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The use of millet husk ash for cement replacement in concrete production

Kefas Michael[1], Usman Ibrahim Audu[2]*, and A. Masari Umar[3]

[1]Department of Civil Engineering Technology, Federal Polytechnic Kaura Namoda, Zamfara state, Nigeria.
[2]Department of Civil Engineering Technology, Federal Polytechnic Kaura Namoda, Zamfara state, Nigeria.
[3]Department of Civil Engineering Technology Federal Polytechnic Kaura Namoda Zamfara state, Nigeria.
.Corresponding author: auduusman162@gmail.com

ABSTRACT

The study conducted a comprehensive analysis of the potential use of Millet husk ash as a substitute for cement in concrete production. Various tests were performed to assess its suitability, including particle size distribution, slump, and compressive strength, specific gravity, and impact value tests. The research emphasized the increasing significance of considering cost implications and the potential for utilizing industrial or agricultural waste as alternative sources of raw materials for the construction industry. One of the main objectives was to investigate the effect on the compressive strength of concrete when millet husk ash partially replaces cement. This involved a detailed evaluation of the pozzolanic properties of the ash obtained from Yankaba Village of Kaura Namoda, Zamfara State, Nigeria. Furthermore, the study aimed to evaluate the mechanical and microstructural properties of concrete prepared with varying proportions of ash. The findings have substantial implications for the construction industry, particularly in terms of sustainability and cost-effectiveness. By exploring the potential use of millet husk ash as a cement replacement, the study contributes to efforts to reduce reliance on traditional raw materials and explore innovative alternatives. The comprehensive testing and evaluation provide valuable insights into the feasibility and potential benefits of incorporating millet husk ash into concrete production processes. Overall, this study represents a significant contribution to the field of construction materials and sustainable engineering practices. The insights offered are valuable for industry professionals, researchers, and policymakers aiming to promote sustainable and environmentally friendly practices within the construction sector. As the demand for sustainable construction materials continues to rise, this study offers a timely and relevant potential avenue for reducing environmental impact and enhancing the long-term viability of construction processes.

Keywords: Millet Husk Ash, Cement, Concrete, Compressive strength

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INTRODUCTION

Concrete is a composite material made of aggregates dispersed in a cement paste matrix (Fapohunda, Akinbile, & Shittu, 2017; Habeeb and Hashim, 2018). The paste itself consist hydration products which include calcium hydroxide, calcium silicate hydrate, calcium monosulphoaluminat, ettringite, and un-reacted cement, pores and water. The need and importance of concrete in construction industry is ever increasing since its discovery.

Concrete is the oldest and most commonly used construction material in the world, because of its durability, low cost and high availability (Hassan Y, 2015). The cost of concrete is relatively high due to the manufacturing cost of its main constituent, the ordinary Portland Cement (OPC). The cost of conventional building materials continue to increase as the majority of the population continues to fall below the poverty line. Thus, is the need to search for local materials as alternatives for the construction of functional but low-cost building in both the rural and urban areas (Raheem, 2010). The aim of this study is to know and investigate the adverse effect on the compressive strength of concrete when cement is partially replaced with millet husk ash.

Concrete material

According to (Jackson and Dhir, 2012), concrete is a man-made composite materials the major constituents of which is natural aggregate, such as gravel and sand or crushed rock.

Constituent of concrete

Concrete is composed mainly of four materials namely cement, coarse, aggregate, fine aggregate and water.

Cement

Cement is the binding materials in concrete. When is added to cement a chemical reaction takes place resulting in the cement setting afterwards. Good concrete therefore depends largely on the quality of the cement being used (Obande M. O, 2013). The different cements used for making concrete are finely ground powders and all have the important property that when mixed with water a chemical reaction (hydration) takes place which in time procedure a very hard and strong building medium for the aggregate particles (Jackson and Dhir, 2012).

