Investigation of the Potential Use of Date Palm Fronds Ash (DPFA) as a Partial Replacement for Cement in Mortar

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Abstract: **Recently, there has been a growing interest in utilizing agro-waste as a source of supplementary cementitious material (SCMs) in construction. - SCMs are commonly used as partial cement substitutes to enhance material performance and reduce the environmental impact of construction. However, their reliance on industrial by-products raises concerns about future availability, emphasizing the need for sustainable alternatives. Agro-waste with pozzolanic properties offers a promising solution by repurposing agricultural residues into effective binders. One such agro-waste is date palm fronds ash (DPFA), evaluated as an additive in cement mortar at replacement levels of 10%, 20%, and 30% by weight. Key parameters studied included flowability, wet density, air content, compressive strength, and flexural strength. Results showed that DPFA reduced flowability and wet density while increasing air content. The optimal performance was achieved at 10% replacement, balancing strength and sustainability, while up to 30% replacement provided acceptable strength for various applications. Although flexural strength decreased compared to the control, higher DPFA levels showed improvement over time, demonstrating long-term potential. From a sustainability perspective, incorporating DPFA addresses agro-waste disposal while reducing the carbon footprint of cement production by lowering clinker demand. This aligns with global efforts to adopt eco-friendly practices, highlighting DPFA's role in advancing sustainable and resource-efficient construction solutions.**

Keywords: **The Date Palm Frond Ash, mortar, compressive strength, flowability, air content.**

I. INTRODUCTION

The primary goal of sustainable development is to appropriately satisfy current needs without endangering prospects for future generations [1]. The building industry is aware that the growing global population poses a significant challenge in terms of finding engineered cementitious composites that satisfy environmental, economic, and performance requirements [2]. Cement-based materials are hydraulic binders; hydrating these materials improves the properties of the produced hard matrix (mortar, concrete). Cement-based materials have been used decades ago to sustain human civilizations. These materials were modified to maintain their functions in our lives as human activities advanced [3].

Currently, no substitute material that can adequately perform the functions that cement plays in the formation of cement-based materials [4]. The primary function of cement is to serve as a hydraulic binder, adhering to other particles to form a cohesive material. This process results in a composite with distinct physical and mechanical properties, driven by the exothermic hydration reactions that occur when cement is mixed with water. [3]. However, cement production is widely regarded as environmentally harmful due to its significant contribution to global warming, primarily by releasing substantial amounts of greenhouse gases into the atmosphere. [5, 6].

To reduce the harmful environmental impact of cement production and promote sustainable development, the use of supplementary cementitious materials (SCMs) derived from agricultural and natural waste as partial replacements for cement has become a well-established practice.[7-9]. There many agricultural waste ash are available and can be used as cementitious materials (SCM) in cement-based materials like olive stones, bagasse, straw, cotton stems, grape seeds, pine mulch, almonds, hazelnuts, nuts and sunflower husks; corn, oats, and rice hulls; date palm, palm oil, coconut shell, and sunflower stalk [9-11]. However, date palm is one of these agricultural wastes that has not been studied its full *potential* as an appropriate binder for improving the properties of cement-based materials [9].

Date palms are growing extensively in North Africa and the Middle East, especially in Libya, Algeria, Tunis, and Saudi Arabia. Libya State is a land famous for date production, and its palm trees are considered one of the oldest trees in the world. A recent estimation showed that Libya has about eight million date palm trees, mainly in the central Libyan oases (Awjilah, Jalo, and Al Jufrah) [12]. Most types of date palm trees start to bear fruit at the age of 3 to 4 years after planting and start commercially producing between about 7–10 of age, with an average age of about 100 years [12]. Annually, for each mature grown date palm tree 20-30 new leaves (fronds) are formed, and up to 25 leaves (about 20 kg) are required to pluck during the seasonal fruit collection [6, 13, 14]. As a result, thousands of tons of these wastes are produced each year and must be disposed of [15].

When date palm fronds are directly disposed of in open spaces, where it might accumulate in trash piles, and creates they might accumulate in trash piles and create an environmental nuisance. So, to reduce the ecological burden of these wastes, the utilization of cement pastes, mortars, or even concrete is a significant aspect [8]. Since the price of cement dramatically contributes to overall cost of construction projects, using date palm waste ash (DPWA) as a partial cement replacement can reduce project costs without any detrimental effect on the quality of the resulting product.

Date palm ash is a by-product obtained from burning the dead trimmed fronds. Similar to other pozzolans such as rise husk ash and coal ash, it contains each chemical compound found in Portland cement, although in different amounts and thus makes it eligible to be utilised in the manufacturing of cement-based materials as a partial replacement for Portland cement [16]. The cement residual ashes' physical and chemical characteristics mostly determine cement quality made from agricultural waste ash.

Burning agricultural waste at optimum temperature meets the requirements for cement replacement material due to the presence of a high amount of reactive silicon dioxide (SiO_2), which provides good pozzolanic reactivity. Several factors can affect the pozzolanic activity of the ashes produced, such as burning temperature, chemical composition, amorphous and crystalline composition, and particle size [9].

