work. Considerations were made on uncrushed maximum aggregate size of 20mm, slump range of 30-60mm, characteristics strength of 25N/mm^2 at 28 days, free water content of 180kg/m^3 and aggregate relative density of 2.6. The Free-water contents (kg/m^3) required to give various levels of consistence as measured by the slump according to the British Standard and Wet density of concrete mix of 2375kg/m^3 corresponding to free water content of 180kg/m^3 used in the mix design proportion [Source: emu.edu.tr/Bremix design (2025)]. The mix ratio of [1: 2.14: 4.18] had 34% proportion of fine aggregate corresponding to a free water/cement ratio of 0.60. The mix design was proportioned for target cube strength of 39N/mm^2 and had a Cementitious material content of 300 kg/m^3, a fine aggregate content of 644.3 kg/m^3, a coarse aggregate content of 1250.7 kg/m^3 and a water cementitious ratio of 0.60.

Slump Test
Slump test was conducted to establish the consistency of plastic concrete.

Setting Time Test
This test was carried out in accordance with the BS 12 (1978) using the Vicat apparatus, OBHA and BHA samples as Cement replacement. The Vicat apparatus uses two pins, initial and final setting time pins for the determination of initial and final setting time of cement respectively.

Compressive Strength Test
For the determination of the Compressive Strength, the concrete cube size measuring 150mm × 150mm × 150mm in dimension was used. The batching of the concrete moulds was by weight. The concrete was produced using 0, 5, 10, 15, 20, 30% Replacement of cement with OBHA and BHA respectively on equal basis. The concrete cubes moulds were cleaned and oil was applied and the moulds were filled in layers approximately 50mm thick with the mixed concrete. Each layer of concrete was compacted with not less than 25 strokes using a tamping rod. The cubes were later filled to two third of their height and finally filled completely with the top surface leveled and smoothen with trowel and left for 24 hours to set before being cured at 3, 7, 14, 21, 28 and 90 days. For the Compressive strength test, the total number of concrete cubes cast was one hundred and eight (108). After curing for a specific number of days, the cubes were brought out of water. The mass/weights of the cubes are measured and recorded. For each of the hydration period, three cubes were tested. The cubes were placed on the crushing machine and crushed to determine the failure load.

Then, the average compressive strength was determined using the formula stated below.
$\sigma = \frac{P}{A}$. Where σ =Compressive Strength (N/mm^2), P=Test load (N), A=Area (mm^2).

Flexural Strength Test
The flexural strength was determined using a beam mould of 150mm x 150mm x 700mm in dimension. The total number of beams cast was one hundred and eight (108). The batching of the concrete moulds was by weight. The concrete was produced using 0, 5, 10, 15, 20, 30% replacement of cement with OBHA and BHA respectively on equal basis. The concrete cubes moulds were cleaned and oil was applied and the moulds were filled in layers approximately 50mm thick with the mixed concrete. Each layer of concrete was compacted with not less than 25 strokes using a tamping rod. The cubes were later filled to two third of their height and finally filled completely with the top surface leveled and smoothen with trowel and left for 24 hours to set before being cured at 3, 7, 14, 21, 28 and 90 days.

After curing for a specific number of days, the beams were brought out of water and kept moist. The top of the beam as molded was turned to its side and marked as to help with centering in machine. The beams were loaded in the machine and centered on support blocks and loads were applied according to BS 1881 at a given rate of 400kg/minute until rapture occurs.

Then, the average Flexural strength or the Modulus of Rupture was determined using the formula stated below.
$R = \frac{PL}{bd^2}$. This is used when the fracture occurs within the middle third of the specimen. Here (a > 200mm) for 150mm beam size or

Where:
R = Modulus of Rupture (N/mm^2)
P = Maximum load applied that causes failure (N)
L = Supported length of beam (mm)
b = Width of specimen (beam) (mm)
d = Failure point depth of specimen (beam) (mm)
a = Line of fracture to the nearest support.

Split Tensile Strength Test
The Split tensile strength was determined using a cylindrical cube size of 300mm in length or height and 150mm in diameter. The total number of concrete cylinders cast was one hundred and eight (108). In the same manner, the concrete was produced using 0, 5, 10, 15, 20, 30% replacement of cement with OBHA and BHA respectively on equal basis. The concrete cubes moulds were cleaned and oil was applied and the moulds were filled in layers approximately 50mm thick with the mixed concrete. Each layer of concrete was compacted

with not less than 25 strokes using a tamping rod. The cubes were later filled to two third of their height and finally filled completely with the top surface leveled and smoothen with trowel and left for 24 hours to set before being cured at 3, 7, 14, 21, 28 and 90 days.

After curing for a specific number of days, the concrete cylinders are brought out of water and kept moist. Before testing, a line is drawn on the specimen through the diameter of the specimen and the weight and dimensions of the specimen are recorded. The specimen is placed longitudinally on the Universal testing machine. A wooden sheet made of plywood is placed on both sides of the specimen before application of the load and must be aligned according to the marking. Loads are continuously applied in the range of 0.7 to 1.4 MPa/minute until the specimen fails by developing cracks.

Then, the Resultant Split Tensile strength is determined using the formula stated below.

$$T = \frac{2P}{\pi DL}.$$ Where:

T =Split Tensile Strength (N/mm^2).
P =Load at which the Specimen breaks (N).
$\pi = \frac{22}{7}$
D = Diameter of specimen (mm).
L = Length of specimen (mm)

Developing Statistical/Mathematical Modeling Using R-Programming

R- Programming is a versatile language primarily used for statistical computing, data analysis, and graphical representation. It's a popular choice for data scientists, statisticians, and researchers due to its capabilities in data manipulation, visualization, and statistical modeling.

The variables used in the analysis are defined as follows:

- **Dependent Variable (Y):** Compressive Strength (CS) or Flexural Strength (FS) or Split Tensile Strength (STS) of Concrete Cubes (N/mm^2)
- **Independent Variables (X):** We used two independent variables:
- Percentage of OBHA/BHA: The percentage of cement replaced by OBHA/BHA.
- Curing Age: The age of curing in days.
- **X_1:** Amount of OBHA & BHA combined on equal ratio (%) the study considered (0, 5,10,15,20 and 30%)
- **X_2:** The **curing age of cement** refers to number of days during which freshly placed concrete is kept moist to ensure proper hydration of cement, which is essential for strength development and durability. The study considered the following days 3, 7, 14, 21, 28 and 90.

Using R-Programming Software language, and putting into considerations **the regression model analysis,** mathematical framework or model was developed to represent the relationships between variables. We modeled linear, quadratic and nonlinear and then select the best model to analyze, interpret, visualize, predict about future events and make the necessary decisions.

Mathematical Model Formulation for Compressive Strength (CS), Flexural Strength (FS) and Split Tensile Strength (STS).

A possible model form could be:

$$CS = \beta 0 + \beta 1.\ \text{Percentage of OBHA/BHA} + \beta 2.(\text{Percentage of OBHA/BHA})2 + \beta 3.\log(\text{Curing Age}) + \varepsilon$$

$$FS = \beta 0 + \beta 1.\ \text{Percentage of OBHA/BHA} + \beta 2.(\text{Percentage of OBHA/BHA})2 + \beta 3.\log(\text{Curing Age}) + \varepsilon..$$

$$STS = \beta 0 + \beta 1.\ \text{Percentage of OBHA/BHA} + \beta 2.(\text{Percentage of OBHA/BHA})2 + \beta 3.\log(\text{Curing Age}) + \varepsilon$$

Where:
β_0 = Beta_0: Intercept (Baseline compressive strength or Flexural Strength or Split Tensile Strength).
β_1 =Beta_1: Coefficient for the linear effect of OBHA/BHA percentage.
β_2 =Beta_2: Coefficient for the quadratic effect of OBHA/BHA percentage (to capture the optimal point and subsequent decrease).
β_3 = Beta_3: Coefficient for the logarithmic effect of curing age.
ϵ = Epsilon: Error term.