Coarse aggregate

According to (Bhushan M, 2021) coarse aggregate is stone which are broken into small sizes and irregular in shape. In construction work the aggregate are used such as limestone and granite or river aggregate. And are aggregate which has a size bigger 4.75mm or which retained on 4.75mm IS sieve. Classification of coarse aggregate based on shape. According to (Bhushan M, 2021) classified coarse aggregate base on shape as following.

i. Rounded aggregate
Ii Angular aggregate
ii. Irregular aggregate
iii. Elongated aggregate
iv. Flasky aggregate
v. Flasky elongated aggregate

Fine aggregate

Fine aggregates are aggregate particles that pass through 4.75mm, fine aggregate include things such as sand, silt and clay, machine crushed stone and crushed gravel might also fall under this under this category. Typically, fine aggregate are used to improve the workability of a concrete mix (Bhushan M, 2021).

Water

Water is used in concrete in addition to reacting with cement and thus causing it to et and harden, also facilities in mixing, placing and compacting of fresh concrete and also for curing purpose. Generally, quality of water for construction works are same as drinking water. This is to ensure that the water is reasonably free from such impurities as suspended solids, organic matter and dissolved salts, which may adversely affect the properties of the concrete, especially the setting, hardening, strength, durability, pit value etc. The water shall be clean and shall not contain sugar, molasses or Gur or their derivatives or sewage, oils and organic substances (Gopal M,2012)

Agro waste

There are advantages characteristics and other have mode concrete to be most widely used construction material as noted by Neville and Books (2002). These have created an opportunity for the use of agro waste, industrial waste and related materials as partial replacement of either sand or coarse aggregate in which called for more research on all aggregates replacing materials as this can give more certainly on other utilization in concrete (Jnyamendre et al, 2016)
The water shall be clean and shall not contain sugar, molasses or gur or their derivative.

Concrete compressive strength

Compressive strength results are primarily used to determine that the concrete mixture as delivered on site meets the requirements of the specified strength, fc', in the job specification. Cylinders tested for acceptance and quality control are made and cured in accordance with procedures described for standard-cured specimens in ASTM C-31 (which is the standard practice for making and curing concrete test specimens in the field). For estimating the in place concrete strength, ASTM c-31 provides procedures for field-cured specimens.

Cylindrical specimens are tested in accordance with ASTM C-39 (which is standard test method for compressive strength of cylindrical concrete specimens).
A test result is the average of at least two standard-cured strength specimens made from the same concrete batch and tested at the same age. in most cases strength requirements for concrete are at 28 day

MATERIALS AND METHODS

Cement

Sokoto Manufactured Port-Land Cement used in this investigation was obtained from cement marketers in Kaura Namoda, Zamfara State.

Aggregates

The coarse aggregate used was a normal weight aggregate with a nominal size of 20mm, obtained from the marketers in Kaura Namoda fine aggregates used is river sand obtained from marketers in Kaura Namoda

Millet husk ash

Millet Husk Ash (MHA) was obtain in 50 kg sacks from Yankaba village of Kaura Namoda, Zamfara State, Nigeria. The ash was then obtained by burning the millet husk in a drum for 24 hours at temperature of $400^0 – 600^0$ C and intermittent turning was done so as to have a uniform temperature throughout the burning process. the burnt and cooled ash was then sieved through 425µm bs sieve. The Ash Passing Through The 425µm BS Sieve Was Used For The Research.

Methods

Determining the properties of cement

Fineness test: this test was conducted in accordance to BS 196-6

- 500g of cement was measured as W_1 and cement was rub very well with hands to avoid slumps
- The 500g of cement was placed in a 90µm sieve and it was perfectly closed with the sieve lid
- The sample was shake for 15minuit with hand
- The retained amount of cement in 90µm was weighed as W_2
- Fineness percentage was calculated using

$$F = \frac{W1}{W1+W2} \times 100$$

The process was repeated for three times

Setting time: this test was conducted in accordance with BS196-3

- a cement paste was prepared with a water-cement ratio of 0.85
- the vicat apparatus mold was filled with the cement paste
- the 1mm vicat needle was placed on the surface of the paste
- I recorded a penetration time till when the needle penetrate 5mm(initial setting time)
- I also recorded the time at which the needle cannot longer penetrate the past(final setting time).
-

