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EVALUATION OF THE FRESH PROPERTIES OF DOUM PALM FIBRE REINFORCED CONCRETE WITH RICE HUSK ASH AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

Concrete is widely used in construction, but its reliance on cement raises environmental concerns due to high carbon emissions. To address this problem, researchers are exploring the use of materials like rice husk ash (RHA) to replace part of the cement and doum palm fibre (DPF) to improve performance. Although each material has shown benefits on its own, there is still limited understanding of how they work together, especially in terms of how the concrete behaves in its fresh state. This study investigates the use of doum palm fibre (DF) as a natural fibre reinforcement and rice husk ash (RHA) as a partial replacement for cement, focusing on the fresh properties of fibre-reinforced concrete. Rice husk ash was used to replace Portland limestone cement at levels of 0, 5, 10, 15, 20, and 25%, while doum palm fibre was added at 0, 0.5, 1.0, 1.5, and 2.0% by volume of concrete. The materials were characterized in accordance with the standard code specification. Workability was assessed using slump flow and compacting factor tests in accordance with relevant British Standards. The results show that workability decreases gradually with increasing RHA content and fibre dosage due to higher water demand, fibre interlocking, and the fine, porous nature of RHA. Despite this reduction, all mixes remained within acceptable workability limits. Slump values ranged from 50 to 60 mm, while compacting factors varied between 0.90 and 0.92, indicating satisfactory compaction. An optimum mix containing 10% RHA and 1.0% DF was identified, offering a balanced combination of workability, fibre effectiveness, and pozzolanic performance.

Keywords: Doum Palm Fibre, Rice Husk Ash, Workability, Compacting Factor, Sustainable, Concrete

INTRODUCTION

Concrete continues to dominate the construction industry because of its adaptability, long-term durability, and economic advantages (Li et al., 2022). Nevertheless, cement production, which forms the backbone of concrete technology, is an energy-intensive process and a major contributor to global carbon dioxide emissions (Abdul-Wahab et al., 2021; Azam et al., 2023). Growing awareness of environmental sustainability has therefore shifted research attention toward the use of supplementary cementitious materials and natural reinforcements sourced from agricultural waste, with the aim of reducing the environmental footprint of concrete while maintaining acceptable performance (Fapohunsda et al., 2017; de Azevedo et al., 2021).

Rice husk ash (RHA), generated from the combustion of rice husks, has emerged as a promising cement replacement material due to its high content of amorphous silica and strong pozzolanic activity (Givi et al., 2010; Hossain et al., 2018). When adequately processed, RHA reacts with calcium hydroxide to form additional cementitious products, resulting in a denser microstructure and improved durability of concrete (Hadipramana et al., 2016; Tulashie et al., 2021). In the other hand, natural fibres such as doum palm fibre (DPF) have gained increasing interest as sustainable reinforcement materials. These fibres are renewable, readily available, and capable of enhancing crack resistance, toughness, and post-cracking energy absorption in cement-based composites (Fatma et al., 2019; Naiiri et al., 2020). However, the simultaneous incorporation of RHA and natural fibres can negatively affect workability and fibre dispersion due to increased surface area, water demand, and fibre interlocking, thereby posing practical challenges that require careful evaluation (Yin et al., 2020).

The fresh properties of fibre-reinforced concrete strongly influence fibre distribution, compaction efficiency, and overall material uniformity, which in turn affect the mechanical and structural performance of flat slabs (Pakravan et al., 2009). Sulaiman and Aliyu (2020) investigated the use of RHA and cement kiln dust (CKD) as partial cement replacements which they found that increasing RHA content leads to a noticeable reduction in workability. It was concluded that moderate replacement levels 5 to 15% offer an optimal balance between workability and cohesiveness.

Sani et al., (2021) found out that natural fibres also influence other fresh properties such as density and cohesiveness. And also observed an improvements in cohesiveness at optimal fibre content, which can reduce segregation, although excessive fibre addition may lead to poor compaction and uneven distribution.