The amount of silica present in agricultural waste ash increased with increasing burning temperature [17]. However, an excessively high burning temperature is given to produce more carbon within the ashes and lead to the crystallisation [18]. Rosseira et al. [9], mentioned that the suitable temperature for burning to produce a better result for pozzolanic reactivity is 500 - 700ºC. Silicon dioxide (SiO_2) can react with calcium hydroxide ($Ca(OH)_2$) to produce calcium silicate hydrate (CSH) [19]. Moreover, silicon dioxide (SiO_2) and calcium oxide (CaO) play crucial roles in cement production. Silicon dioxide (SiO_2) reacts with calcium oxide (CaO) to form calcium silicates (C_2S and C_3S), which provide the binding properties and give strength to the cement. Together, these two compounds help create a strong and durable material. However, if CaO is present in excess, makes the cement unsound (i.e., cement expands), and hence it disintegrates. Another essential chemical composition to be monitored in agricultural waste ash is alumina content. Alumina content in agricultural waste ash can contribute to of forming calcium aluminum silicate (CASH) during the hydration. As a result, the presence of alumina increases the strength of the mixture [19]. Additionally, it found that magnesium oxide (MgO) and amorphous silica can react together upon hydration to form a mixture of magnesium silicate hydrate (M-S-H) and $Mg(OH)_2$, which present good cementitious properties and contribute to the strength development of $MgO – SiO_2 – H_2O$, with its other outstanding properties, such as high corrosion resistance and high-temperature resistance [20].

Agricultural waste ash is commonly reported to have a high loss on ignition (LOI) due to uncontrolled burning conditions [19]. Generally, LOI represents the quantity of unburned carbon in the agricultural waste ash. Higher LOI value leads to lower performance of the blended cementitious system. Therefore, the amount of unburned carbon in agricultural waste ash needs to be reduced to maintain it within the acceptable limit [19]. As per ASTM C 618 [21] the LOI value of natural pozzolans needs to be less than 10%. Also, grinding can control the particle size distribution and increase the specific area of the agricultural waste ash produced [18, 22, 23]. Decreasing particle size can improve the pozzolanic activity of the agricultural waste ash and lead to an increase in the amount of amorphous silica, which is essential to produce pozzolanic activity [24].

Fresh and hardened properties of agro-waste ashes blended with cement-based materials are reported [19, 25-28]. However, *few studies have attempted* to explore the possibility of using dates palm ash as a supplementary cementitious material for improving the physical and mechanical properties of cement-based materials [6, 7, 15, 16].

Al-Kutti et al. [7, 16] replaced up to 30% traditional cement with date palm ash (DPA) in concrete and mortar mixes. They observed that 10% DPA content dramatically improves the mechanical and durability characteristics. Nasir and Al-Kutti [6] studied the feasibility of using DPA in mortar as a cement replacement and they found that the compressive strength of mortar increased with increasing DPA content up to 10%, and thereafter was adversely affected. Moreover, Alrshoudi and Alshannag [15] investigated the effect of palm frond waste ash (PFWA) on physical and mechanical properties of concrete compared to ordinary Portland cement based type. Test results indicated that, up to 30% of palm frond waste ash can be added to PC cement mortar without compromising the strength properties. According to the literature, there remain significant gaps in understanding the potential of date palm frond ash (DPFA) as a sustainable cementitious material. Despite Libya being renowned for its abundant date production, limited research has been conducted on utilizing date palm waste ash in construction applications. This presents a compelling opportunity to develop a local, eco-friendly construction material that replaces a portion of cement with DPFA, reducing reliance on traditional cement and addressing agro-waste management challenges. This research aims to evaluate the effects of incorporating DPFA on the fresh and hardened properties of cement mortar and determine the optimum or reasonable level of DPFA incorporation. The study aims to assess how DPFA, as a pozzolanic material, influences the performance of cement mortar. Experiments were conducted to investigate fresh properties such as flowability, air content, wet density, and hardened properties, including compressive and flexural strength. These results were compared against those of plain cement mortar to highlight the potential advantages of DPFA integration. Additionally, analytical tests, including X-ray fluorescence (XRF) spectrometry, were performed to analyze the chemical composition of cement and DPFA. By exploring the viability of DPFA in cement-based materials, this research contributes to reducing the carbon footprint of construction and aligns with the principles of sustainability. The use of DPFA offers a dual benefit: reducing cement production emissions and repurposing agricultural waste, fostering a circular economy and advancing sustainable development in Libya and beyond.

II. EXPERIMENTAL METHODOLOGY AND DESIGN

A. Materials

Cement

ASTM type I cement (El-Borge, Zliten (BZ) from Arab Union Contracting Company (AUCC), Libya which meets GPC requirements (ASTM C 150/C 150M) [29], was used to produce the mortars. General purpose cement is preferred because mortar properties can be observed during the normal hydration process; hence, the effect of DPFA can be noticed.

Fine aggregates

Fine aggregates used were locally available silica sand procured from Awjilah town. They called El-Borge sand, with an absorption capacity of 0.20% and a specific gravity of 2.60. Prior to use, the fine aggregates were dried in ambient conditions to eliminate any free water. The particle size distribution by a sieving method specified in ASTM C 136 [30], is illustrated in Fig. 1.

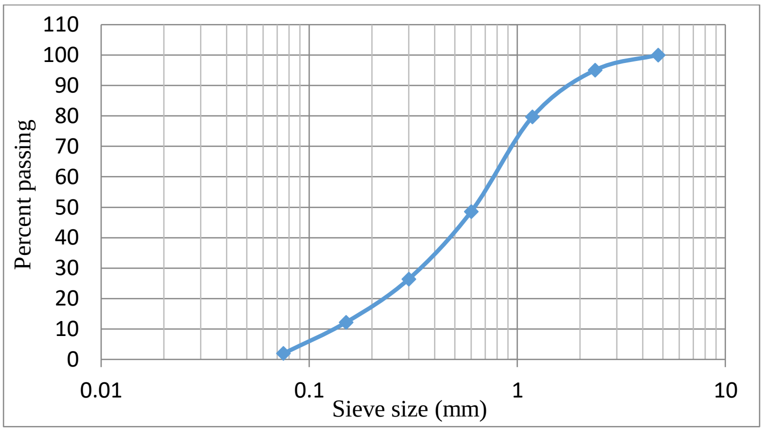

Fig.1: Particle size distributions (Sieving method) of El-Borge sand

Mixing water

Drinking-grade tap water (TW) (pH 7.4; conductivity 2.29 µS/cm) was used, conditioned to a temperature of 22 ± 2°C prior to use.