Soundness Test: this test was conducted in accordance to BS 196-3

- A cement sample of 100g was mixed with 0.78 times the water required for standard consistency
- The Le-chatelia mold was fill with cement pest
- Initial measurement L_1 was taken before immersing the sample in a water bath
- The sample was removed after 24hrs
- Final measurement was taken as L_2
- Expansion (mm)=L_1-L_2

Compressive strength of cement: this test was conducted in accordance to BS196-1

- A cement past was fill in a 40mm mold which was compacted using a tamper
- The sample was removed from the mold after 24hrs and was cured for 28days
- The compressive strength was obtained crushing for 1day, 7days and 28days

Determining the properties of coarse aggregates

Mineralogical composition of aggregate: this test was conducted in accordance to BS 812-3

- An aggregate sample less than 100µm was well mixed to ensure homogeneity
- The sample was placed in XRF sample holder and the XRF analysis was performed.
- Record was taken from the spectrum for further analysis

Texture and grain shape analysis this test was conducted in accordance to BS 812-1

- Aggregate sample was collected, washed and dry to removed fines
- The sample was separated into individual grains

to examine grains under magnification

- The texture was determined using a standard classification system ASTM C125, ISO14688
- The grain shape analysis was done to measure the dimension of the aggregate

Dustiness and porosity analysis; this test was done according to BS 812-2:1992

- Aggregate sample was dry to remove moisture
- Dustiness apparatus was used to measure the amount of dust generated by the aggregate
- Porosity testing apparatus was used to determine the voids in the concrete
-

Frost resistance test: this test was conducted in accordance with BS 812-9

- The aggregate sample was collected and prepared in 10-15 specimens
- The sample was subjected to freeze-thaw cycle for 16 to 20 hrs at temperature 17^0C to 20^0C and thaw at 8-12hrs at temperature 20-25^0C
- Mass loss was measured after each 5 cycle and relative durability factor was calculated

Abrasion resistance test: this test was done in accordance with BS 812-3

- The aggregate sample was collected and prepared in 3-5 specimens
- Specimens were place in Los Angeles Abrasion machine
- The machine was rotated for 1000 evolutions
- Mass loss was determined by Abrasion loss calculation.

Asphalt absorption capacity test (ASTM D2172): This test was conducted in accordance to BS 128-9:1998.

- Collected coarse aggregate sample was dried to remove moisture content for sieving
- Sieve number 4, 8, and 10 was used to obtain uniform size fraction
- 5% by weight Coat aggregate with asphalt cement AC-20 was allowed to absorbed asphalt for 2hrs
- The sample was removed and percentage asphalt absorption was calculated

Fine aggregates tests

Particle size distribution for fine aggregate; this test was conducted in accordance with BS 933-1

- Fine aggregate sample was collected and weighed in grams
- The sample weighed was placed in different diameters of sieves
- It was shaken for 5min and all sample retained were weighed
- The percentage of aggregate that passes through the sieve was calculated
- Fineness modulus was calculated using the particle size distribution values.

Specific gravity test for fine aggregate *(BS 812, 1984)*

- The Pycnometer was filled with water to the calibration mark which was recorded as initial water level V_1
- The final water level was also recoded as V_2
- The volume of aggregate was calculated using $V= V_1- V_2$
- The pycnometer fill with aggregate and water was recorded as W_1
- The pycnometer fill with only water was recorded as W_2
- The weight of aggregate was calculated using $W= W_1 -W_2$
- Specific gravity was calculated using $G= \frac{W}{V}$

Coarse aggregates tests

Specific Gravity of coarse aggregate (BS 812, 1984)

- The Pycnometer was filled with water to the calibration mark which was recorded as initial water level V_1
- The final water level was also recoded as V_2
- The volume of aggregate was calculated using $V= V_1- V_2$
- The pycnometer fill with aggregate and water was recorded as W_1
- The pycnometer fill with only water was recorded as W_2
- The weight of aggregate was calculated using $W= W_1 -W_2$
- Specific gravity was calculated using $G= \frac{W}{V}$

Aggregate impact value (Bs 812-110, 1990)

- the mould was fill with aggregate which was compacted using tamping rod
- the sample was placed in the impact testing machine
- 15 blow was applied
- The sample was sieved through 6.3mm