V. Results And Discussion

Slump Test Results

Figure 4.1 below shows the Variation in Slump of OBHA and BHA – Cement Concrete as percent replacement varies from 0% to 30%. . It is observed that the slumps were within the assumed slump of 30-60mm, thereby showing no serious effect. The slump test results showed that slump increases with increase in percentage addition of OBHA and BHA. This flow could be attributed to the fine and spherical particles of OBHA and BHA in contact with cement (Chaiyesena, 1992). The Slump increased from 31mm at 0% to 46.3mm at 30% addition levels. This is comparable to the results of (Oluwaseye *et. al*., 2019) and (Attah *et al*., 2018) using two other Agro waste materials in their analysis. However, the concrete is still workable and has ease of placement despite the increased slump.

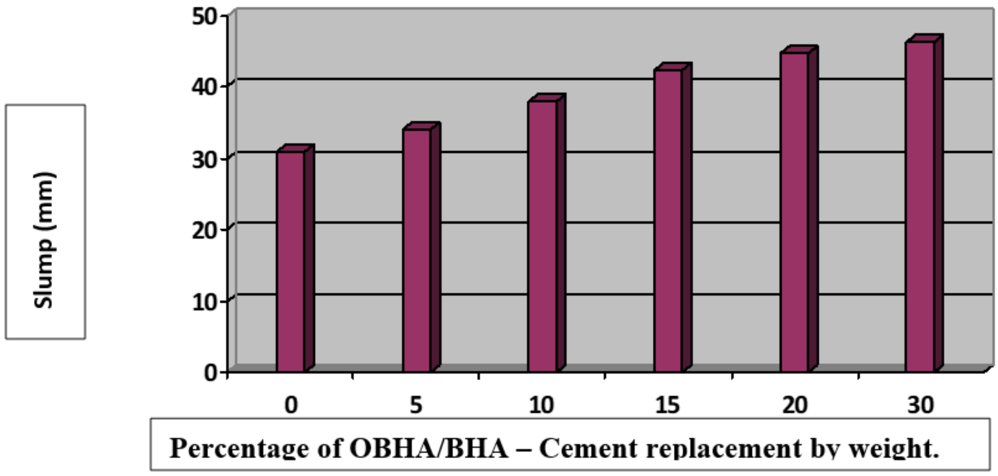

Figure 4.1: Variation in Slump of OBHA/BHA-Cement concrete as percentage replacement varies.

Variation of Setting times of Cement with Percentage Replacement

Figure 4.2 below shows the result of the initial and final setting times considered using cement and different percentages of Oil bean husk ash (OBHA) and Breadfruit husk ash (BHA). The initial and final setting times increase with increase in OBHA/BHA content. The reaction between cement and water is exothermic which is defined as the reaction that releases energy by heat. The liberation of heat and evaporation moisture causes the stiffening of the paste and slower heat induced evaporation of water from the cement/OBHA & BHA paste due to its lower cement content (Ikpong 1993), and therefore an accelerated increase in the initial setting time of the mixture was observed. Thus, an increase in the setting time was noticeable from 137 minutes (at 5% OBHA/BHA) to 155 minutes (at 15% OBHA/BHA) and the setting time continued to increase until the last proportion as the percentages of OBHA/BHA increased to 30% (165 minutes). Similarly, the final setting time also increases as the percentages of OBHA/BHA increase thereby retarding the hydration process. This result is interconnected with the work of Dashan and Kamang (1999) and that of Oyetola and Abdullahi (2004).

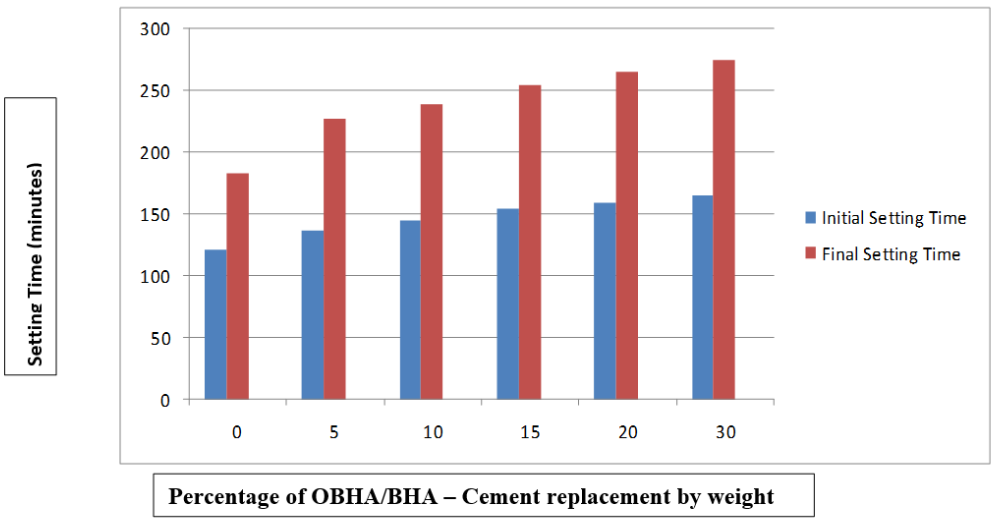

Figure 4.2: Variation in setting time of OBHA/BHA-Cement as percentage replacement varies.

Sieve Analysis of Fine Aggregates: Figure 4.3 below shows the result of the sieve analysis graph of fine aggregates used. The result shows that the fine aggregate falls into zone 2 of calibration graph which shows that the sand is classified as "moderately coarse sand. According to Indian Standard, IS 383 (2016), this type of sand is considered suitable for general-purpose concrete mixes which is crucial for creating a workable, strong, and durable concrete mix. The Sieve analysis determines particle size distribution of fine aggregates which is crucial for assessing material suitability, ensuring quality control in construction projects, and designing concrete mixes which allows Engineers to select appropriate aggregates that meet specific project requirements and achieve desired performance characteristics.

Figure 4.1 below shows the Sieve Analysis of Fine Aggregates Graph. The values of D_{10}, D_{30}, and D_{60}, which are the diameters that correspond to the percent finer of 10%, 30%, and 60%, respectively were determined from the grain-size distribution curve. Here, D_{10}=0.27, D_{30}=0.6 and D_{60}=1.1

The values of Coefficient of Uniformity (C_U) of 4.07 and Coefficient of Curvature (C_C) or Coefficient of Gradation of 1.21 were obtained using the following equations:

$$Cu = \frac{D_{60}}{D_{10}} = \frac{1.1}{0.27} = 4.07.$$

$$C_C = \frac{(D_{30})^2}{D_{60} x D_{10}} = \frac{(0.6)^2}{1.1x0,27} = 1.21.$$

This shows that the fine aggregate is a well graded soil since C_U is greater than 4 and C_C varies between 1 and 3. The values of C_u and C_c are used to classify whether the soil is well-graded or not. Also, the Coefficient of Uniformity and Void ratio are inversely related, primarily influencing soil density. Since C_u is high with a value of 4.07, means the soil is well-graded, which is preferred for construction because smaller particles fill the voids between larger ones, leading to better compaction, higher density, and increased strength.

Standard Sieve size (mm)	Percentage passing (g)
8	100
5	93.76
2.36	76.04
1.18	62.88
0.6	32.86
0.3	11.2
0.15	4.84
Pan	0

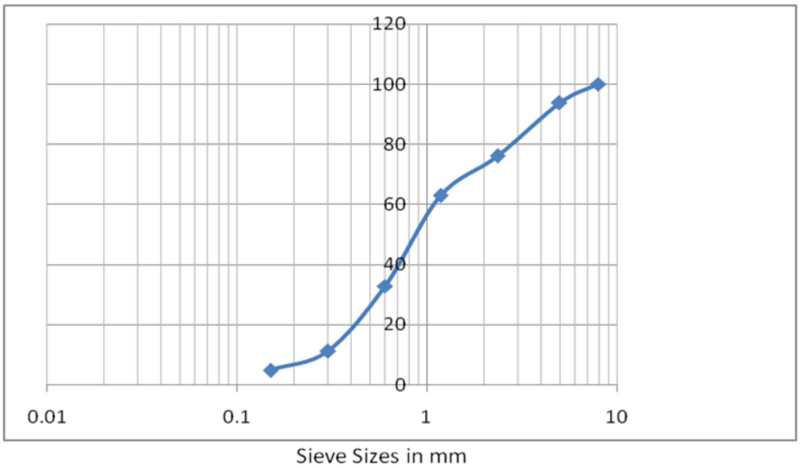

Figure 4.1: Fine Aggregate Sieve Analysis Graph

Average Compressive Strength of Concrete Cubes (N/mm²) with various percentages of OBHA and BHA

Figure 4.4 below showed the Compressive Strength curve for OPC/OBHA & BHA which showed the results of the average compressive strength tests of OBHA & BHA concrete cubes of mix ratio (1 : 2.14 : 4.18), and water cement ratio of 0.60. The Compressive Strength value ranges from (3.65N/mm^2 - 29.84N/mm^2). The result of the average compressive strength of concrete produced for all mix increases with age at curing and decreases as the OBHA/BHA content increases. This is consistent with (Parmod *et al.,* 2024) research, though the Agro waste used was Rice Husk Ash (RHA). The best compressive strength result was obtained with the percentages of cement replaced by 5% OBHA/BHA and it decreased significantly as the percentages of OBHA/BHA increased. In fact, the strength showed remarkable increase with ageing, with highest compressive strength encountered in the 90 days; which may be due to retention of water with the structural frame of the mixture thereby allowing better hydration.