Date palm frond ash (DPFA)

The date palm fronds (leaves) waste used in this study was obtained from Saidi date palm trees (local name) from Awjilah town located in the Al Wahat district in the Cyrenaica region of north-eastern Libya. The process of producing the ash from the raw material is demonstrated in Fig. 2a – 2c. It includes (a) Collecting the dry palm leaves after trimming, (b) Placing them in trenches for burning (c) Grinding the resulting ash using an electrical machine, (d) The ashes obtained was then screened to pass through 300 µm standard sieve to remove any impurities and ensure uniform grading of the particles.

Fig. 2a: Collecting the date palm frond waste (Fallen and trimmed frond)

Fig. 2b: Placing date palm frond waste in trenches for burning

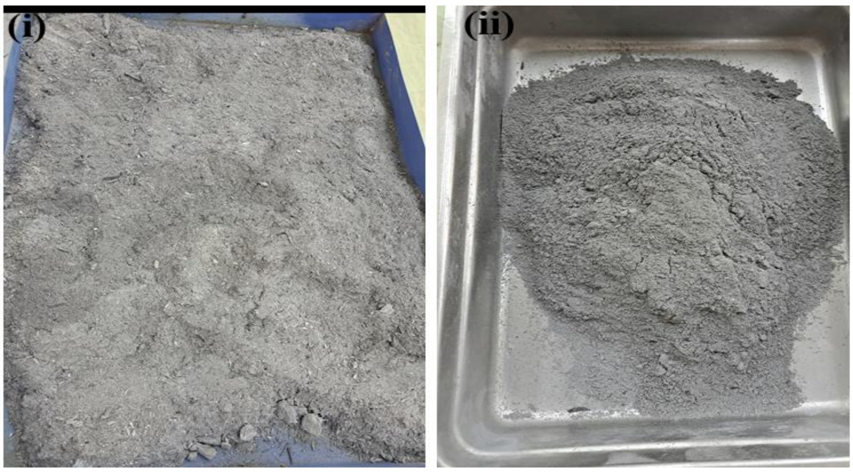

Fig. 2c:(i) Date palm frond waste ash after burning, (ii) Date palm frond waste ash after Grinding and sieving

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B. Mortar composition and mixing procedure

The composition of the control mortar followed ASTM C270 [31] , with mix proportions of 1 part cement to 3 parts sand (by mass) and a fixed water-to-cement ratio (w/c) of 0.50. Each mortar batch contained 450 g of cement, 1350 g of fine aggregate, and 225 g of water. Cement and DPFA were mixed in dry form until a uniform mixture was achieved, with DPFA replacing 10%, 20%, and 30% of the cement by mass. The mixing process adhered to the procedure outlined in ASTM C305 [32], using a Hobart mixer (model N-50 G).

C. Casting and Curing

The cement mortar specimens were cast using cubes of (50*50*50 mm) and prisms of (40*40*160 mm) from steel moulds. The moulds containing consolidated mortar were sealed using zip lock plastic bags to prevent moisture loss and stored in a moist atmosphere for 24 h using a large plastic box. Once the samples were stripped from their respective mould, demoulding took place thereafter, and they were placed in a curing tank filled with water saturated with lime ASTM C511 [33] for up to 90 days at a temperature of 23.0 ± 0.5ºC. Water not saturated with calcium hydroxide (high-calcium hydrated lime) may affect test results due to the leaching of lime from the test specimens.

D. Test methods

Determination of the fresh mortar properties was through measuring flow (ASTM C 1437) [34], wet density (ASTM C 138) [35], and air content (TESTING Bluhm & Feuerherdt GmbH) (ASTM C231) [36]. The chemical compositions of cement and DPFA were performed with the sequential X-ray fluorescence technique model ARL 9400, Switzerland. In this method, about 10 g of each sample was mixed with boric acid in 10 a 1 ratio, and then the mixture was milled in a milling machine for two minutes at 800 rpm to produce a homogeneous mixture. The sample was placed in dice and pressed by a briquette press machine for one minute. Then, it was transferred to the X-ray fluorescence for analysis.

The hardened mortar properties were determined by compressive and flexural strength measurements. Mortar specimens (50 x 50 x 50 mm) were tested at the age of 3,7, 28, and 90 days for compressive strength following the listed procedures of the test method (ASTM C109/MC109) [37]. Vertical load at a rate of 0.99 kN/s was exerted on the specimens and the maximum load indicated by the testing machine (load at failure) has been recorded. An ADR –Auto V2.0 250/25 compression testing machine (ELE International, UK) was used for compressive strength test (Fig. 3a). In addition, the flexural strength of the prism mortar specimens (160 x 40 x 40 mm) was examined at the age of 28 and 90 days curing using three-point bending method according to the BS EN 1015-11 [38] using a 10 kN single lever flexural testing machine (ELE International, UK) (Fig. 3b). The load is vertically applied using the loading roller to the opposite side faces of the prism of the prism and increased smoothly at the rate of 0.05 ± 0.01 kN/s until fracture. The automatic horizontal jolting table was used instead of tampering at a rate of 60 jolts per minute to compact the fresh cement mortar in the three gangs moulds tampering at a rate of 60 jolts per minute to compact the fresh cement mortar in three gang molds instead of tamper.