- The sample passing 6.3mm sieve was weighed as W_1
- The mean percentage generated AIV=$(W_1/W)X100$

Particle size distribution for coarse aggregate-sieve analysis

This test was done in accordance to BS 812-103:1995

- 500g of coarse aggregate was placed on the sieve
- The sieve was shaken for about 10minutes
- Sample retained in each sieve was weighed to the nearest 0.01g
- Percentage of coarse retained by each sieve was calculated

Properties of millet husk ash

Chemical composition of MHA: this was done in accordance with the BS 196-2

- The P^H value was measured using the P^H meter
- The loss ignition was determined by heating the ash to 950^oC to get the loss

Specimen preparation and test methods

A bone ash concrete was prepared by replacing the cement with bone ash at 0%, 5%, 10%,15%and 20% by respectively. an m25 grade of concrete would be use throughout the test and the replacement of the cements will be by weight.

Cube mould: The cube mould (150x150x150 Mm) was place in position on an even surface, all the interior face and sides were coated with mud oil to prevent the sticking of concrete to the mould.

Batching and mixing of concrete

This test was done according to BS 1881-125 (1986) "Method for mixing and sampling fresh concrete in laboratory

Curing

The cubes were removed from the mould 24 hours after casting; the cubes were then immersed into a clean tank filed with drinkable tap water. Thus, the curing was carried out for the periods of 14 and 28 days.

Compressive strength test

Concrete mixtures can be designed to provide a wide range of mechanical and durability properties to meet the design requirements of a structure. The compressive strength of concrete is the most common performance attribute used by the engineer when designing structures. Compressive strength is measured by breaking cylindrical concrete specimens in a compression-testing machine. Compressive strength was calculated from the failure load divided by the cross-sectional area resisting the load and reported in units of pound-force per square inch (psi) or Mega Pascals (Mpa). Concrete compressive strength can vary from 2500 psi (17mpa) for residential concrete to 4000 psi (28 Mpa) and higher in commercial structures. Some applications use higher strengths, greater than 10,000 Psi (70 Mpa).

Laboratory tests

In this research work, the following tests were carried out to ascertain the required properties of concrete, within the limits specified by their respective BS codes. The Following Tests Were Carried Out:

i. Slump test to determine workability
ii. Compressive strength of concrete

Workability test (Slump test)

This test done according to BS 1881 Part 102 (1983) "method for the determination of slump"

- The mould was placed on a smooth surface i.e. on top of the tray
- The mould was then filled with concrete in three equal layers. Each layer was tamped 25 times with the steel rod, and the top was then leveled smoothly. Thus, the mould was firmly held against its base during the entire operation; this was facilitated by handle or feet-rests braced on the mould.
- Immediately after filling, the cone mould was slowly lifted and allowing the unsupported concrete to slump
- The slump was then measured by inverting the empty cone alongside the slump concrete, thus, the tamping rod was placed across it and measured down with a ruler.

Casting

- The mould and base plate were kept clean and oiled lightly to prevent the concrete form sticking on the sides. No undue force was used during assembling.
- The concrete paste was poured into the mould and it was fully compacted in three layers. The strokes was evenly distributed over the surface of the concrete in a regular pattern and then the top was leveled with a hand trowel, as smooth as possible, the cubes were then marked for easy identification.

Table 1: Sieve analysis of fine aggregate.

Sieve (Mm)	Mass Of Soil Retain On Each Sieve	Percentage Of Mass Retain (%)	Cumulating Percentage F(%)	Percentage Of Passing (%)
4.00	2.0	0.2	0.2	99.8
3.15	4.0	0.4	0.6	99.4
2.5	15.0	1.5	2.1	97.9
2.00	23.0	2.3	4.4	95.6
1.00	813.0	81.3	85.7	14.3
Pan	140.0	14	99.7	0.3

