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POZZOLANIC AND MECHANICAL PROPERTIES OF DATE PALM SEED ASH (DPSA) CONCRETE

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ABSTRACT

This paper presents the findings of a research work conducted on how to improve the mechanical properties of concrete using Date Palm Seed Ash (DPSA) as partial replacement of cement. The DPSA used was obtained by controlled burning of date palm seed in a kiln at a maximum temperature of 630°C for eight hours and air cooled afterwards. The ash obtained was sieved through 75μm sieve and its oxide composition analysed using X-ray fluorescence (XRF) procedures. DoE method of mix design was used to produce concrete ingredients for grade 30N/mm² giving a water-cement ratio of 0.53. The effect of partial replacement of cement with DPSA on cement paste and concrete using 0, 2.5, 5, 7.5, 10, 15 and 20% DPSA was investigated through consistency and setting times tests, workability test, compressive strength test (at 7, 21, 28 and 56 days curing duration), pozzolanic activity index evaluation and water absorption test. Results show that DPSA has high silicon dioxide (45.50%), aluminum oxide (20.75%) and Iron oxide (7.25%). Findings indicate that the consistency and setting times of cement-DPSA paste increased with increase in the replacement of cement with DPSA. The workability of DPSA concrete decreased with increase in cement replacement. Compressive strength test results show that cement can be replaced with DPSA up to 10% as the compressive strength at 10% replacement is 31.5N/mm² as against the 31N/mm² of the normal concrete, at 56 days. The pozzolanic activity index result also show that DPSA concrete meets up the minimum requirement of 75% specified by ASTM C618-15. Also, the water absorption capacity of DPSA concrete at the highest replacement (20%) is 11% less than that at 0%.

Keywords: *Cement, Compressive strength, Concrete, Date palm seed ash, Partial replacement, Pozzolana*

1. INTRODUCTION

Concrete is made by mixing the right proportion of cement, fine aggregate, coarse aggregate, water and sometimes admixtures added to modify certain of its properties both in the fresh and hardened forms. Concrete is of three types namely: heavy weight, normal weight and light weight concrete. Concrete is a reliable material that is applied in many kinds of construction developments given its many desirable properties. However, report indicates that concrete made with conventional Portland cement suffers several problems like brittleness, low tensile strength, as well as susceptibility to acid and sulphate attacks [1]. In order to solve some if not all of these problems, the construction industry is changing drastically with changes in conventional building materials such as bricks and stones to newer materials like fibre-reinforced plastics, aluminium, glass and steel. In fact, the list of new materials in the construction industry is almost in-exhaustive which is good for the economy of the building and construction industry [2].

Nigeria's building and construction industry, like many other developing countries, is exploring and combining materials within its vicinity so as to meet the ever increasing demand of shelter for man. The choice and sustainability of a particular material depends largely

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on its availability, nature of projects, durability, individual preference and economic considerations. However, efforts made to provide materials which are comparable to the strength of cement composites have not significantly reduced the cost of construction [3]. And since the demand in the concrete manufacturing is increasing day by day, the utilization of river sand as fine aggregate and the use of natural stones as coarse aggregate lead to exploitation of natural resources, resulting into ecological imbalance of the environment, lowering of water table, sinking of the bridge piers as a common threat. Great efforts have been made by researchers on studying the suitability of materials like palm kernel shells, incinerated ash, crushed glass, periwinkle shells for concrete production [4]. Just as new materials are being researched for replacement of conventional fine and coarse aggregates, so also new materials are being researched to be used in partial replacement of cement [5]. In recent years, many researchers; [6 – 8] have established that the use of supplementary cementitious materials (SCMs) can, not only improve the various properties of concrete (both in its fresh and hardened states) but also can contribute to economy in construction costs [9]. These cementitious materials are known as "Pozzolanas."

In North America, natural pozzolanas have been in use since the early 20th century for public works projects, such as dams, to control temperature rise in mass concrete and provide cementitious material [10]. In addition to controlling heat rise, [10] also stated that natural pozzolanas were used to improve resistance to sulfate attack and were among the first materials to be found to mitigate alkali-silica reaction. The most common natural pozzolanas used today are processed materials, which are heat treated in a kiln and then ground to a fine powder; they include calcined clay, calcined shale, fly ash (FA), blast furnace slag (BFS), silica fume, metakaolin (MK), rice husk ash (RHA), hypo sludge [11].