Fig. 3: a) ADR Auto compression machine with digital readout; b) Single lever fflexural testing Machine

E. Results and discussion

Chemical composition analysis

Table 1 shows the chemical analysis results of DPFA and ASTM Type I ((El-Borge) used in the mortar mixes. The chemical composition of agro-waste ash is directly related to its reactivity [19]. The silica content in DPFA was around 37%. The presence of a high amount of silica makes agro-waste ashes a better substitute for cement [19]. Furthermore, it is noticeable from Table 1 that DPFA have a reasonable amount of alumina content (≈ 3%). Alumina content in agro-waste ash can contribute to the formation of calcium aluminum silicate hydrate (C-A-S-H) during the hydration. As a result, the presence of alumina increases the strength of the mixture [19]. However, it can be observed that the percentage composition of SiO_2 + Al_2O_3 + Fe_2O_3 of DPFA produced in this study was around 41%**.** As per ASTM C 618 [21], the combined proportion of SiO_2, Al_2O_3 and Fe_2O_3 in natural pozzolanic materials should between 50 – 70%. In addition, calcium oxide showing 14.54% in amount which follows to sodium oxide as 3.33%. Alkaline substances like K_2O were the main foreign particles in DPFA, having a content of 7.29%. According to Zain et al. [39] is evidently below the permissible limit (>10%) as defined in K2O content depending on the types and amounts of fertilizers used during the plant's growing period. The loss of ignition (LOI) of DPFA obtained was 8.1%, which is evidently below the permissible limit (>10%) as specified in the ASTM C618 standard.

TABLE I: Percent chemical composition of El-Borge cement and DPFA

Oxide (%)	El Borge cement	DPFA
CaO	62.7	14.54
SiO_2	21.2	36.73
Al_2O_3	5.8	2.67
Fe_2O_3	3.1	1.21
MgO	2.4	7.16
K_2O	0.9	7.29
Na_2O	0.2	3.33
LOI	2.89	8.1

Effect of DPFA on flowability and wet density of mortar mixes

Fig. 4 shows the variation in mortar flow with the addition of DPFA dosages. Maximum flow was measured in 0% DPFW mortar, and flow tended to decrease with the addition of DPFA content. The mortar flow in 100% PC (0% DPFWA) was about 4.5%, 7.7%, and 16.6% higher than mortar prepared with 10%, 20%, and 30% DPFA, respectively. The drop in flow values with DPFA addition was due to its irregular particles, in nature than PC, which resists mortar flow [6]. Moreover, Nassef et al. [40] indicated that the slump loss can be referred to as palm leaf ash absorbing more water, which leads to the decreased slump of concrete mixes.

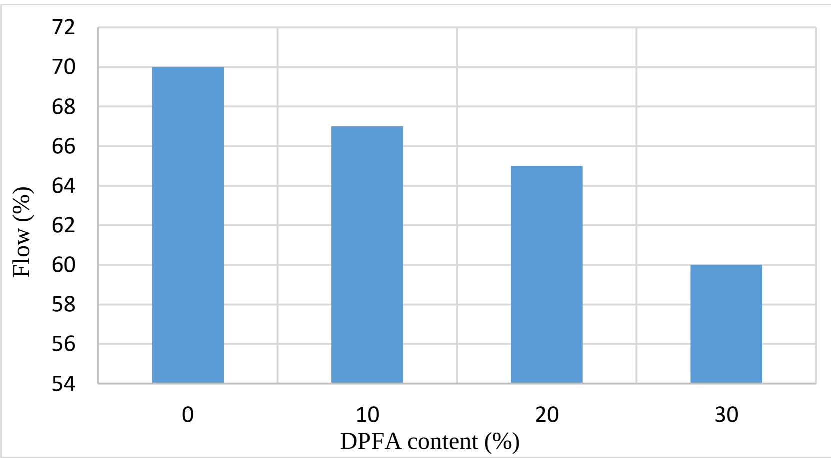

Fig.4: Effect of DPFA on the flow of mortar mixes

According to Fig. 5, the wet density decreases as the percentage of DPFA increases. This slight reduction can be attributed to the control mortar (2270 kg/m3) being replaced by lower-density DPFA when it is placed in a mould of a fixed volume. Previous studies showed that Agro-waste ash is considered a lightweight material with low density. Oyetola and Abdullahi [41] reported the density of rice husk ash is 530 kg/m^3. In addition, the density of wood ash was found to be 760 kg/m^3 [42]. Also, Dashan and Kamang [43], stated a value of 740 kg/m^3 for Fonio husk ash.