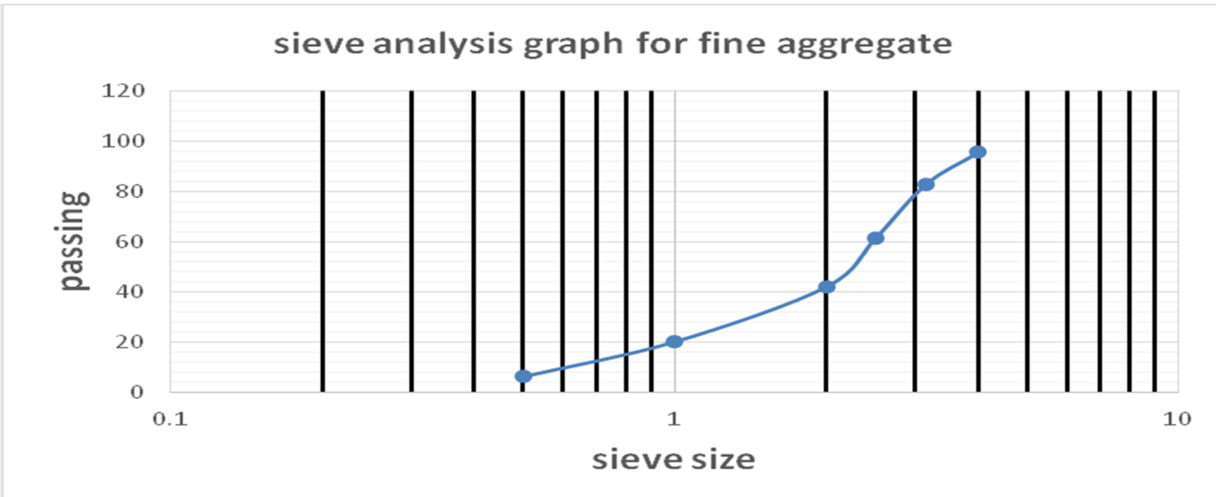

Figure 1: Sieve analysis for fine aggregate.

Table 2: Sieve analysis of coarse aggregate.

Sieve (Mm)	Mass Of Soil Retain on Each Sieve	Percentage of Mass Retain (%)	Cumulating Percentage (%)	Percentage of Passing (%)
20.00	125	12.5	12.5	87.5
12.00	838	83.8	96.3	3.7
10.00	27	2.7	99	1.0
8.0	5	0.5	99.5	0.5
Pan	0	0	0	0

The lost percentage of coarse aggregate is = 1000 -995 =5g.

Thus, 15 cubes were casted for the research work i.e. 5 for each percentage replacement.

Test for hardened concrete

Compressive strength test was done according to BS 1881: Part 116: “method of determination of compressive strength of concrete”.

- The cubes were removed from the curing after the days of curing and were allowed to dry completely.
- The cubes were then weighed.
- The casted face of the cube was placed in contact with the platens of a very denison compression testing machine and a constant rate of stress was applied until failure occurs
- Maximum loads were recorded and the failure mechanisms of the specimens were observed.

RESULTS AND DISCUSSION

Sieve analysis

Upon reviewing the sieve analysis results presented in (Tables 1 and 2), it is evident that the sand exhibits a fine grading with a fineness modulus of 2.11. This value falls within the specified range of 2.0 to 3.0 as outlined in the (BS 882:1992) standard. The sieve analysis serves as a valuable tool for determining the particle size distribution, gradation, as well as the shape and surface texture of the sand. Furthermore, the results from (Tables 1, 2 and Figure 1) also indicate fine aggregate grading sand with a fineness modulus of 0.93, once again aligning with the specified range of 2.0 to 3.0 as per the (BS 882:1992) standard. It is important to note that the sieve analysis plays a crucial role in providing insights into the characteristics of the sand, aiding in informed decision-