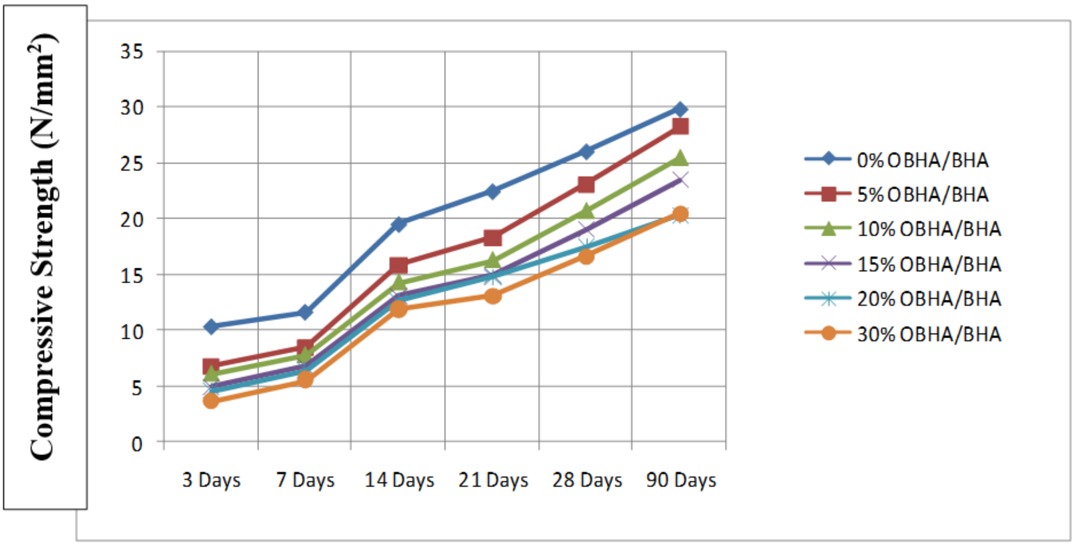

Figure 4.4: Compressive Strength Development of concrete mixes with varying percentage addition of OBHA & BHA cured in water (1: 2.14: 4.18/0.60).

Statistical/Mathematical Model Analysis for the Compressive Strength of Cement/OBHA & BHA Concrete.

Preliminary observations from Compressive strength data;

1. Compressive strength increases with age at curing**:** This suggests a positive correlation with curing age, likely a non-linear one (e.g., rapid increase initially, then a slower gain, eventually levelling off).
2. Compressive strength decreases as OBHA/BHA content increases: This indicates a negative correlation with the percentage of OBHA/BHA replacement.
3. Best compressive strength at 5% OBHA/BHA replacement: This suggests an optimal point, implying that a simple linear decrease might not fully capture the behaviour across all percentages. It could be a quadratic relationship where the strength initially increases (or maintains well) with low percentages and then drops more significantly with higher percentages.
4. Highest compressive strength at 90 days**:** This confirms the age-dependent strength gain.

The study employed a quantitative, experimental research design to investigate the relationship between a set of independent variables and a continuous dependent variable. The primary analytical techniques are multiple linear regression and Polynomial Regression. The dataset for this analysis was Average Compressive Strength of Concrete Cubes (N/mm^2) with various percentages of OBHA and BHA. Using R-Programming Software language version 4.5.1 with the tidy verse, broom, ggpubr, caret, grid Extra, nls2 and nls tools libraries, create the data set based on the Average Compressive Strength of Concrete Cubes obtained after loading the required packages.

```
# Create the dataset
data <- data.frame(
Cement_Percent = rep(c(100, 95, 90, 85, 80, 70), each = 6),
OBHA_BHA_Percent = rep(c(0, 5, 10, 15, 20, 30), each = 6),
Curing_Age = rep(c(3, 7, 14, 21, 28, 90), times = 6),
Compressive_Strength = c(
10.36, 11.66, 19.52, 22.46, 26.04, 29.84,
6.86, 8.48, 15.92, 18.38, 23.13, 28.27,
6.13, 7.81, 14.35, 16.34, 20.75, 25.51,
4.96, 6.76, 13.06, 14.93, 19.03, 23.46,
4.60, 6.42, 12.65, 14.79, 17.46, 20.31,
3.65, 5.56, 11.90, 13.10, 16.64, 20.47))
```

Taking the logarithm of age in regression modeling is often done for several statistical and practical reasons but in this case, we take log of age.

Model Formulation

Considering these observations, a multiple regression model would be suitable. Using two independent variables

➢ Percentage of OBHA/BHA: The percentage of cement replaced by OBHA/BHA.
➢ Curing Age: The age of curing in days.
Let CS be the Compressive Strength.
A possible model form could be:
$CS=\beta_0+\beta_1\cdot Percentage\_OBHA\_BHA+\beta_2\cdot(Percentage\_OBHA\_BHA)^2+\beta_3\cdot\log(Curing\_Age)+\epsilon$
Where:

- beta_0: Intercept (baseline compressive strength).
- beta_1: Coefficient for the linear effect of OBHA/BHA percentage.
- beta_2: Coefficient for the quadratic effect of OBHA/BHA percentage (to capture the optimal point and subsequent decrease).
- beta_3: Coefficient for the logarithmic effect of curing age.
- ϵ : epsilon: Error term.

To model the relationship of compressive strength with Percentage OBHA/BHA and curing age, we modeled linear, quadratic and nonlinear and then select the best model. For the Compressive Strength test, the Model Comparison metrics obtained from R Programming is as follows:

Table: Model Comparison Metrics

R2	RMSE	AIC	BIC	Model
0.939	1.761	152.905	160.823	Linear
0.956	1.490	144.891	155.975	Quadratic
1.000	NaN	137.847	144.181	Non-linear

>

Interpretation of Quadratic Regression Rationale Model selected.

- High R-squared (0.956) indicates that the model explains 95.6% of the variability in compressive strength.
- Significant predictors: The intercept, second degree of OBHA/BHA %, first degree of curing age were significant at ($p<0.01$) and their interaction at ($p<0.1$), confirming the non linear relationship of OBHA & BHA Percent and Curing Age on compressive strength.
- Negative interaction term: The coefficient for OBHA & BHA Percent: Curing Age is negative, indicating that increasing OBHA/BHA content reduces the rate of strength gain with age.
- Model fit: The residuals are small and evenly distributed, suggesting a good fit.