Usman *et..al.,* (2025) assessed coconut fiber-reinforced concrete's strength, sourced from Ivbiaro,

Owan West, Edo State. Results showed workability decreases as fiber content rises, while density increases. Compressive strength peaks at 1% fiber (22.44 N/mm²) from 0% (19.87 N/mm²), but declines beyond 1%. Thus, coconut fiber enhances concrete sustainability and strength optimally at 1%, supporting eco-friendly construction with economic and waste management benefits. A research conducted by Garba.et.al (2024) on the effect of laterite on strength and durability of reinforced concrete as partial replacement of fine aggregate. The findings indicates the strength properties decreases with increase in laterite content, however, the water absorption is increased by the inclusion of laterite .It was concluded that the use of laterite in the production of concrete should not exceed 10%.

This study therefore focuses on the fresh properties of doum palm fibre reinforced concrete incorporating rice husk ash as partial replacement of cement, employing a statistically based experimental design.

MATERIALS AND METHODS

Materials

Portland Limestone Cement

Portland Limestone Cement (PLC) of grade 42.5N was obtained from a nearby dealer at Samaru Zaria, Kaduna state. Quality control and standard compliance tests were carried out on the cement.

Rice Husk Ash

RHA is the product of incineration of rice husk. The rice husk was burnt for four hours at 600 ^{O}C to 700^{O}C in a muffle furnance, then cooled and sieved to a sieve of size less than 75µm to obtain the calcined ash. XRF test was conducted in order to determine the oxides composition of the RHA.

Coarse Aggregate

A granite of 20mm maximum nominal particle size crushed with a machine was sourced from a quarry opposite Nigeria College of Aviation Technology (NCAT), Zaria. Bulk density, water absorption, specific gravity, Aggregate impact and crushing value tests were determined.

Fine Aggregate

The fine aggregate was locally sourced at river Saye along Kaduna Road, Zaria. The specific gravity, bulk density, silt content, water absorption of the fine aggregate was determined.

Doum Palm Fibre

Doum palm fibre (DF) was obtained from doum palm tree at Buzai close by Zaria City, Kaduna State.

Mixing Water

Water is one of the most desirable constituent materials of concrete due to its need in hydration of the Portland limestone cement. The mixing water was sourced from a pipe borne hole at Department of Civil Engineering, Ahmadu Bello University, Zaria.

Design Expert Software

Design expert version 13 (2021) was used in this research work for the design of experiment (DOE).

Methods

Physical Properties of Portland Limestone Cement

The physical properties that were carried out consist of the determination of consistency, setting times, and the soundness of cement. These tests were carried out in accordance with BS EN 196-3 (2016).

Oxides Composition Test (XRF)

The X-ray fluorescence test was carried out to determine the oxides composition of the rice husk ash. It was carried out at the multi user laboratory, Department of chemistry, Ahmadu Bello University, Zaria.

Particle Size Distribution of Fine and Coarse Aggregate

This is a process of screening a sample of aggregate into sizes fractions each consisting of particles of different range sizes. The particle size distribution test for the fine and coarse aggregates was carried out in accordance with BS EN 933-2: (2020).

Specific Gravity

This test determines the aggregate quality and quality ensuring accurate proportioning in the concrete production. The specific gravity test for coarse and fine aggregate was carried out in accordance with BS EN 12390-7:(2019).

Aggregate Impact Value (AIV)

The aggregate impact value gives a relative measure of resistance of aggregate to sudden shock or impact. The test was conducted in accordance to BS EN-1097-2, (2020).

Aggregate Crushing Value (ACV)

Aggregate crushing value gives the relative measure of crushing resistance of aggregate under an increasing compressive load. The test was conducted in accordance to BS EN-1097-2, (2020).

Tensile Strength of Doum Palm Fibre

Tensile strength of the doum palm fibre was conducted in the laboratory at the Department of Polymer and textile Engineering, ABU Zaria. The test was carried out in accordance with BS EN 14889-2:2006. Plate I shown laboratory set up for the determination of tensile strength of the fibre.