In contribution to the ongoing research in finding suitable materials to replace conventional construction materials, the use of Date Palm Seed (DPS) as coarse aggregate has been studied by [12]. Date Palm Seed is obtained from date palm (Phoenix dactylifera), tree of the palm family (Arecaceae or Palmae) which can be found in Canary Islands, Northern and Western Africa, the Middle East, Pakistan, India, and the U.S. State of California. Date is highly cultivated for animals and human consumptions. As stated by [12], after consumption, the seeds (DPS) served as nothing but contribute to wastes and littered the environment. The aim of this study is to investigate the potentials of using Date palm seed ash as cement replacement material in concrete production with the objectives of determining the pozzolanic properties of DPSA, as well as determining the effect of DPSA on: consistency and setting times of cement paste, concrete workability, compressive strength of concrete and water absorption capacity of concrete.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Date Palm Seed Ash (DPSA)

Date Palm Seed is an agricultural produce from date palm (Phoenix dactylifera), tree of the palm family (Arecaceae or Palmae) which can be found in Canary Islands, Northern and Western Africa, the Middle East, Pakistan, India, and the U.S. State of California. Date is highly cultivated for animals and human consumptions. After consumption, the seeds (DPS) served as nothing but contribute to wastes and littered the environment [12]. The date palm seed was obtained from date palm sellers in Yankura and Wambe markets of Kano state, Nigeria. The seeds were burnt in a kiln in two stages in order to obtain the amorphous form of the ash: Firstly, the DPS was burnt for a duration of eight hours at a temperature of about 590^{o}C. Secondly, after allowing it to cool for two days, it was further burnt for three hours at a temperature of 630^{o}C and was again allowed to cool for another three days. The ash obtained from the burning was then sieved through 75μm sieve before it was used for concrete production.

2.1.2 Cement

The cement used was Ordinary Portland cement manufactured by Dangote cement plc, it is available in 50kg bag in Nigeria and was observed to conform to [13].

2.1.3 Fine Aggregates

The fine aggregate used was clean river sand from Chalawa river in Kumbotso Local government area of Kano state, Nigeria. The fine aggregate conformed to [14].

2.1.4 Coarse Aggregates

The coarse aggregate used was clean, crushed granite obtained from Rano quarry site in Kano state, Nigeria and it conformed to [14].

2.1.5 Water
The water used was tested and conformed to [15]. It was portable and was obtained from the water supplied by Bayero University Kano to Civil Engineering department laboratory.

2.2 Methods
2.2.1 Specific Gravity
This test was conducted on cement, DPSA, sand and crushed granite in accordance with [16]. The specific gravity of sand, granite, cement and Date palm seed ash is shown in Table 2.

2.2.2 Concrete Mix Design
Department of Environment (DoE) method of mix design [17] was used to determine the quantity of the various concrete ingredients (cement, sand, granite and water) required to produce a concrete grade of 30N/mm^2 for this research work, and this method gave a mix design of 1.0:1.850:2.625 (cement: fine aggregate: coarse aggregate) and water-cement ratio of 0.53. Medium size slump of 30-60mm and maximum aggregate size of 20mm were used for this design. The concrete mix proportion is shown in Table 1.

2.2.3 Chemical Composition of DPSA:
Oxide composition of cement and DPSA was conducted based on [18] at Centre for Energy Research and Training (CERT) Samaru Zaria, Kaduna State. Mineral oxide composition of cement and DPSA were obtained by X-Ray fluorescence (XRF) analysis. Results from this analysis is presented in Table 3.

2.2.4 Consistency and Setting Times of Cement-DPSA Paste:
Consistency and setting times of cement-DPSA paste was carried out using 0, 2.5, 5, 7.5, 10, 15 and 20% DPSA to replace cement in accordance with [19]. The result is shown in Figure 1 and 2.

2.2.5 Slump of DPSA Concrete:
The workability of fresh DPSA concrete was determined based on [20] using the designed mix stated in section 2.2.2 and the result is shown in Figure 3.