Mathematical Model Formulation obtained from R Programming was summarized as follows;
Call:
lm(formula = Compressive_Strength ~ poly(OBHA_BHA_Percent, 2) + poly(log(Curing_Age), 2) + OBHA_BHA_Percent:log(Curing_Age),
data = train_data)
Residuals:
Min 1Q Median 3Q Max
-3.3132 -0.8797 -0.0094 1.2740 2.4424
Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 16.32284 0.99895 16.340 3.42e-15 ***
poly(OBHA_BHA_Percent, 2)1 -7.55082 4.32796 -1.745 0.09286 .
poly(OBHA_BHA_Percent, 2)2 4.48183 1.60603 2.791 0.00972 **
poly(log(Curing_Age), 2)1 39.18925 2.53477 15.461 1.27e-14 ***
poly(log(Curing_Age), 2)2 0.17599 1.60838 0.109 0.91371
OBHA_BHA_Percent:log(Curing_Age) -0.03830 0.02601 -1.472 0.15300
Signif. codes: 0 ‘*’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1**
Residual standard error: 1.596 on 26 degrees of freedom
Multiple R-squared: 0.9581, Adjusted R-squared: 0.9501
F-statistic: 118.9 on 5 and 26 DF, p-value: < 2.2e-16

```
# Predict for new values
> new_data <- data.frame(
+   OBHA_BHA_Percent = c(10, 15, 20),
+   Curing_Age = c(28, 28, 28)
```

> # Predict compressive strength
> predicted_strength <- predict(model, newdata = new_data)
> print(predicted_strength)
Prediction Results
1 2 3
18.71129 17.16536 16.04978
> library(ggplot2)
Plot actual vs predicted
data$Predicted <- predict(model, newdata = data)
ggplot(data, aes(x = Curing_Age, y = Compressive_Strength, color = as.factor(OBHA_BHA_Percent))) + geom_point(size = 3) + geom_line(aes(y = Predicted), linetype = "dashed") +labs(title = "Compressive Strength Prediction",
x = "Curing Age (Days)", y = "Compressive Strength (N/mm²)",
color = "% OBHA & BHA") + theme_minimal() library(dplyr)

Interpretation:

- At 10% OBHA/BHA, the predicted compressive strength at 28 days is 18.711 N/mm²**.**
- At 15%, it drops to 17.165 N/mm²**.**
- At 20%, it further drops to 16.05 N/mm²**.**
- This confirms the experimental observation that compressive strength decreases with increasing OBHA/BHA replacement.

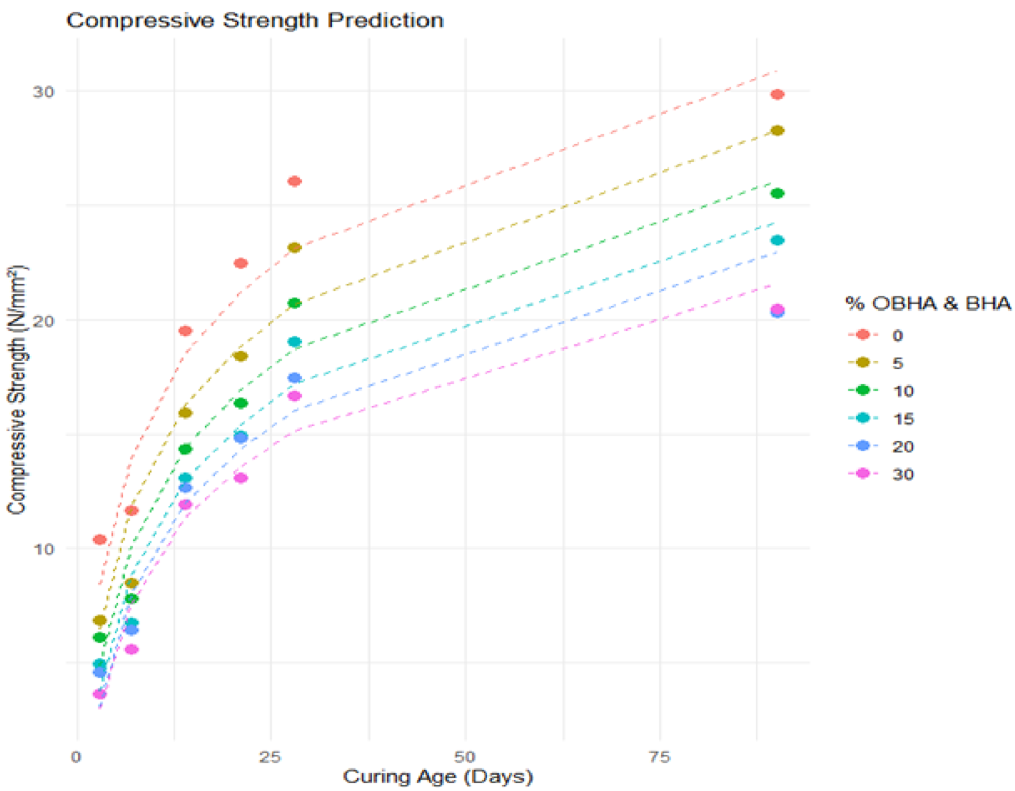

Figure 4.5: Compressive Strength Prediction

 # Generate grid of possible values
 # Find optimal combination
optimal <- grid %>% arrange(desc(Strength)) %>% head(1)
print(optimal

OBHA_BHA_	**Percent Curing_Age**	**Strength**	
1	**5**	**90**	**28.25416**

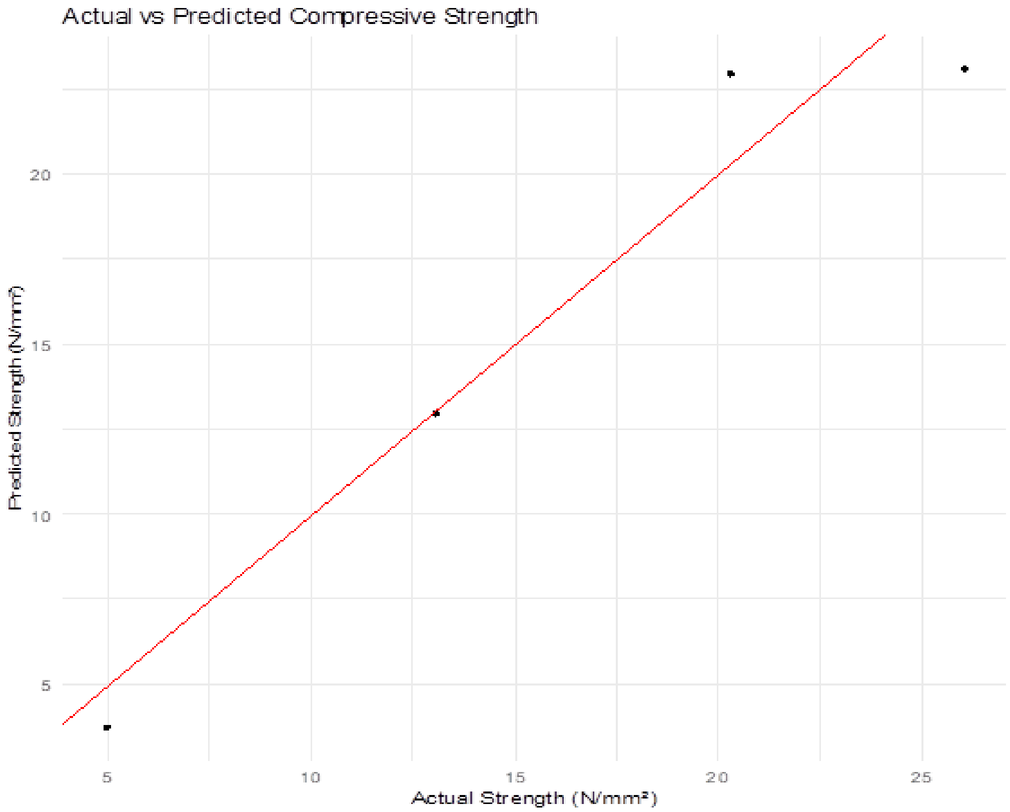

Figure 4.6: Actual Vs Predicted Compressive Strength.

Optimization Result

OBHA/BHA	Percent Curing Age	Strength	
1	5	90	28.25905

Interpretation:

- The optimal mix for maximum compressive strength is:
  - 5% OBHA/BHA replacement
  - 90 days curing
  - Predicted strength: 28.26 N/mm²
- This aligns with the experimental result where 5% replacement yielded the highest strength.

Table 4.6 below shows the Average Actual Compressive Strength of Concrete Cubes compared with the Predicted Compressive Strength of Concrete Cubes **in Red** based on R-Programming Software Predictions as percentage replacement varies respectively. The Table confirms that Compressive strength increases with age at curing**.** Compressive strength decreases as OBHA/BHA content increases: This indicates a negative correlation with the percentage of OBHA/BHA replacement. Best compressive strength at 5% OBHA/BHA replacement: This suggests an optimal point, implying that a simple linear decrease might not fully capture the behavior across all percentages. Therefore, a quadratic relationship used in the modeling where the strength initially increases (or maintains well) with low percentages and then drops more significantly with higher percentages is ideal.