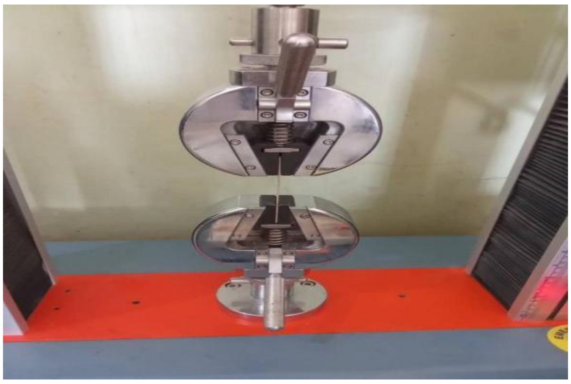

Plate. I. Determination of the Tensile Strength of the Doum Palm Fibre

Treatment of the Doum Palm Fibre

The Doum palm fibres (DF) was treated with a NaOH solution of 1% concentration to enhance their resistance against chemical degradation. Chemical treatment of fibre was conducted in order to remove some hemicellulose and lignin which tends to make the fibre more homogenous, and enhances fiber matrix interfacial properties.

Design of Experiment and Development of Mix design Matrix

The design of experiment was developed using design expert software. Discrete multi-level factorial experiment was adopted for the mix design. Two (2) factors (independent variables) were considered, namely RHA having six (6) levels at 0, 5, 10, 15, 20 and 25%, doum palm fibre (DF) having four (4) levels at 0.5, 1.0, 1.5 and 2.0% by total volume of concrete. Table 1 presents the parameters considered with their various levels.

Table 1: Design of Experiment and their Levels

Categoric Factors	Name	Units	Type	Levels	L1	L2	L3	L4	L5	L6
A	Rice husk ash (RHA)	%	Nominal	6	0	5	10	15	20	25
B	Doum palm fibre (DF)	%	Nominal	4	0.5	1.0	1.5	2.0	-	-

Mix Design

The fibre reinforced concrete mixes were designed in accordance with the guideline's specification of British standard code of practice BS EN 14889-1: (2006) with constant water-cement ratio of 0.5 and mix ratio of 1:1.5:3. The RHA was used in partial replacement of Portland limestone cement at 0, 5, 10, 15, 20 and 25%, and doum palm fibre at a different dosage of 0.5, 1.0, 1.5 and 2.0% by total volume of concrete. Twenty to twenty-five millimeter of doum palm fibre length was used in order to maintain an aspect ratio (l/d) of 80-120 for better natural fibre performance in the concrete mix.

Mix Design Proportion for the Fibre Reinforced Concrete with Dosages of Doum Palm Fibre at Different Percentage Replacements of Rice Husk Ash for Cement

In the mix preparation, twenty-four (30) mixes were prepared for fresh fibre reinforced concrete (FRC) at different percentage replacement of cement with RHA were presented in Table 2.

Table 2: Mix Proportions for the Fibre Reinforced Concrete with Rice Husk Ash Partially Replacing Cement

S/NO.	Mix ID	Cement (kg/m^3)	RHA (kg/m^3)	W/C Ratio	Water (kg/m^3)	DF (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)
1	CONTROL	400	0	0.5	200	0	600	1200
2	0RHA0.5DF	400	0	0.5	200	6	600	1200
3	0RHA1.0DF	400	0	0.5	200	12	600	1200
4	0RHA1.5DF	400	0	0.5	200	18	600	1200
5	0RHA2.0DF	400	0	0.5	200	24	600	1200
6	5RHA0.0DF	380	20	0.5	200	0	600	1200
7	5RHA0.5DF	380	20	0.5	200	6	600	1200
8	5RHA1.0DF	380	20	0.5	200	12	600	1200
9	5RHA1.5DF	380	20	0.5	200	18	600	1200
10	5RHA2.0DF	380	20	0.5	200	24	600	1200
11	10RHA0.0DF	360	40	0.5	200	0	600	1200
12	10RHA0.5DF	360	40	0.5	200	6	600	1200
13	10RHA1.0DF	360	40	0.5	200	12	600	1200
14	10RHA1.5DF	360	40	0.5	200	18	600	1200
15	10RHA2.0DF	360	40	0.5	200	24	600	1200
16	15RHA0.0DF	340	60	0.5	200	0	600	1200
17	15RHA0.5DF	340	60	0.5	200	6	600	1200
18	15RHA1.0DF	340	60	0.5	200	12	600	1200
19	15RHA1.5DF	340	60	0.5	200	18	600	1200
20	15RHA2.0DF	340	60	0.5	200	24	600	1200
21	20RHA0.0DF	320	80	0.5	200	0	600	1200
22	20RHA0.5DF	320	80	0.5	200	6	600	1200
23	20RHA1.0DF	320	80	0.5	200	12	600	1200
24	20RHA1.5DF	320	80	0.5	200	18	600	1200
25	20RHA2.0DF	320	80	0.5	200	24	600	1200
26	2RHA0.0DF	300	100	0.5	200	0	600	1200
27	25RHA0.5DF	300	100	0.5	200	6	600	1200
28	25RHA1.0DF	300	100	0.5	200	12	600	1200
29	25RHA1.5DF	300	100	0.5	200	18	600	1200
30	25RHA2.0DF	300	100	0.5	200	24	600	1200

Determination of the Fresh Properties of Concrete

Fresh properties of FRC that were considered were the Slump flow and compacting factor.