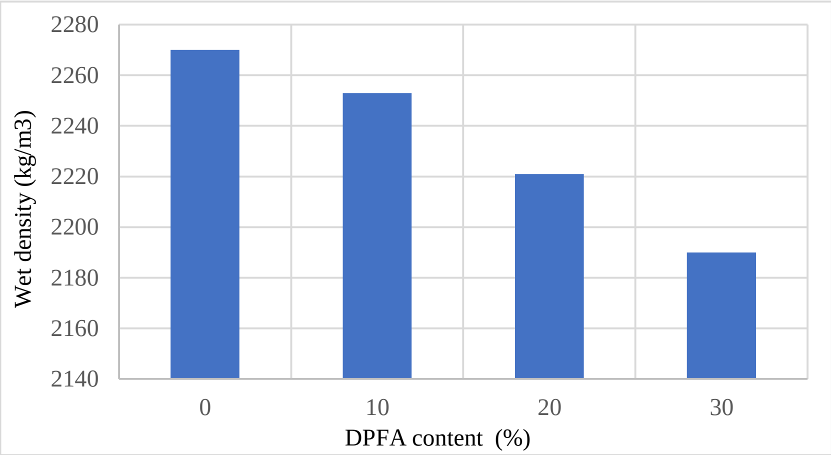

Fig. 5: Effect of DPFA on wet density of mortar mixes

Effect of DPFA on air content of mortar mixes

As shown in Fig. 6, the air content of the mortar mixes increases with the addition of DPFA, with the control mix (0% DPFA) exhibiting the lowest air content of 6.5%. This trend correlates with the workability results presented in Fig. 4, where the maximum flow was observed in the 0% DPFA mortar. The flow of the mortar decreased as DPFA content increased. Specifically, the mortar prepared with 100% PC (0% DPFA) exhibited flow values of 4.5%, 7.7%, and 16.6% higher than the mixes with 10%, 20%, and 30% DPFA, respectively. The reduction in flow with increasing DPFA content can be attributed to the irregular particle shape and texture of DPFA compared to the more uniform particles of Portland cement (PC). These irregular particles increase the resistance to mortar flow, thus reducing workability. Lower workability leads to less compaction of the mix, which in turn creates more air voids. Consequently, the increased air content reflects the reduced compaction ability, contributing to a more porous structure. This increase in air content is a common outcome when incorporating agro-waste materials like DPFA, which have less cohesive properties than conventional binders like PC.

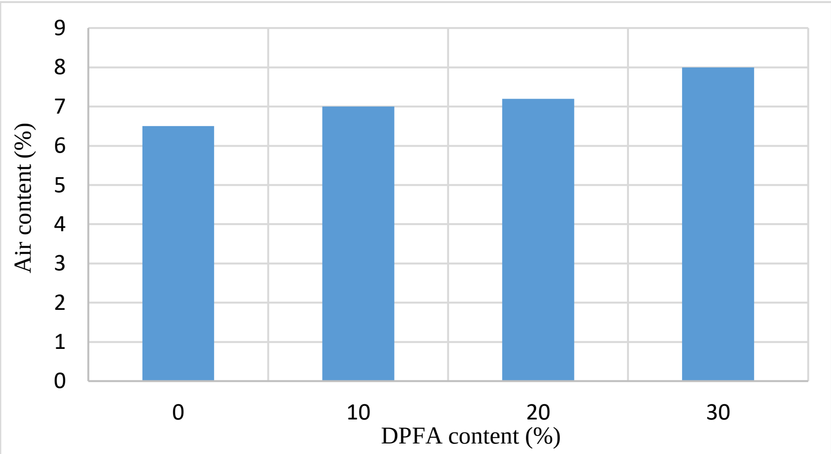

Fig. 6: Effect of DPFA on air content of mortar mixes

Effect of DPFA on compressive strength of mortar mixes

(Fig. 7 and Fig. 8) displays the compressive strength development in 0%, 10%, 20%, and 30% DPFA mortar specimens with a curing period of up to 90 days. The highest compressive strength observed at all curing periods was noted in mortar specimens prepared with 10% DPFA, followed by 20%, 0%, and 30% DPFA specimens in decreasing order of efficiency.