Table- 4.6: Average Actual Vs Predicted Compressive Strength of Concrete Cubes (N/mm^2) with various percentages of OBHA and BHA

Amount of Cement (OPC) (%)	Amount of OBHA & BHA combined on equal ratio (%)	Design strength (N/mm^2) 3 Days	Design strength (N/mm^2) 7 Days	Design strength (N/mm^2) 14 Days	Design strength (N/mm^2) 21 Days	Design strength (N/mm^2) 28 Days	Design strength (N/mm^2) 90 Days
100	**0 (Actual) (Predicted)**	**10.36 8.38**	**11.66 13.93**	**19.52 18.50**	**22.46 21.19**	**26.04 23.09**	**29.84 30.88**
95	**5(Actual) (Predicted)**	**6.86 6.40**	**8.48 11.79**	**15.92 16.23**	**18.38 18.83**	**23.13 20.69**	**28.27 28.25**

90	**10(Actual)** **(Predicted)**	**6.13** **4.86**	**7.81** **10.08**	**14.35** **14.38**	**16.34** **16.91**	**20.75** **18.71**	**25.51** **26.05**
85	**15(Actual)** **(Predicted)**	**4.96** **3.74**	**6.76** **8.80**	**13.06** **12.97**	**14.93** **15.42**	**19.03** **17.17**	**23.46** **24.28**
80	**20(Actual)** **(Predicted)**	**4.60** **3.05**	**6.42** **7.95**	**12.65** **11.99**	**14.79** **14.36**	**17.46** **16.05**	**20.31** **22.95**
70	**30(Actual)** **(Predicted)**	**3.65** **2.96**	**5.56** **7.54**	**11.90** **11.31**	**13.10** **13.53**	**16.64** **15.11**	**20.47** **21.56**

Average Flexural Strength of Concrete Cubes (N/mm^2) with various percentages of OBHA and BHA.

Figure 4.7 below shows the Flexural Strength curve for OPC/OBHA & BHA concrete which is used to determine the concrete's ability to resist cracking and failure when subjected to bending forces. It also showed the results of the average flexural strength tests of OBHA & BHA concrete cubes of mix ratio (1 : 2.14 : 4.18), and water cement ratio of 0.60. The Flexural Strength value ranges from (0.50N/mm^2 – 3.79N/mm^2). The result of the average flexural strength of concrete produced for all mix increases with age at curing and decreases as the OBHA/BHA content increases. The best flexural strength result was obtained with the percentages of cement replaced by 5% OBHA/BHA and it decreased significantly as the percentage of OBHA/BHA increased. In fact, the strength showed remarkable increase with ageing, with highest flexural strength encountered in the 90 days; which may be due to retention of water with the structural frame of the mixture thereby allowing better hydration. This is in conformity with the research of (Umeonyiagu and Uzuhonyeisi, 2022)

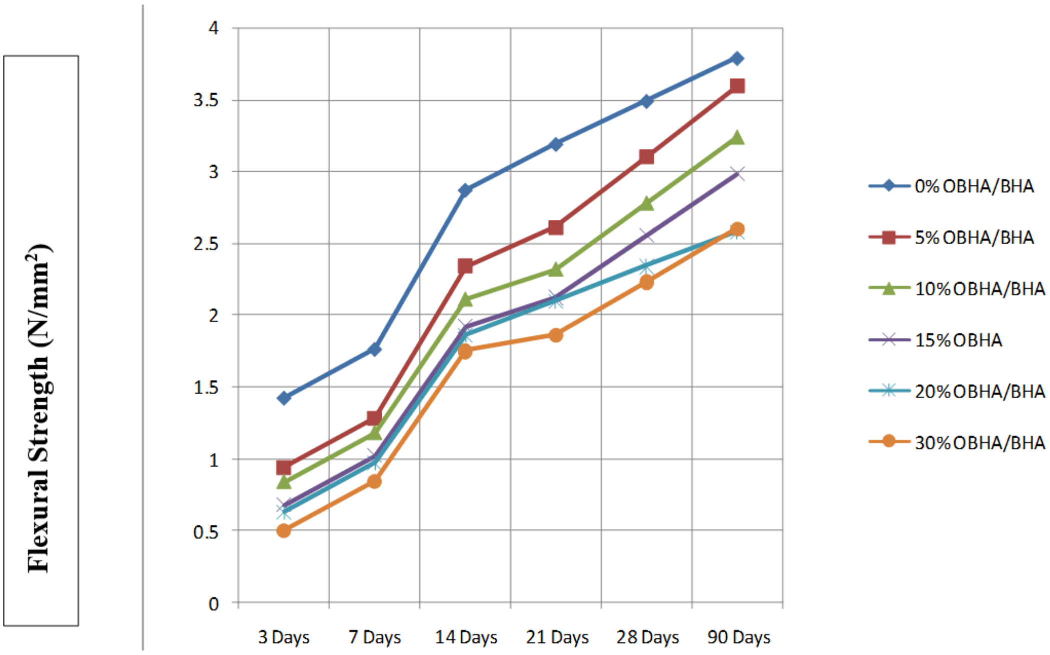

Fig. 4.7: Flexural Strength Development of concrete mixes with varying percentage addition of OBHA/BHA cured in water (1: 2.14: 4.18/0.60).

Statistical/Mathematical Model Analysis for the Flexural Strength of Cement/OBHA & BHA Concrete.
Preliminary Observations from Flexural Strength Data (OBHA & BHA Concrete)

1. Flexural Strength Increases with Curing Age
2. Best Performance at 5% Replacement
3. 90-Day Strength is the Peak

- At all mix levels, 90 days produced the maximum strength values.
- This suggests long-term strength development due to better hydration and possible latent pozzolanic activity of OBHA and BHA.

In the same manner, the study employed a quantitative, experimental research design to investigate the relationship between a set of independent variables and a continuous dependent variable. The primary analytical techniques are multiple linear regression and Polynomial Regression. The dataset for this analysis was Average Flexural Strength of Concrete Cubes (N/mm^2) with various percentages of OBHA and BHA. Using R-Programming Software language version 4.5.1 with the tidy verse, broom, ggpubr, caret, grid Extra, nls2 and nls tools libraries, create the data set based on the Average Flexural Strength of Concrete Cubes obtained after loading the required packages as shown below.
Load required packages, library(tidyverse), library(broom), library(ggpubr), library(caret)

```
library(gridExtra), library(nls2)  # For non-linear least squares, library(nlstools)  # For model diagnostics
# Create the dataset
data <- data.frame(
```

Mathematical Model Formulation:

Considering these observations, a multiple regression model would be suitable. Two independent variables were used;

- Percentage of OBHA/BHA: The percentage of cement replaced by OBHA/BHA.
- Curing Age: The age of curing in days.

Since the relationship with Percentage of OBHA/BHA is not simply linear (due to the optimal 5% point), we might consider a quadratic term for it. The relationship with Curing Age is also non- linear, often modeled with logarithmic or power functions, or even as a polynomial. Given the "remarkable increase with aging, with highest flexural strength encountered in the 90 days," a logarithmic or square root transformation of age, or a polynomial up to a certain degree, could be explored.

Let FS be the Flexural Strength. A possible model form could be:

$FS=\beta0 +\beta1 \cdot \text{Percentage of OBHA/BHA}+\beta2 \cdot(\text{Percentage\_OBHA\_BHA})^2+\beta3 \cdot\log(\text{Curing Age})+ \epsilon$ Where:

- beta_0: Intercept (baseline compressive strength).
- beta_1: Coefficient for the linear effect of OBHA/BHA percentage.
- beta_2: Coefficient for the quadratic effect of OBHA/BHA percentage (to capture the optimal point and subsequent decrease).
- beta_3: Coefficient for the logarithmic effect of curing age.
- ϵ = epsilon: Error term.