Determination of the Slump flow of the Fresh Concrete

This test was aimed to measure the consistency of fresh concrete before it sets. It was performed to check the workability of freshly made concrete, and the easiness with which the concrete flows and to also measure the vertical settlement of a fresh concrete. This test was conducted in accordance with BS EN 12350-5:2019. Plate II shows the slump value test set- up.

Plate II. Determination of Slump Value for the Fresh Concrete

Determination of the Compacting Factor of the Fresh Concrete

This test was performed to ascertain the workability of the concrete. The test was carried out in accordance with BS EN 12350-4:2019. It measures the density ratio of partially compacted to fully compacted concrete.

$$Compacting\ Factor = 0.80 + \frac{Slump\ value(mm)}{500} \quad (1.0)$$

RESULTS AND DISCUSSION

Test Result of Portland Limestone Cement

The tests result for the Portland limestone cement that was used for the research were presented in Table 3. The standard consistency of cement was achieved at 28% moisture content with 5.5mm penetration depth of needle to the cement paste. The results obtained fell within the range specified by BS EN 196-3 (1995), with a penetration depth ranging between 5 to 7mm and moisture content of 26% to 33% for the consistency test.

The initial and final setting times of the cement tested were achieved at 105 and 165 minutes respectively. The soundness of the cement was found to be 0mm expansion. Therefore, the cement used was sound as such recommended for concrete production.

Table 3: Properties of the Portland Limestone Cement Used

S/No	Test	Average value	Code specification	Remark
1	Consistency	28%	$26 \leq$ consistency ≤ 33	Satisfactory
2	Initial setting time	105minutes	≥45minutes	Satisfactory
3	Final setting times	165minutes	≤600minutes	Satisfactory
4	Soundness	0mm	≤10mm	Satisfactory

Oxides Composition of Rice Husk Ash

The oxide composition test result for the RHA that was used for the research was presented in table 4. It was observed that the sum of SiO_2, Fe_2O_3, Al_2O_3 is 90.4%, which is above the minimum requirement of 70% as specified by ASTM C 618-23 for class N and class F pozzolana. Since it was observed that CaO was found to be less than 10%, it aligns with class F low calcium pozzolan and it can be referred to as highly reactive pozzolan. However, it can be used to partially replace Portland limestone cement in production of concrete.

Table 4: Oxide Composition of Rice Husk Ash

Chemical Compound	Percentages of Oxides (%)
SiO_3	89.5
Fe_2O_3	0.10
Al_2O_3	0.80
MgO	1.00
CaO	3.50
Na_2O	0.07
K_2O	0.51
Loss of ignition	4.52

Properties of Aggregate

Properties of fine and Coarse Aggregate used in the Study

Properties of the fine and coarse aggregate that were considered in this research were presented in Table 5. Table 5 presents the results on average properties of aggregate. The Fine and coarse aggregates have specific gravities of 2.54 and 2.83 respectively. The specific gravities obtained for both the fine and coarse aggregate are within the limit specified by BS EN 1097-6:2022. The aggregate crushing value (ACV) and aggregate impact value (AIV) of the coarse aggregates are 29.30% and 23.8% respectively. The recommended range of values satisfied the requirement of BS812-110(1990) and BS812-112(1990) for ACV and AIV respectively.

The fine and coarse aggregates were found to have water absorptions of 1.04 and 0.3% respectively, while the bulk densities for the fine and coarse aggregate were 1291kg/m^3, 1418 kg/m^3 respectively.