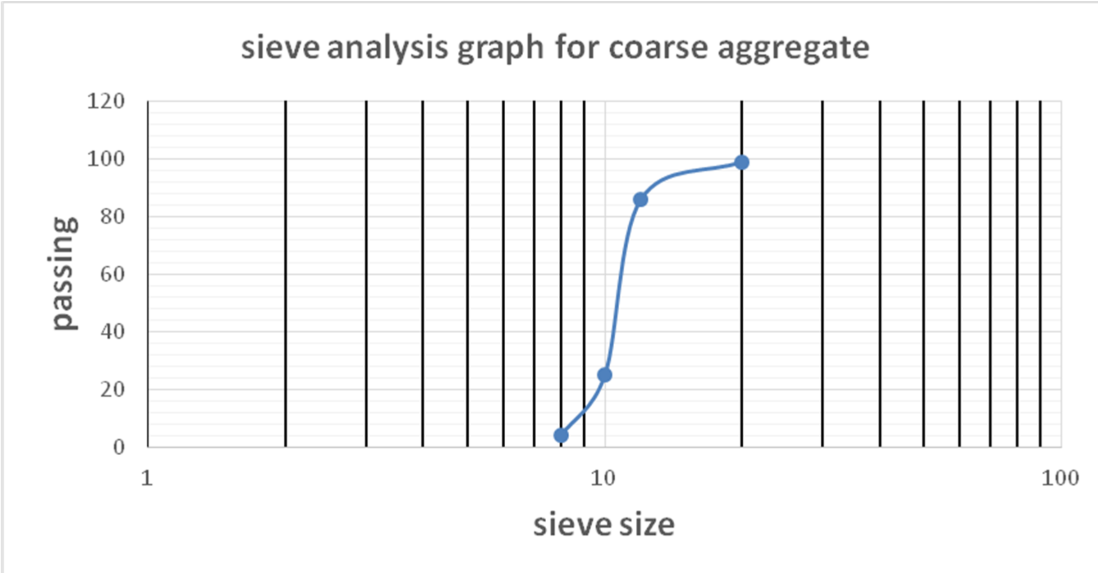

Figure 2: Sieve analysis for coarse aggregate.

Table 3: Standard consistency for percentages replacement of cement by adding millet husk ash.

Setting time (min).	Millet host ash					Percentage replacement (%)
	0	5	10	15	20	25
Initial	125	156	169	176	185	190
Final	259	278	306	349	368	395

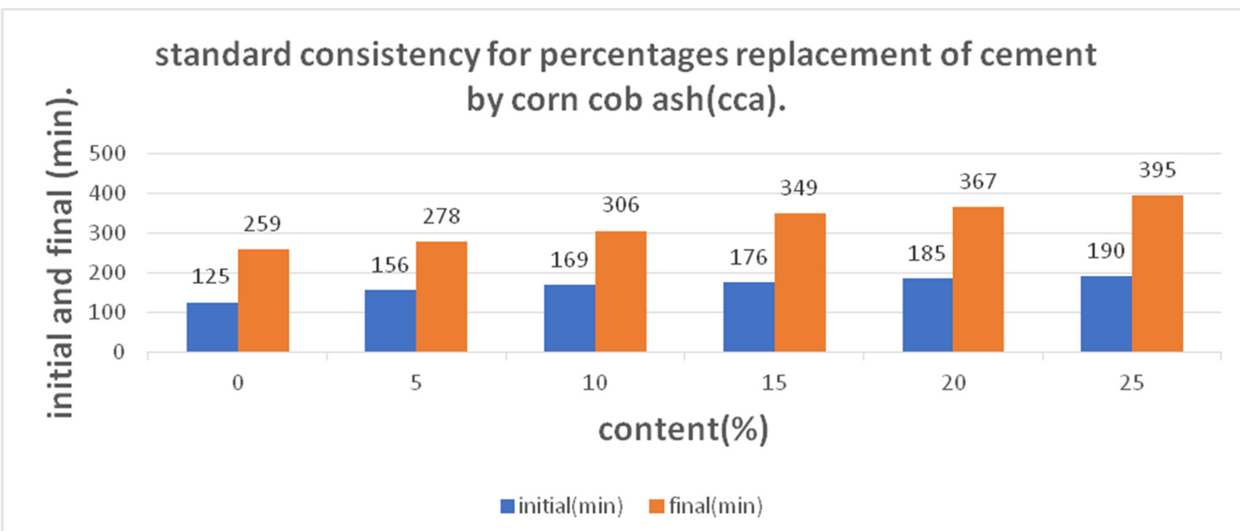

Figure 3: Standard consistency for percentages replacement of cement by corn cob ash (CCA).