To model the relationship of Flexural strength with Percentage OBHA/BHA and curing age, we modeled linear, quadratic and nonlinear and then select the best model. For the Flexural Strength test, the Model Comparison metrics obtained from R Programming is as follows:

Model Comparison Metrics obtained

R^2	RMSE	AIC	BIC	Model
0.925	**0.248**	**11.834**	**19.751**	**Linear**
0.959	**0.184**	**-5.667**	**5.417**	**Quadratic**
-2.944	**1.797**	**152.365**	**158.699**	**Non-linear**

```
Call:
lm(formula = Flexural_Strength ~ poly(OBHA_BHA_Percent, 2) + poly(log(Curing_Age), 2) +
OBHA_BHA_Percent:log(Curing_Age), data = data)

Residuals:
Min           1Q   Median      3Q     Max
-0.47874 -0.06706  0.02745  0.15270  0.23209

Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept)                       2.284406   0.121957  18.731  < 2e-16 ***
poly(OBHA_BHA_Percent, 2)1       -1.155850   0.557903  -2.072  0.04698 *
poly(OBHA_BHA_Percent, 2)2        0.782630   0.201707   3.880  0.00053 ***
poly(log(Curing_Age), 2)1         5.262307   0.339239  15.512 7.16e-16 ***
poly(log(Curing_Age), 2)2        -0.620372   0.201707  -3.076  0.00445 **
OBHA_BHA_Percent:log(Curing_Age) -0.005932   0.003186  -1.862  0.07241 .
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Residual standard error: 0.2017 on 30 degrees of freedom Multiple R-squared:  0.9586,    Adjusted    R-squared:
0.9517 F-statistic: 138.9 on 5 and 30 DF,  p-value: < 2.2e-16
# Predict for new values
> new_data <- data.frame(
+   OBHA_BHA_Percent = c(5, 10, 15),
+   Curing_Age = c(28, 28, 28)
> # Predict Flexural strength
> predicted_strength <- predict(model, newdata = new_data)
```

> print(predicted_strength)
 # Find optimal combination
optimal <- grid %>% arrange(desc(Strength)) %>% head(1)
print(optimal)

Interpretation
- $R^2 = 0.959$: The model explains 95.9% of the variation in flexural strength.
- All predictors are significant, confirming that both OBHA/BHA content and curing age strongly influence flexural strength.
- Negative interaction term**:** Indicates that increasing OBHA/BHA reduces the rate of strength gain with age.

Prediction Results
Predict (model, newdata = new_data)

1	2	3
2.887091	2.585989	2.354610

Interpretation:
- At 5% OBHA/BHA, predicted flexural strength at 28 days is 2.88 N/mm².
- At 10%, it drops to 2.59 N/mm².
- At 15%, it further drops to 2.35 N/mm².
- This confirms the experimental observation that Flexural strength decreases with increasing OBHA/BHA replacement.

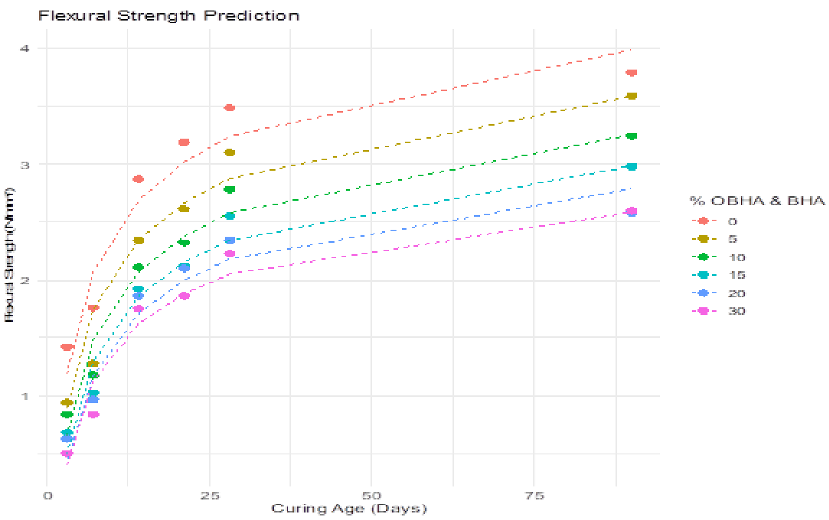

Figure 4.8: Flexural Strength Prediction.

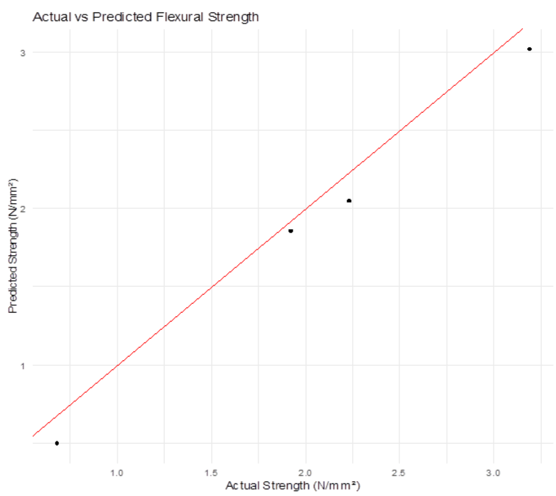

Figure 4.9 Actual Vs Predicted Flexural Strength.

Optimization Result

OBHA/BHA	Percent	Curing	Age	Strength
1		0	90	3.997141

Interpretation:
The optimal mix for flexural strength is:
- 5% OBHA/BHA replacement
- 90 days curing
- Predicted strength: 3.997 **N/mm²**

We can say that;
The R-based model for flexural strength prediction demonstrates:
- Strong predictive power with high R^2.
- Flexural strength increases with curing age, due to enhanced hydration.
- Strength decreases with increasing OBHA/BHA content, confirming dilution effects.
- Optimal performance is achieved at 5% OBHA/BHA replacement and 90 days curing, making it ideal for structural applications requiring flexural durability.

Average Split Tensile Strength of Concrete Cubes (N/mm^2) with various percentages of OBHA and BHA.

Figure 4.10 below shows below shows the Split tensile Strength curve for OPC/OBHA & BHA concrete cubes of mix ratio (1: 2. 14: 4.18), and water cement ratio of 0.60. The Split tensile Strength value ranges from (0.28N/mm^2 – 2.06N/mm^2). The result of the average Split tensile strength of concrete produced for all mix increases with age at curing and decreases as the OBHA/BHA content increases. The best split tensile strength result was obtained with the percentages of cement replaced by 5% OBHA/BHA and it decreased considerably as the percentage of OBHA/BHA increased. The strength showed remarkable increase with ageing, with highest split tensile strength encountered in the 90 days; which may be due to retention of water with the structural frame of the mixture thereby allowing better hydration.
This is in compliance with the research of (Umeonyiagu and Uzuhonyeisi,

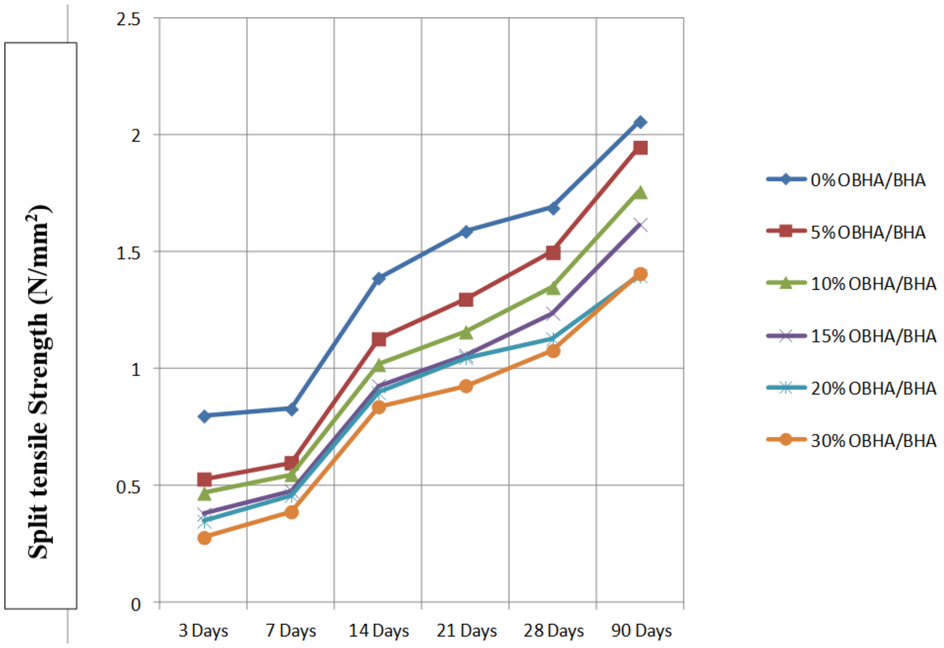

Figure 4.10: Split tensile Strength Development of concrete mixes with varying percentage addition of OBHA/BHA cured in water (1: 2.14: 4.18/0.60).