2.2.6 Compressive Strength of DPSA Concrete
Compressive strength of DPSA concrete was carried out after curing for 7, 21, 28 and 56 days based on [21]. 75μm fineness of DPSA was used to replace cement at 0, 2.5, 5, 7.5, 10, 15, and 20%. Cube mould of sizes 100mm×100mm×100mm was used to cast a total of 84 cubes for compressive strength test. The compressive strength behavior is shown in Figure 4.

2.2.7 Pozzolanic Activity Index (PAI) of DPSA Concrete
Pozzolanic activity index (PAI) of DPSA concrete was evaluated in accordance with [18] as specified by [22] that; the strength activity index of a pozzolana must meet the requirement of 75% of the control strength at 7 days or 28 days. The results are shown in Table 4.

2.2.8 Water Absorption of DPSA Concrete
The water absorption capacity of DPSA concrete was determined based on [23]. 75μm fineness of DPSA was used to replace cement at 0, 2.5, 5, 7.5, 10, 15, and 20%. Cube mould of sizes 100mm × 100mm × 100mm was used to cast a total of 21 cubes for water absorption test and the behavior is shown in Figure 5.

3. RESULTS AND DISCUSSIONS
3.1 Specific Gravity
The Specific gravity of cement, date palm seed ash (DPSA), sand and granite is shown in Table 2.

Table 1: Concrete Quantities at various Replacement of DPSA

DPSA Content (%)	Cement (kg/m^3)	DPSA (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	Water (kg/m^3)
0.0	400.0	0.0	740.0	1050.0	210.0
2.5	390.0	10.0	740.0	1050.0	210.0
5.0	380.0	20.0	740.0	1050.0	210.0
7.5	370	30.0	740.0	1050.0	210.0
10	360.0	40.0	740.0	1050.0	210.0
15	340.0	60.0	740.0	1050.0	210.0
20	320.0	80.0	740.0	1050.0	210.0

Table 2: Specific Gravity of Concrete Materials

Sample	Specific Gravity
Cement	3.15
DPSA	1.44
Sand	2.68
Granite	2.65

3.1 Chemical Composition of DPSA
The result of chemical analysis of DPSA is shown in Table 3. The total percentage composition of Iron oxide (Fe_2O_3=7.25%), Silicon dioxide (SiO_2=45.50%) and Aluminium oxide (Al_2O_3=20.75%) summed up to 73.50%, which satisfies the 70% minimum requirement specified by [18], and hence it is a good

pozzolana. The analysis also showed that DPSA has a substantial amount of Calcium oxide (CaO=9.82%) which makes the ash to be self-cementitious. It also has 9.07% of potassium oxide (K_2O) and 3.0% Sodium oxide (Na_2O) which may inhibit the formation of Calcium trisilicates in concrete and hence affect strength at early curing age as reported by [24]. The alkali content in DPSA also exceed the limit of alkali known as equivalent sodium oxide content of cement and expressed as (Na_2O)=Na_2O+0.658K_2O allowed in cement [25], which may affect the concrete durability in terms of drying shrinkage [26], as it makes the microstructure of Calcium trisilicates hydrate to become coarser and heterogeneous in alkali solutions according to [27], in agreement to [28] report that high-alkali cement pastes have a less dense microstructure compared to low-alkali cement pastes. Meanwhile, pozzolana with high alkali content can be used in concrete to delay the final setting time of concrete. The combined content of Silicon dioxide, Iron oxide and Aluminium oxide is responsible for the pozzolanic activity [29] of DPSA. In addition, DPSA also possesses cementitious property that most pozzolana lack due to the substantial quantity of Calcium oxide in its oxide composition. This makes DPSA a good replacement material of cement for concrete production.

3.2 Consistency and Setting Times of Cement-DPSA Paste

The consistency and setting times of cement-DPSA paste for cement replacement with DPSA as shown in Figures 1 increased with increase in DPSA content. The consistency increased because of particle interference effect, and so a large amount of water is needed to properly wet higher percentage of DPSA in the mix to produce cement gel as the cement is more soluble than the DPSA, and this led to the increase in the consistency of the DPSA concrete as explained by [30]. The increase in setting times may be due to the high content of K_2O in the ash which may react with water to produce caustic potassium hydroxide that absorbs the water available for hydration of cement, as reported by [31]. Also, the setting times for all percentage replacement of cement with DPSA are within [32] specification for Ordinary Portland Cement, which is a minimum of 45 minutes for initial setting time and a maximum of 375 minutes for final setting time. The increase in setting times of DPSA concrete means that DPSA can be used as a set retarder in concrete to be transported over a long distance.