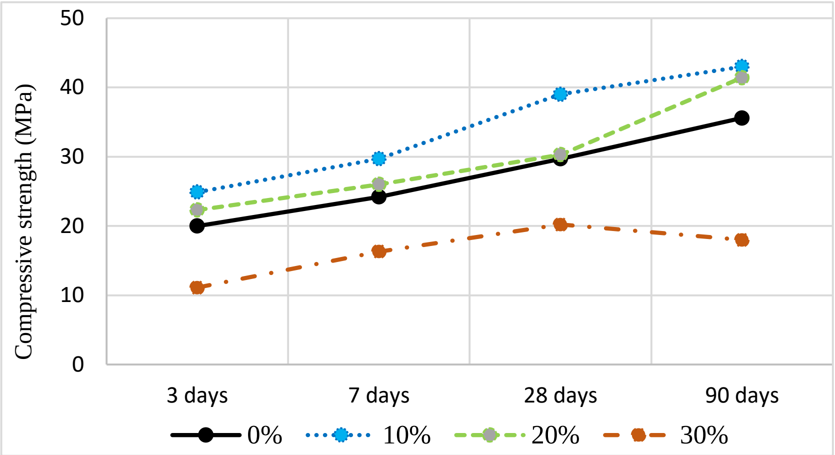

Fig. 7: Compressive strength development in all mortar mixtures

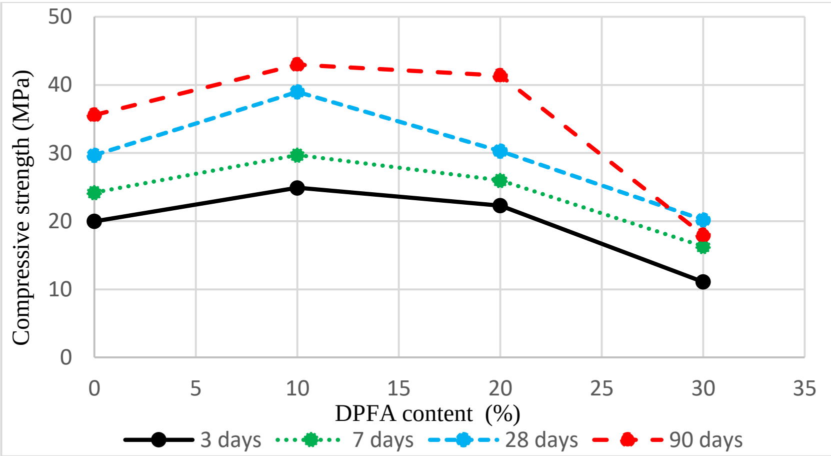

Fig. 8: Effect of DPFA on compressive strength of mortar mixes

The 3-day compressive strength of 0%, 10%, 20%, and 30% DPFA mortar specimens was 20.0, 24.9, 22.3 and 11.1 MPa, respectively. Furthermore, the 7-day strength development was found to be highest in 10% DPFA specimens, and the lowest strength was achieved in both 0% and 30% DPFA specimens. The 28-day compressive strength of 10% DPFA specimens was 39.0 MPa, which is about 31.3, 28.7, and 93.1% more than that of 0%, 20%, and 30% DPFA specimens, respectively. Similarly, the 90-day strength in 10% DPFA mortar specimens was noted to be 43.0 MPa (about 10.3% gain from 28-day) which is 20.8, 3.9 and 138.9% higher than that in 0%, 20% and 30% DPFA specimens, respectively.

The increase in strength in 10% DPFA may be attributed to the continuous formation of additional C-S-H gel from hydration reaction till the later ages in mortar specimens, as mentioned by the author in recent studies [6, 44]. Additionally,Yusuf [45] found from a microstructural investigation that the addition of palm oil fuel ash contributes significantly to the mechanical strength by pore filling effects and the formation of additional calcium (aluminate) silicate hydrate.

Abderrezak et al.[46] have also reported the influence of incorporating date palm waste ash (DPWA) on the compressive strength of cement-based materials. It was found that incorporating 8% date palm ash (DPA) as a cementitious material improved the compression strength of pavement layers of low-traffic roads. Likewise, Al-Kutti et al. [7, 16], observed that the mechanical and durability characteristics of concrete and mortar mixes were improved when cement was replaced with 10% of DPA. Furthermore, Gunarani and Chakkravarthy [47] investigated the suitability of date palm seed ash (DPSA) by partially replacing cement up to 10% in mortar mixes. The results revealed that 4% DPSA was the optimum replacement dosage that enhanced the strength and durability. Nasir and Al-Kutti [6], investigated the effect of DPA as cementitious materials up to 30% on compressive strength of mortar at 3, 28, and 360 days. The results showed that the Compressive strength of mortar increased with DPA dosage, up to 10%, and thereafter was negatively affected.

From the point of view of stability, results suggest that the cement-based mortar, partially replaced with date palm frond waste ash (DPFA), yields adequate compressive strength for many end-uses. Even though cement was replaced with 20%

DPFA, the compressive strength at 28 days was 30.3MPa. This value remains higher than the minimum value specified for use in the construction of sidewalks given by Ontario provincial standards for roads and public roads [48]. Also, Even with 30% replacement of cement, the compressive strength noted at 7 days and 28 days were 16.3 MPa and 20.2 MPa, respectively. These values still comply with using masonry mortar according to BS 5628-1 [49].

Effect of DPFA on flexural strength of mortar mixes

The effect of DPFA additions on mortar flexural strength is shown in (Fig. 9). When compared to control mortar, it is evident that the flexural strength after 28 days was decreased by 4.6%, 3.7%, and 1.5% for the mortar containing 10%, 20%, and 30% of PDFA, respectively, while the drop was 6%, 4%, and 1.3% after 90 days of curing. However, the flexural strength of 20% and 30% DPWA mortar specimens slightly improved by 1**%** and 2.2% respectively at 28-day while was 3% and 2.8% at 90-day compared to 10% DPWA mortar specimens.

Improvement of flexural strength of mortar containing PDFA with time may be attributed to the enhanced microstructure of the mortar at higher levels of PDFA, whereas the reduction in flexural strength regarding to mortar without PDFA may result from the existence of interconnected microporous in the specimens [15].

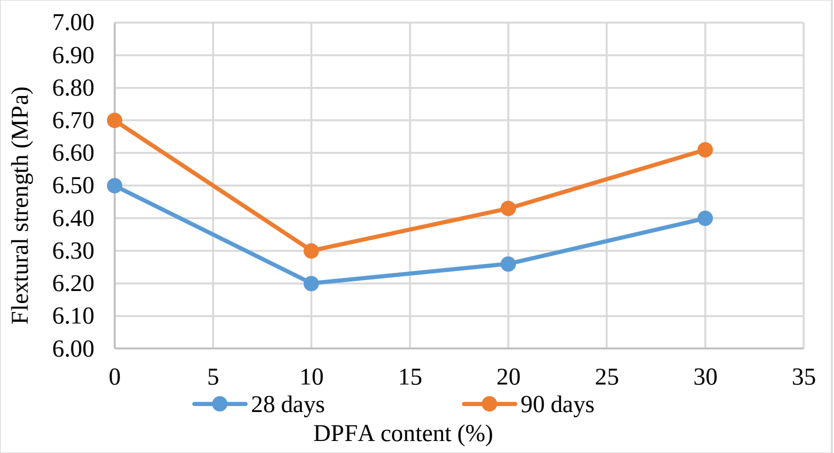

Fig. 9: Effect of DPFA on flexural strength of mortar mixes

III. CONCLUSION

This study investigated the effects of replacing Portland cement (PC) with Date Palm Frond Ash (DPFA) on the fresh and mechanical properties of cement mortar mixes. The results indicate that as DPFA content increased, there was a reduction in flow and wet density, while air content increased compared to the control mix. Compressive strength tests revealed that the optimal DPFA replacement level was 10%, providing the best balance of strength and sustainability. However, up to 30% of PC could be effectively replaced by DPFA, offering a cost-effective alternative and contributing to enhanced sustainability in construction.