Statistical/Mathematical Model Analysis for the Split Tensile Strength of Cement/OBHA & BHA Concrete.

Preliminary observations from the data:
- The average Split tensile strength of concrete decreases as the OBHA/BHA content increases.
- The best split tensile strength result was obtained when 5% of the cement was replaced by OBHA/BHA.
- The split tensile strength decreased considerably as the percentage of OBHA/BHA increased beyond 5%.

- The strength showed a remarkable increase with aging, with the highest split tensile strength observed at 90 days, possibly due to water retention within the mixture's structural frame, allowing for better hydration.
- The Split tensile strength values ranged from 0.28 N/mm² to 2.06 N/mm².

The study also employed a quantitative, experimental research design to investigate the relationship between a set of independent variables and a continuous dependent variable. The primary analytical techniques are multiple linear regression and Polynomial Regression. The dataset for this analysis was Average Split Tensile Strength of Concrete Cubes (N/mm^2) with various percentages of OBHA and BHA. Using R-Programming Software language version 4.5.1 with the tidy verse, broom, ggpubr, caret, grid Extra, nls2 and nls tools libraries, create the data set based on the Average Split Tensile Strength of Concrete Cubes obtained after loading the required packages as shown below.

# Load required packages; library(tidyverse), library(broom), library(ggpubr), library(caret), library(gridExtra), library(nls2) # For non-linear least squares, library(nlstools) # For model diagnostics
# Create the dataframe from the given data
data <- data.frame(
OBHA_BHA_Percent = c(100, 95, 90, 85, 80, 70, 100, 95, 90, 85, 80, 70,
100, 95, 90, 85, 80, 70, 100, 95, 90, 85, 80, 70,
100, 95, 90, 85, 80, 70, 100, 95, 90, 85, 80, 70),
obha_bha_pct = c(0, 5, 10, 15, 20, 30, 0, 5, 10, 15, 20, 30,
0, 5, 10, 15, 20, 30, 0, 5, 10, 15, 20, 30,
0, 5, 10, 15, 20, 30, 0, 5, 10, 15, 20, 30),
Curing_Age = rep(c(3, 7, 14, 21, 28, 90), each = 6),
Split Tensile_strength = c(0.8, 0.53, 0.47, 0.38, 0.35, 0.28, 0.83, 0.6, 0.55, 0.48, 0.46, 0.39,
1.39, 1.13, 1.02, 0.93, 0.9, 0.84, 1.59, 1.3, 1.16, 1.06, 1.05, 0.93,
1.69, 1.5, 1.35, 1.24, 1.13, 1.08, 2.06, 1.95, 1.76, 1.62, 1.4, 1.41))

Model Formulation:

Considering these observations, a multiple regression model would be suitable. We'll use two independent variables:

- Percentage of OBHA/BHA: The percentage of cement replaced by OBHA/BHA.
- Curing Age: The age of curing in days.

Let STS be the Split Tensile Strength.
A possible model form could be:

$$STS=\beta_0+\beta_1\cdot \text{Percentage\_OBHA\_BHA}+\beta_2\cdot(\text{Percentage\_OBHA\_BHA})^2+\beta_3\cdot\log(\text{Curing\_Age})+\epsilon$$

Where:

- beta_0: Intercept (baseline compressive strength).
- beta_1: Coefficient for the linear effect of OBHA/BHA percentage.
- beta_2: Coefficient for the quadratic effect of OBHA/BHA percentage (to capture the optimal point and subsequent decrease).
- beta_3: Coefficient for the logarithmic effect of curing age.
- ϵ : epsilon: Error term.

To model the relationship of Split Tensile strength with Percentage OBHA/BHA and curing age we model linear, quadratic and nonlinear and then select the best model.

Model Comparison Metrics Result from R Programming:

R^2	**RMSE**	**AIC**	**BIC**	**Model**
0.942	**0.114**	**-44.480**	**-36.562**	**Linear**
0.959	**0.093**	**-55.077**	**-43.992**	**Quadratic**
1.000	**NaN**	**61.483**	**67.817**	**Non-linear**

>

Call:
lm(formula = Tensile_strength ~ OBHA_BHA_Percent + I(OBHA_BHA_Percent^2) + log(Curing_Age) + I(log(Curing_Age)^2) + OBHA_BHA_Percent:log(Curing_Age), data = train_data)

Residuals:
Min 1Q Median 3Q Max

```
-0.24753 -0.03903  0.02269  0.07459  0.14035

Coefficients:
Estimate Std. Error        t value   Pr(>|t|)
(Intercept)                        4.1778953  1.4903257   2.803       0.00943 **
OBHA_BHA_Percent                   -0.1123220  0.0344768  -3.258       0.00312 **
I(OBHA_BHA_Percent^2)               0.0007254  0.0002015    3.601        0.00131 **
log(Curing_Age)                0.1491747  0.1747743   0.854  0.40116
I(log(Curing_Age)^2)            0.0029741  0.0148410   0.200  0.84273
OBHA_BHA_Percent:log(Curing_Age)  0.0026599  0.0017125   1.553  0.13246
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1055 on 26 degrees of freedom
Multiple R-squared:  0.9594,    Adjusted R-squared:  0.9516
F-statistic:   123 on 5 and 26 DF,  p-value: < 2.2e-16

> # Predict on test set
> test_data$predicted_strength <- predict(model, newdata = test_data)
> # Calculate RMSE
> rmse <- sqrt(mean((test_data$Tensile_strength - test_data$predicted_strength)^2))
> print(paste("RMSE:", rmse))
[1] "RMSE: 0.0770521998325546"
```

Model Fit and Accuracy

The model demonstrates excellent predictive capability with:

- High R-squared value (0.9594)**:** Indicates that 95.94% of the variability in split tensile strength is explained by the model
- Low RMSE (0.00770 N/mm²)**:** The average prediction error is very small compared to the range of strength values (0.28-2.06 N/mm²)
- Coefficients of Linear and quadratic terms for cement percentage are statistically significant (p-values < 0.01), confirming the importance of each term in the model. Linear and quadratic terms for log(age) and interaction term between cement percentage and log(age) to account for how the effect of cement percentage might change with curing age were not significant