3.3 Slump of DPSA Concrete

The slump of DPSA concrete as shown in Figure 2 decreased with increased content of DPSA and this may be due to particle interference effects, in that the loss on ignition of DPSA (1.72%) is higher than that of the cement (1.3%) used as explained by [5]. The result also showed that all the slumps except that for 20% DPSA mix is within the range of medium workability (35mm–75mm) as specified in [20].

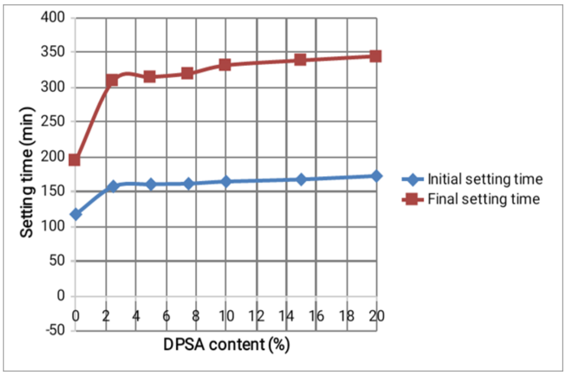

Figure 1: Setting times of cement-DPSA paste for cement replacement

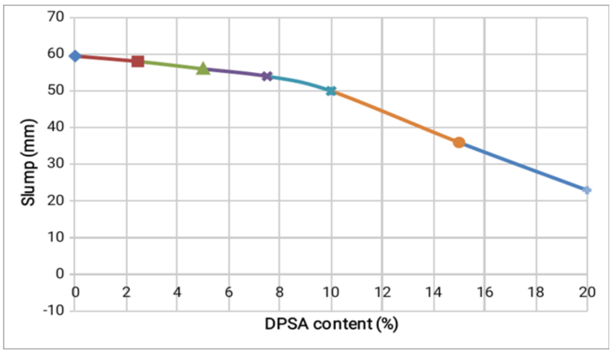

Figure 2: Slump of DPSA concrete

This makes DPSA concrete up to 10% replacement of cement good for lightly reinforced concrete section without vibrations and heavily reinforced sections with vibrations [33]. DPSA concrete higher than 10% replacement of cement with low workability can also be used for mass concrete projects as explained by Jackson and cited by [34].

3.4 Compressive Strength of DPSA Concrete

Results of the compressive strength of DPSA concrete as shown in Figure 3 show that the compressive strength of DPSA concrete up to 10% replacement is higher than control and design strength at 56 days with 2.5% replacement giving the optimum strength of 33 N/mm^2. The 2.5% optimum strength may be due to the hydration of cement and DPSA. The 10%

replacement strength could be due to the DPSA behaving as a filler that decelerates cement hydration. This decceleration of the hydration process generates more calcium hydroxide at later curing ages to react with the active silica and aluminate phases of the DPSA to produce secondary calcium aluminosilicate hydrates, enhancing strength performance [35]. Further increase in DPSA content showed a decrease in compressive strength when compared with the normal concrete. The reduction in compressive strength with 15% and 20% replacement of cement with DPSA may be due to the saturation of the cement mix with K_2O in DPSA which forms composite that inhibits the formation of calcium silicate hydrates from cement hydration as reported by [24]. DPSA can be used up to 10% to replace cement for concrete production since the results showed that DPSA concrete tends to gain more strength over a longer period of time beyond 28 days curing age in agreement to [36].

3.5 Pozzolanic Activity Index (PAI) of DPSA Concrete

Table 4 shows the results of pozzolanic activity index of DPSA concrete. It is seen that at both 7 and 28 days curing age, the PAI for 20% DPSA meet the minimum requirement specified by [22] that the strength activity index of a pozzolana must meet the requirement of 75% of the control strength at 7 and 28 days. This indicates that DPSA is a good pozzolana and can be used to replace cement for concrete production.