While flexural strength decreased compared to the control mortar, higher DPFA content showed improved strength over time, suggesting potential long-term performance benefits. This research provides valuable insights for future investigations into the use of agro-waste materials in cement-based products, helping to fill existing gaps in the literature. Additionally, the study contributes to promoting sustainability in construction, particularly in developing regions where waste management and environmental concerns are significant challenges. The findings align with the primary goal of sustainable development: meeting the needs of the present without compromising the ability of future generations to meet their own needs.

IV. RECOMMENDATIONS

- It is recommended to extend this work by evaluating the durability performance of DPFA-based cement in the sulphate and acid environment, as well as to monitor chloride diffusion and reinforcement corrosion.
- It is recommended to add mixing ratios of 15% and 25% of DPFA.
- Using closed loop incinerator instead of open burning method for date palm frond waste to examine if there is any difference in chemical constituents of the resulted ashes.

REFERENCES

[1] Almabrok, M.H. (2014). Cement-based stabilisation/solidification of oil and salt contaminated materials, PhD in Civil and Environmental Engineering. University of Technology, Sydney (UTS).

[2] Horn, R., Dahy, H., Gantner, J., et al. (2018). Bio-inspired sustainability assessment for building product development—concept and case study. Sustainability,10 (1), P. 1-25.

[3] Saleh, H.M and Rahman, M.K.(2018). Introductory chapter: Properties and application of cement-based materials, in Cement based materials, Hosam, S and Rehab, O. Editors. IntechOpen: London, UK.

[4] Aïtcin, P.C.(2000). Cements of yesterday and today: Concrete of tomorrow. Cement and Concrete Research. 30 (9), P. 1349-1359.

[5] Bélaïd, F. (2020). How does concrete and cement industry transformation contribute to mitigating climate change challenges? Resources Conservation and Recycling Advances,15 (1),P. 200084.

[6] Nasir, M and Al-Kutti, W.(2019). Performance of date palm ash as a cementitious material by evaluating strength, durability, and characterization. Building, 9(1).

[7] Al-Kutti, W.,Islam, A and Nasir, M. (2017). Potential use of date palm ash in cement-based materials. Journal of King Saud University - Engineering Sciences,31(1).

[8] Darweesh, H and Abo El-Suoud, M. (2019). Palm ash as a pozzolanic material for portland cement pastes. To Chemistry Journal,4, P. 72-85.

[9] Rosseira, A., Sarbini, N., Ibrahim, I., et al. (2018). Overview of the influence of burning temperature and grinding time to the properties of cementitious material based agricultural waste products. in 14th International Conference on Concrete Engineering and Technology. University of Malaya, Kuala Lumpur, Malaysia: IOP Publishing Ltd.

[10] Amin, M., Zeyad, A., Tayeh, B., et al. (2021). Effects of nano cotton stalk and palm leaf ashes on ultrahigh-performance concrete properties incorporating recycled concrete aggregates. construction and Building Materials, 302.

[11] Aprianti, E., Shafigh, P., Bahri, S., et al. (2015). Supplementary cementitious materials origin from agricultural wastes—A review. Construction and Building Materials,74**,** P**.** 176–187.

[12] Almabrok, M., Alriyifi, A and Mohammed, A. (2022). Influence of date palm mesh fibre on the physical and mechanical characteristics of cement mortar in a desert climate. International Journal of Research in Civil Engineering and Technology,3 (1), P. 08-15.

[13] Ahmed, M and Al-Dousari, A.(2018). Rehabilitation soils with date palm mulching treatments. Journal of Agricultural Science and Technology A, 8(3), P. 129 - 141.

[14] Sharma, R., Oberoi, H and Dhillon, G .(2016). Fruit and vegetable processing waste, in Agro-industrial wastes as feedstock for enzyme production,Dhillon, G.S andKaur,S, Editors, Elsevier Inc.

[15] Alrshoudi, F and Alshannag, M. (2020). Suitability of palm frond waste ash as a supplementary cementitious material. Arabian Journal for Science and Engineering,45, P. 7967 - 7974.

[16] Al-Kutti, W., Nasir, M., Johari, M., et al.(2018). An overview and experimental study on hybrid binders containing date palm ash, fly ash, OPC and activator composites. Construction and Building Materials, 159**,** p. 567–577.

[17] Jaya, R., Nor, M., Ahmad, Z., et al. (2013). Properties of mortar containing Rice Husk Ash at different temperature and exposed to aggressive environment. Advanced Materials Research,620**,** p. 87 - 93.

[18] Chusilp, N., Jaturapitakkul, C and Kiattikomol,K. (2009). Utilization of bagasse ash as a pozzolanic material in concrete. Construction and Building Material, 23**,** p. 3352 - 3358.

[19] Charitha, V., Athira, V., Jittin, V., et al. (2021). Use of different agro-waste ashes in concrete for effective upcycling of locally available resources. Construction and Building Materials, 285.

[20] Onwudiwe, K.C. (2017).Utilisation of Rice Husk Ash (RHA) in the production of magnesium oxide (MgO)-based cement. African University of Science and Technology, Abuja, Nigeria. p. 47.

[21] ASTM C618 (2019). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. American Society for Testing and Materials (ASTM), USA

[22] Cordeiro, G., Toledo Filho, R., Tavares, L., et al. (2009). Ultrafine grinding of sugar cane bagasse ash for application as pozzolanic admixture in concrete. Cement and Concrete Research, 39**,** p. 110 - 115.