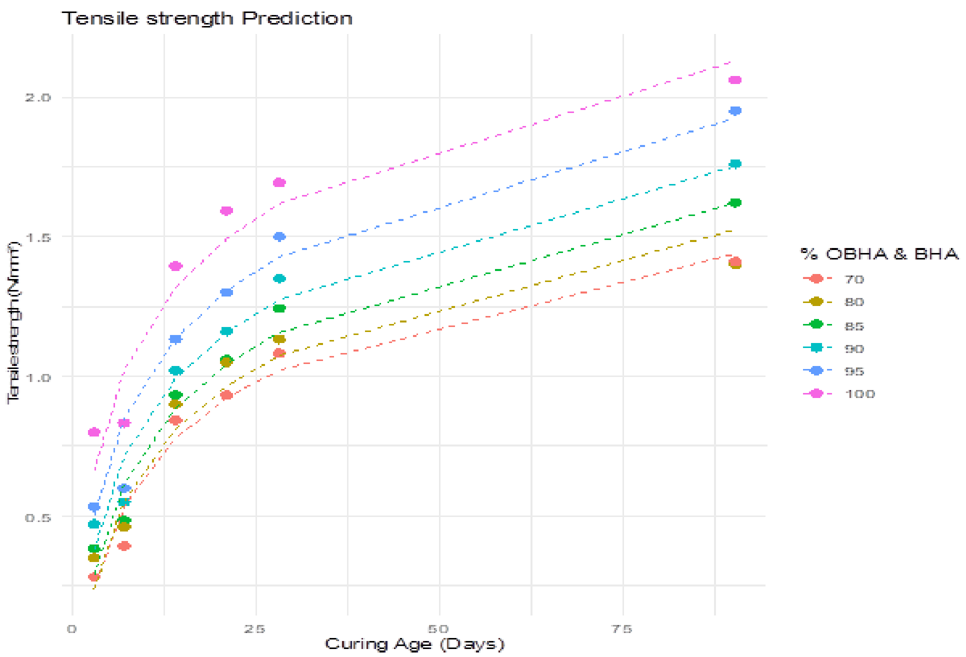

Figure 4.11: Split Tensile Strength Prediction

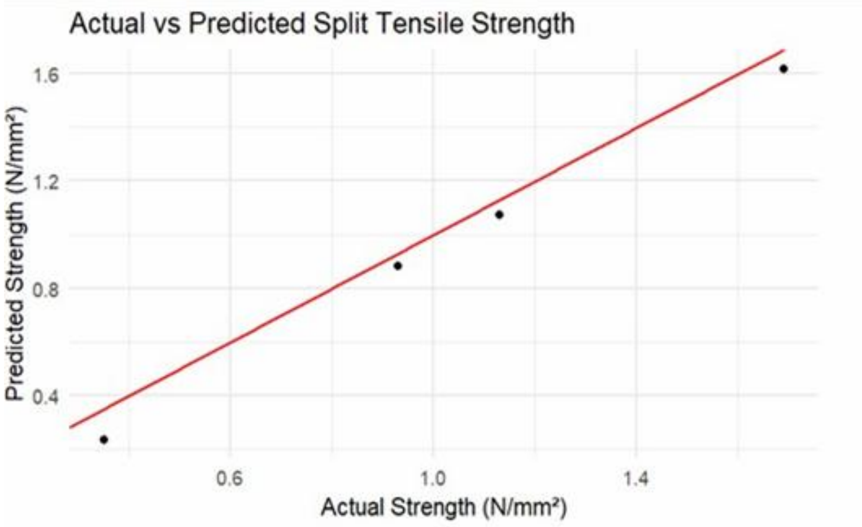

Figure 4.12 Actual Vs Predicted Split Tensile Strength.

Predictive Performance
print(paste("Predicted strength for 92% cement at 28 days:", example_pred, "N/mm²"))
[1] "Predicted strength for 92% cement at 28 days: 1.32981179760707 N/mm²"

The actual vs. predicted plot shows points closely clustered around the 45-degree line, confirming good predictive accuracy. The example predictions demonstrate practical utility:

- For 92% cement at 28 days, the model predicts 1.329 N/mm²
- To achieve 1.5 N/mm² at 28 days, the model recommends 93.6% cement content

Practical Implications
1. Strength Development**:**
- The model confirms that strength increases with curing time, with the most rapid gains in the first 7-14 days
- The logarithmic relationship suggests diminishing returns with extended curing

Optimization Approach
print(paste("Optimal cement percentage for 1.5 N/mm² at 28 days:",
+ round(example_opt$optimal_pct, 1), "%"))
[1] "Optimal cement percentage for 1.5 N/mm² at 28 days: 97.1 %"
Optimal Mix Design**:**
The optimization function provides practical guidance for mix design to achieve target strengths
For example, to achieve 1.5 N/mm² at 28 days, about 6.4% OBHA/BHA replacement is optimal

Material Efficiency:
- The concave relationship suggests there's a point where increasing cement content yields diminishing strength returns
- This helps balance material costs with performance requirements

Therefore, the developed model successfully captures the complex relationships between cement content, curing age, and split tensile strength. It provides both accurate predictions and practical optimization capabilities for concrete mix design. The excellent statistical metrics and logical coefficient signs confirm the model's validity for the tested conditions. This tool can significantly aid in material optimization for OBHA/BHA concrete applications.

VI. Conclusion And Recommendations

Conclusion:

In conclusion, by comparing the results of concrete cubes and beams produced based on the practical that have been carried out which includes the grading of aggregates, production of concrete with varying percentages having 0%, 5%, 10%, 15%, 20% and 30% of OBHA and BHA combined on equal ratio respectively, slump test, curing of concrete cubes/beams and crushing of concrete cubes/beams, setting time test, and Mathematical modeling, there are variations in the results which could be summarized as follows:

i. The strength development in the concrete produced increases with the increase in the hydration period.
ii. The higher the setting time, the lower the strength of concrete produced.
iii. Curing is very important in concrete so as to ensure the complete hydration of cement.
iv. The strength development in concrete depends on the percentage chemical composition of cement and other materials in the Concrete.
v. The use of agricultural waste products like Oil bean husk ash and Breadfruit husk ash in concrete production is part of a growing interest in sustainable materials. These materials can potentially improve certain properties of concrete while also providing an environmentally friendly disposal method for agricultural waste. Therefore, utilizing agricultural waste like OBHA and BHA in concrete production is environmentally beneficial, reducing the carbon footprint of cement manufacturing by lowering the clinker content and promoting recycling.
vi. The combination of Oil bean husk ash and Breadfruit husk ash in concrete has the potential to create a more sustainable and cost-effective construction material. However, it is crucial to optimize the mix design and thoroughly test the concrete to ensure it meets the required standards for structural applications.
vii. The inclusion of ash affects the workability of the concrete mix. Ash particles are generally finer than cement particles, which can increase the water demand for achieving the desired consistency. This might require adjustments in the mix design, such as increasing the water content or using water-reducing admixtures.
viii. Based on the Compressive, Flexural and split tensile strength tests performed, there is a confirmation that the incorporation of OBHA/BHA in concrete can influence the strength of the concrete. Therefore, the optimal replacement levels need to be determined thoroughly. Typically, small replacement percentages (e.g., 5-10%) might enhance strength due to pozzolanic action, while larger proportions could reduce strength if the ash content is too high and affects the cement matrix negatively.
ix. The R-Programming based model for Compressive, flexural and Split tensile strength prediction demonstrates:

- Strong predictive power with high R^2.
- Compressive, Flexural and Split tensile strength increase with curing age, due to enhanced hydration.
- Strength decreases with increasing OBHA/BHA content**,** confirming dilution effects.
- Optimal performance is achieved at 5% OBHA/BHA replacement and 90 days curing, making it ideal for structural applications requiring flexural durability.

Based on the results so far, it is vital to note that the use of Oil Bean Husk Ash and Breadfruit Husk Ash in concrete is a promising area of research that aligns with sustainable construction practices.

Therefore, we can conclude that OBHA/BHA has effect on the concrete and the optimal replacement levels need to be determined thoroughly as larger proportions could reduce strength if the ash content is too high and affects the cement matrix negatively

VII. Recommendations

From the results of the practical test carried out, it was observed that combining Oil Bean Husk Ash and Breadfruit Husk Ash in concrete is an innovative approach to sustainable construction. The combination is a welcome development and based on the investigation, it can be recommended that concrete with 5-10% OBHA & BHA are suitable for use as admixture to

improve the workability and Compressive, Flexural & Split Tensile strength of concrete in normal environment. Using R-Programming software in the research modelling is a welcome development as R-Programming can predict and give you the compressive, split tensile and flexural strengths of Concrete. Also if given the compressive, split tensile and tensile strengths of Concrete containing two or more products, the R-Programming mathematical modelling of this concrete can give you the optimal percentages range of the mix proportions that will produce the best strength of the concrete. It can therefore be recommended that Researchers should use R-Programming modelling in their research works.

Contribution To Knowledge

This research work has contributed to exiting literature and it will guide the Engineers and Contractor in working accurately with such green concrete produced using OBHA and BHA. R-Programming modeling successfully captures the complex relationships between cement content, curing age, Compressive, Flexural and split tensile strengths. It provides both accurate predictions and practical optimization capabilities for concrete mix design. The excellent statistical metrics and logical coefficient signs confirm the model's validity for the tested conditions. This tool can significantly aid in material optimization for OBHA/BHA concrete applications.

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