3.6 Water Absorption of DPSA Concrete

Water absorption of concrete containing DPSA as shown in Figure 4 reviews that the water absorption decreased with increase in the quantity of DPSA as compared with the normal concrete.

This is because the paste formation from cement-DPSA reaction coats the aggregates and larger micro voids better than that resulting from cement, since [37] reported that water absorption mechanism depends on factors like paste pores, capillarity, surface energy, surface tension and concrete sorptivity. The figure also indicates that the water absorption for each percentage replacement of cement with DPSA is less than that for normal concrete. Meanwhile, the water absorption for all the mixes are well below the maximum of 10% stated by [33]. This low water absorption capacity of DPSA concrete makes it a more suitable concrete than normal concrete for construction works in a waterlogged environment.

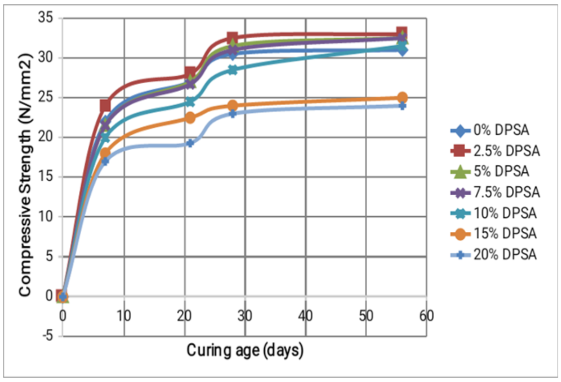

Figure 3: Compressive strength of DPSA concrete

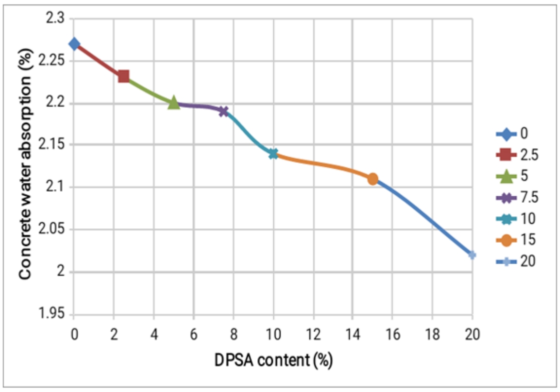

Figure. 4: Water absorption of DPSA concrete

Table 3: Oxide Composition of Date Palm Seed Ash (DPSA) and Ordinary Portland Cement used

Oxide	SiO_2	Fe_2O_3	Al_2O_3	P_2O_5	CaO	K_2O	Cl	SO_3	Na_2O	ZnO
DPSA (%)	45.5	7.25	20.75	0.50	9.82	9.07	0.45	0.12	3.00	0.31
OPC (%)	20.99	9.72	10.30	-	55.00	0.72	-	0.40	0.33	-
Oxide	MgO	BaO	MnO	PbO	ZrO_2	As_2O_3	LOI			
DPSA (%)	0.52	0.05	0.32	0.02	0.05	0.55	1.72			
OPC (%)	0.44	-	0.80	-	-	-	1.30			

Table 4: Pozzolanic Activity Index of DPSA Concrete

DPSA content (%)	Compressive strength (N/mm^2)		PAI (%)	
	7 days	28 days	7 days	28 days
0	22.0	30.5	---	---
20	17.0	23.0	77.3	75.4

4. CONCLUSION

The results of pozzolanic property and evaluation (oxide composition and pozzolanic activity index) of DPSA concrete as reported in this research work have shown that it is a good pozzolana. Concrete made using DPSA to partially replace cement can be used for projects involving long hauling distances due to its increased final setting time. DPSA can be used up to 10% to replace cement for concrete production in order to improve its compressive strength. The decreased water absorption capacity of DPSA concrete with increased DPSA content is a sign that DPSA concrete will be more durable than normal concrete in an environment where the concrete is exposed to water in form of a solution

5. RECOMMENDATION

It is recommended that further tests be conducted to determine the durability potentials of DPSA concrete. Test should also be conducted to determine the effects of DPSA on the mechanical properties of concrete for longer curing duration beyond 56 days.

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