Table 4: Result of specific gravity for sample materials.

Material	Sample 1	Sample 2	Averages
M.H.A	2.28	2.31	2.30
Cement	3.14	3.18	3.16
Fine Aggregate	2.35	2.75	2.55
Coarse Aggregate	2.55	2.85	2.70

Table 5: Aggregate impact value.

Parameters	Weights
Weight Of Empty Cylindrical Cup(W_1)	622g
Weight Of Cup +Aggregate(W_2)	966g
Weight Of Aggregate (W_3) = W_2.W_1	344g
Weight Of Aggregate Passing Through 2.5mm Sieve (W_4)	38
Aggregate Impact Value (%) = W_4/W_3X100	34/344x100=11.04%

Table 6: Oxide composition of cement and M.H.A

Oxides	Cement	M.H.A
SiO_2	12.01	64.22
Al_2O_3	3.03	3.71
Fe_2O_3	4.14	3.49
CaO	74.06	6.55
MgO	1.4	2.81
SO_3	2.05	1.56
Na_2O	-	0.86
K_2O	1.27	6.01
P_2O_5	-	4.06
Cl	0.1	1.05
TiO_2	0.33	0.71
Cr_2O_3	-	-
Mn_2O_3	-	0.09
ZnO	-	0.09
SrO	0.49	0.06
LoI	1.04	4.54

making for various applications. The lost percentage of fine aggregate of fine aggregate is = 1000 -997 =3g

$$FM=\sum\frac{F}{100}=\frac{93}{100}=0.93$$

Figure 2 show the results of sieve analysis for coarse aggregate with a uniform particle size distribution the material meets the ASTM C33 specification indicating its suitability for use in concrete and asphalt application.

Setting time of cement and ash from (Table 3 and Figure 3) above, show that as the cement is being replace at various percentages of ash it also affect the setting time, which is by increasing the initial and final setting time.

Specific gravity test from (Table 4) shows the result of specific gravity test for both fine and coarse aggregates as presented in table4.4.which Fall within the specification 2.53 -3.0 for crush aggregate in accordance to ASTMC127 and BS 812. And also that of cement and millet husk ash fall within the specification of 2.20 to 3.20 in accordance with fly ash (ASTMC618): the specific gravity test is conducted to determine the density of the material (cement, aggregate,), check compliance with specifications and standards, determine the water absorption and porosity of the material, calculate the volume of the material needed for a specific application, determine the weight of the material per unit volume (density). The aggregate impact value test results, as shown in (Table 5), indicate a value of 11.04%. According to BS 812-112:1990 (British standard for testing aggregate), when the AIV is less than 10%, it signifies that the aggregate is exceptionally strong, resistant to abrasion, and suitable for construction purposes. Despite the obtained result being slightly higher at 11.04%, it still implies that the aggregate is exceptionally strong and can be utilized for construction and concrete work involving high forces or loading. This test is crucial in ensuring that the aggregate used in construction is capable of withstanding imposed stresses and loads, thereby minimizing the risk of premature failure or degradation.

Chemical composition and analysis

Chemical composition and analysis of cement and millet husk ash. From (Table 6) shows the chemical composition of corn cob ash. The total percentage composition of iron oxide (Fe_2O_3=2.95), silicon dioxide (SiO_2=68.60) and aluminum oxide (Al_2O_3=5.15) was found to be 76.7%. The values are within the required value of 70% minimum for pozzolas as specified by ASTMC618 (2005).

Conclusion

Based on the experiment, calculations, analysis, and observations of the research, it can be concluded that millet husk ash exhibits pozzolanic properties, making it suitable for concrete production. The incorporation of millet husk ash in concrete results in an increase in the strength of the concrete with age when cured in normal water for the determination of compressive strength. This indicates that millet husk ash can effectively enhance the performance of concrete over time. However, it was also observed that the workability of the concrete decreases with an increase in millet husk ash content. This suggests that while the use of millet husk ash can improve certain properties of concrete, it may also have an impact on the workability of the material. Further research and testing may be necessary to optimize the use of millet husk ash in concrete production and to understand its full range of effects on concrete properties.

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