Table 5: Properties of Aggregate Used in The Research

Properties	Fine Aggregate	Coarse Aggregate
Specific gravity	2.54	2.83
Bulk density (%)	1291	1418
Aggregate Crushing value (%)	-	23.80
Aggregate impact value (%)	-	29.30
Water Absorption (%)	1.04	0.3
Silt Content (%)	2	-

Particle Size Analysis of fine and Coarse Aggregate

The particle size analysis for the fine and coarse aggregate that were used in this research were presented in Figure 1 and Figure 2 respectively. The fine aggregate particles fall within the range specified by BS 882 (1992) and EN 12620: (2002) and as such categorized as medium sand, this shows that the fine aggregate is suitable for the production of concrete. For the coarse aggregate, it has 20mm maximum nominal size and it is uniformly distributed this makes to meet the grading requirements, and will be good to achieve the required fresh properties of the fibre reinforced concrete.

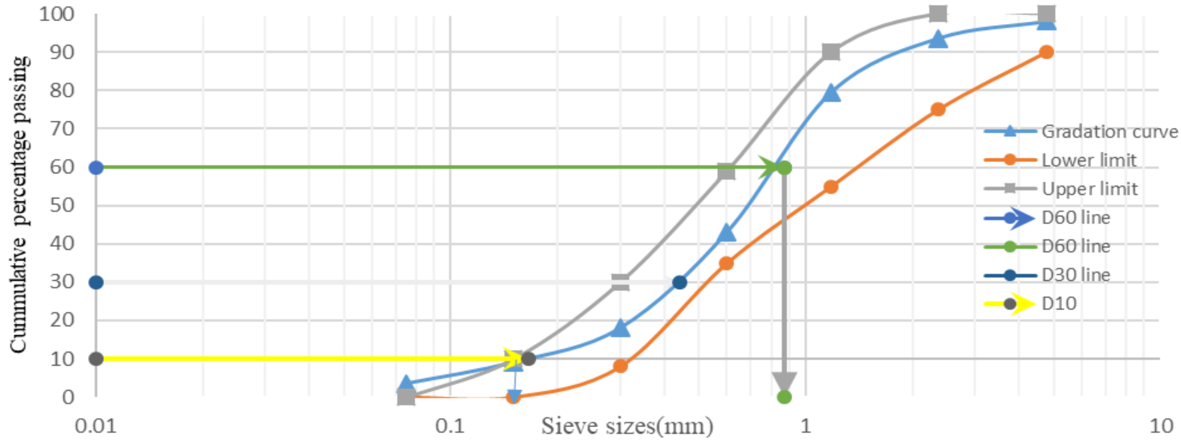

Figure 1: Particle Size Distribution of fine Aggregate

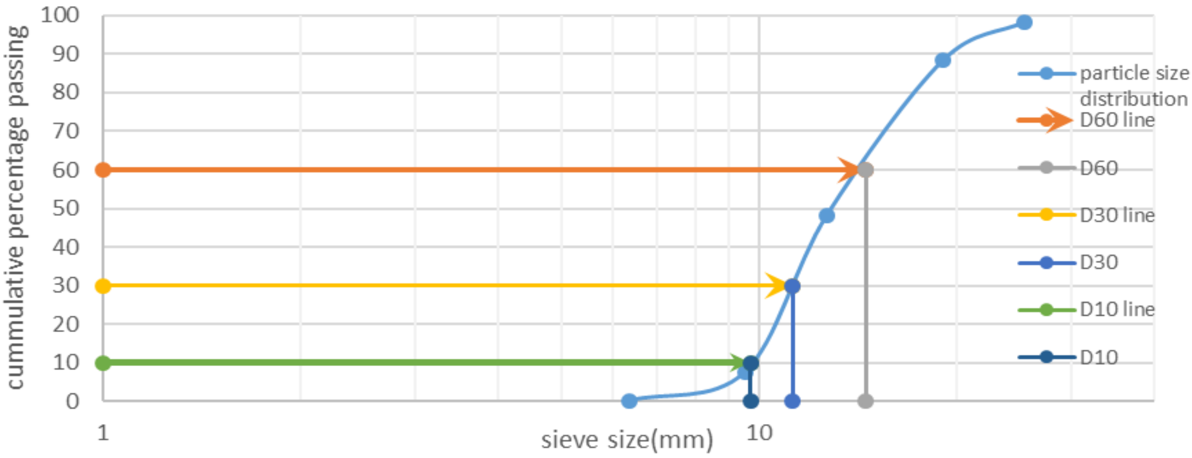

Figure 2: Particle Size Distribution of Coarse Aggregate

Tensile Strength of Doum Palm Fibre used in the Research

The tests result for the tensile strength of the doum palm fibre that was used for this research were presented in table 6.The tensile strength of doum palm fibre used for the research was found to be between the ranges of 17.65 N/mm^2 to 52.401 N/mm^2, with significant variability across samples. This variability could be attributed to the natural inconsistencies in fibre diameter, defects, or testing condition. The elongation of the fibre was also observed, it varied at the peak load between 2.169mm and 4.176mm, corresponding to 3.615% to 6.960% strain. This indicates moderate ductility, which is beneficial for absorbing energy and preventing brittle failure in FRC.