[23] Frias, M.,Villar-Cociña,e andValencia-Morales, E.(2007). Characterisation of sugar cane straw waste as pozzolanic material for construction: Calcining temperature and kinetic parameters. Waste Management, 27**,** p. 533 - 538.

[24] Jamo, U. and Abdu, S. (2015). Characterization of a treated palm oil fuel ash. Science World Journal, 10 (1), p. 27 - 31.

[25] Bagcal, O. and Baccay, M. (2019).Influence of agricultural waste ash as pozzolana on physical properties and compressive strength of cement mortar Journal of Applied Engineering Science, 9 (1), p. 29 - 36.

[26] Igba, T., Ehikhuenmen, S., Olawale, A., et al. (2019).The effect of partial replacement of Nigerian Portland limestone cement with rice husk ash agricultural waste in concrete, in 1st International Conference on Sustainable Infrastructural Development, IOP Conference Series Materials Science and Engineering, IOP Publishing: Ota, Nigeria.

[27] Orogbade, B and Raheem,A. (2018). Chemical and physical characteristics od blended cements produced from softwood ash. Journal of Civil and Environmental Studies, 1(1).

[28] Qinfei, L., Yao, Z., Heng, C., et al. (2021). Effect of waste corn stalk ash on the early-age strength development of fly ash/cement composite. Construction and Building Material, **303**.

[29] AASTM C150/C150M (2016). Standard specification for Portland Cement, American Society for Testing and Materials (ASTM), USA.

[30] AASTM C136 (2001). Standard test method for sieve analysis of fine and coarse aggregates, American Society for Testing and Materials (ASTM), USA.

[31] ASTM C270 (2014), Standard specification for mortar for unit masonry, American Society for Testing and Materials (ASTM), USA.

[32] ASTM C305 (2014). Standard practice for mechanical mixing of hydraulic cement pastes and mortars of plastic consistency, American Society for Testing and Materials (ASTM), USA.

[33] ASTM C511 (2003). Standard specification for mixing rooms, moist cabinets, moist rooms, and water storage tanks used in the testing of hydraulic cements and concrete, American Society for Testing and Materials (ASTM), USA.

[34] ASTM C1437 (2009). Standard test method for flow of hydraulic cement mortar, American Society for Testing and Materials (ASTM), USA.

[35] ASTM C138 (2010). Standard test method for density (Unit weight), yield and air content (Gravimetric) of concrete, American Society for Testing and Materials (ASTM), USA.

[36] ASTM C231 (2010) . Standard test method for air content of freshly mixed concrete by the pressure method, American Society for Testing and Materials (ASTM), USA.

[37] ASTM C109/C109M (2013), Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens), American Society for Testing and Materials (ASTM), USA.

[38] BS EN 1015-11 (2019). Methods of test for mortar for masonry, in Part 11: Determination of flextural and compressive strength of hardened mortar, British Standard Institution: London, UK.

[39] Zain, M., Islam, M., Mahmud, F., et al. (2011). Production of rice husk ash for use in concrete as a supplementary cementitious material. Construction and Building Materials, 25(2), p. 798 - 805.

[40] Nassef, A.,Almaqbali,K., and Alnaqabi, S. (2021). Effects of replacing cement by date palm trees wastes on concrete performance. in International Structural Engineering and Construction Society (ISEC), Cairo, Egypt: ISEC Press.

[41] Oyetola, E and Abdullahi,M. (2006). The use of rice husk ash in low cost sandcrete block production. Leonardo Electronic Journal of Practices and Technologies, 5 (8), p. 58 - 70.

[42] Abdullahi, M. (2006). Characteristics of wood ASH/OPC concrete. Leonardo Electronic Journal of Practices and Technologies, 5(8), p. 9 - 16.

[43] Dashan, I. and Kamang,E. (1999). Some characteristics of AHA/ OPC concrete: A preliminary assessment. Nigerian Journal of Construction Technology and Management, 2(1), p. 22 - 29.

[44] Al-Amoudi, O., Al-Kutti, W., Ahmad, S., et al. (2009). Correlation between strength and certain durability indices of plain and blended cement concretes. Cement and Concrete Composites, 31**,** p. 672 - 676.

[45] Yusuf, M.O. (2014). Strength and microstructure of alkali-activated binary blended binder containing palm oil fuel ash and ground blast-furnace slag. Construction and Building Materials, 52**,** p. 504 - 510.

[46] Abderrezak, K., Kriker, A., Hafssi, A., et al. (2016). Effect of the addition of by-product ash of date palms on the mechanical characteristics of gypsum-calcareous materials used in road construction. in Technologies and materials for renewable energy, environment and sustainability: Tmrees, Beirut, Lebanon: API Conference Proceeding.

[47] Gunarani, G and Chakkravarthy, S. (2017). Chakkravarthy, Experimental studies on effect of Date Seed Ash (DSA) on strength properties of cement sand mortar, in IOP Conference Series: Earth and Environmental Science, IOP Publishing: Tanjavur, India.

[48] OPSS.PROV 351. Construction Specification for Concrete Sidewalk. 2019, Ontario Provincial Standard Specification: Canada, https://tcp.mto.gov.on.ca/sites/default/files/2023-05/OPSS.PROV%20351%20TCP%20Comments%20%20Responses_April_24_2023.pdf.

[49] BS 5628-1 (1992). Code of practice for use of masonry, in Part 1: Structural use of unreinforced masonry, British Standard Institution: London, UK.