Table 6: Tensile Strength of the Doum Palm Fibre Used in the Research

Sample	Force at Peak (N)	Elongation at Peak (mm)	Tensile Stress (N/mm^2)	Elongation percentage at peak (%)	Area (mm^2)	Gauge Length (mm)
A	317.344	2.787	34.850	4.645	9.106	60.000
B	292.337	2.996	32.104	4.994	9.106	60.000

C	606.541	4.176	52.401	6.960	11.575	60.000
D	211.334	2.684	17.651	4.474	11.973	60.000
E	193.584	2.169	26.281	3.615	7.366	60.000

Slump Test Value and Compacting Factor for the Fresh Doum Palm Fibre Reinforced Concrete

Slump Value for the Various Mixes of the Doum Palm Fibre Reinforced Concrete

The slump value for the different mix of the percentage replacement of the RHA with the cement at different dosages of doum palm fibre was shown in Figure 3. The slump value in relation to the rice husk ash percentage replacement and dosage of doum palm fibre shows that as the fibre content increases the slump value decreases slightly which could be due to increase in inter particle friction, while also in the other hand as the content of rice husk ash increases it was also observed that the slump value decreases which could also be as result of porous and high- surface area of the RHA that may contribute to absorbing more water and reducing fluidity. It was also observed that the slump values are on the range of 50 to 60mm indicating that the slump fall in **class S2** which is falls as low workability in accordance with BS EN 206 between 50-90mm as pumpable range.

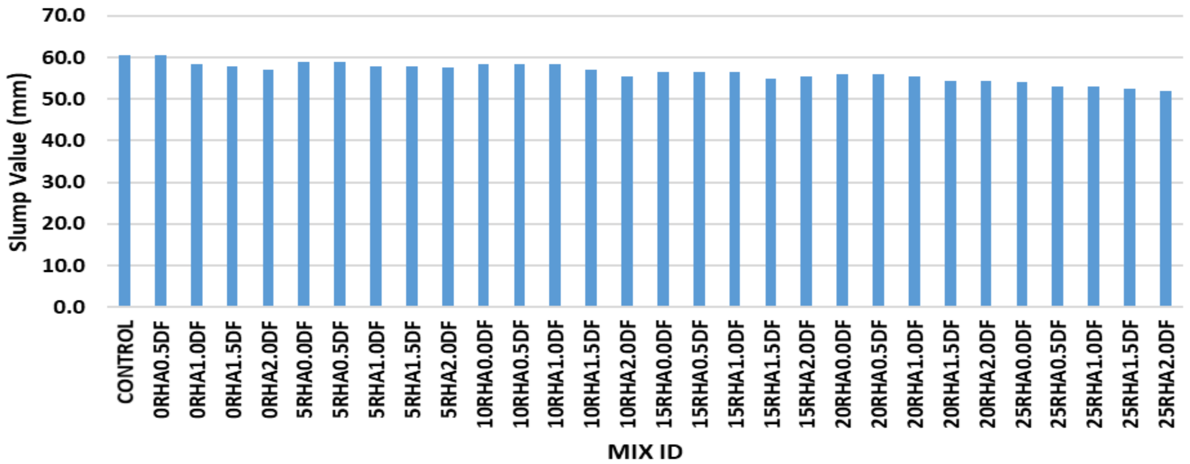

Figure 3: Slump Value for the Different Design Mix

Compacting Factor for the Various Mixes of the Doum Palm Fibre Reinforced Concrete

The compacting factor results shown in Figure 4 varied slightly between 0.91 and 0.92 for all the concrete mixes tested. The control mix produced the highest compacting factor value of 0.92, while the other mixes recorded values ranging from 0.911 to 0.915. An increasing trend was observed from sample with Mix ID of 5RHA0.0DF to 10RHA1.0DF having CF of 0.92, indicating a slight improvement in the workability of the concrete. This gradual increase suggests that adjustments in the mix proportions contributed more significantly to the workability behavior of the concrete than the variations in aggregate type. Based on the classification provided by BS EN 206, compacting factor values within the range of 0.85 to 0.92 fall under **Class C2**, which represents medium workability concrete. Consequently, all the concrete mixes investigated can be classified as having medium workability, making them suitable for normal reinforced concrete works requiring vibration during placement.

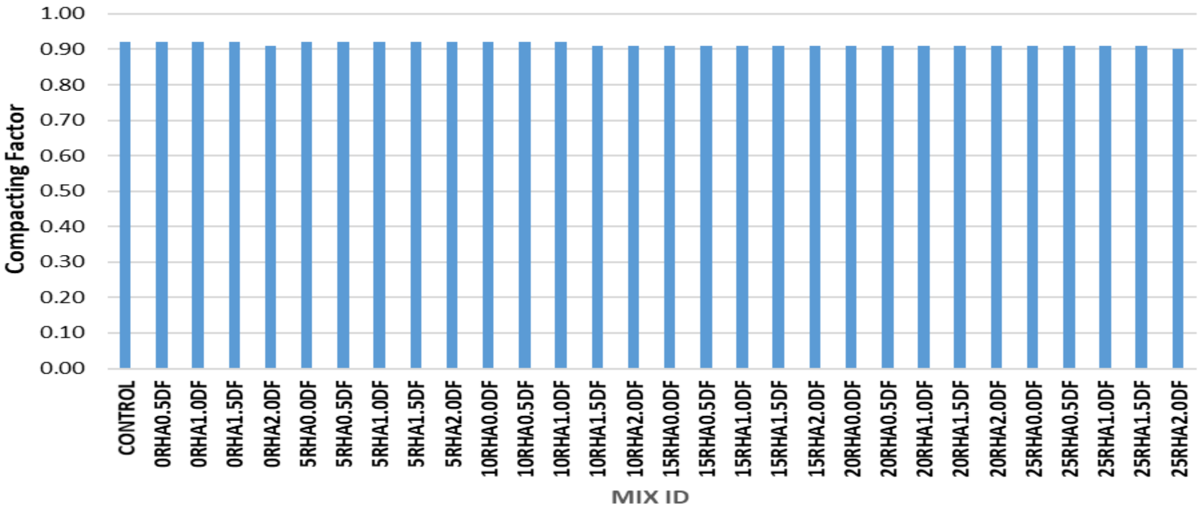

Figure 4: Compacting Factor for the Different Design Mixes

CONCLUSION

The following conclusions can be drawn based on the results presented on this study:

i. The preliminary tests on the constituent materials showed that the aggregates, Portland limestone cement all satisfy the requirements of BS 882(1992), BS 812-112(1990), BS 812-110(1990), BS EN 196-3(1995) respectively for use in concrete and hence are suitable for concrete production and the RHA was classified as a highly reactive pozzolans, with the sum of SiO_2, Fe_2O_3, Al_2O_3 is 90.4%, greater than the minimum requirement of 70% as specified by ASTM C 618-23 for class N and F, but due to low CaO content less than 10%, then it was classified as class F while the tensile strength and elongation tests on the doum palm fibre revealed that the fibre was having moderate ductility, which is beneficial for absorbing energy (toughness) and preventing brittle failure in FRC.

ii. The fresh properties of doum palm fibre reinforced concrete at different dosages of the doum palm fibre with different percentages of RHA as partial replacement of cement were characterized on the basis of slump flow and compacting factor, 10%RHA and 1.0%DF was found to be the optimal mix having slump value of 60mm indicating low to medium workability and compacting factor of 0.92 indicating excellent compaction.

RECOMMENDATION

It is recommended that doum palm fibre reinforced concrete with 10%RHA and 1.0%DF can be used to produce doum palm fibre reinforced concrete with good workability, fibre effectiveness and pozzolanic benefits while minimizing water demand.

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