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Influence of date palm mesh fibre on the physical and mechanical characteristics of cement mortar in a desert climate

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Abstract
The growing concerns regarding the environmental impact generated by the use of inorganic materials in different field applications increased the interest in the use of agricultural fibres as an alternative for conventional reinforcements in cementitious composites. Date palm fibres are one of the most available agricultural fibres in North Africa and the Middle East. However, a significant amount of these fibres are wasted annually without any beneficial use. The present work consists of studying the effect of cement-based mortar reinforcing with date palm mesh fibres at fractions of 0%, 0.5%, 1%, 1.5% ,2% and 2.5% by weight of cement. The investigations were performed by exposing the sample to various environments: immersion in water saturated with lime and controlled hot-dry climate. The performance was studied in terms of workability, air content, wet density, compressive and flexural strength.
The results indicated that the addition of DPMF had affected the fresh and hardened properties. Increased DPMF content in the cement mortar was found to reduce the flow and wet density, whereas there was an increase in the air content. Furthermore, it was observed that flexural and compressive strength proportionally decreased with the date palm mesh fibers addition, irrespective of the type of curing method used. However, it was found that specimens cured in LSW presented, on average, higher values of their mechanical properties than specimens cured in HC. The compressive strength decreased by ~17-20% compared to the control at 28 days' age. However, since the compressive strength covered a wide range of values, various feasible end-use scenarios for date palm mesh fibers incorporated mortar exist.

Keywords: Mortar, date palm mesh fibre, compressive and flexural strength

1. Introduction

The primary goal of sustainable development is to responsibly meet the demands of today without jeopardizing opportunities for the next generation [1]. Increasing world population is recognised as a vital concern facing the construction industry to find engineering cementitious composites meet the performance, economic and environmental requirements [2, 3]. Incorporation of fibres in cementitious composites has been suggested as one of the most helpful methods in improving the performance behaviour of the resulting mix. However, this improvement mainly depends on the type and shape of the used fibres [4].

Fibres can be utilised as primary reinforcement in the thin-sheet products to increase its strength and toughness properties. Fibres are also incorporated in the matrix as secondary reinforcement to control cracking caused by humidity or temperature variations [5, 6].

There are many different types of fibres that can be used to reinforce cementitious composites. Steel fibres, hybrid fibre and synthetic fibres (such as glass, nylon and polypropylene) are widely used today for building reinforcement of cementitious composites [4, 7-10]. Their effectiveness in improving the mechanical performance such as compressive, tensile and flexural strength as well as controlling their cracking behaviour has been studied and confirmed by several researchers [11-14]. However, these fibres need high energy during the manufacturing process and the contradiction between price and performances of these fibres has not been solved yet [15].

On the other hand, using cement- based composites containing agricultural fibre wastes (often are waste with no economic utilisation value) were attracted attention and have been studied by several researchers as an alternative to conventional reinforcements [16-19]. Agricultural fibres are distinguished by their low environmental impact, renewability, low cost, low density as well as biodegradability of the developed materials, and good mechanical properties [20-22].

Globally, the production of the commonly used agricultural – based on natural fibres (e.g. date palm, Bamboo and Jute) are increased annually [23]. 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 considers one of the oldest trees in the world. A recent estimation showed that Libya has about eight million date palm trees [24] mainly in the central Libyan oases (Awjilah, Jalo and Al Jufrah).

Date palm production can take place in a short-run and consider as a renewable natural resource [23]. Most types of the 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. The date palm tree should be cleaned and pruned annually to produce dates. Consequently, large waste of dry leaves, empty fruit bunches and the mesh will be generated.

The date palm tree is considered one of the sources of agricultural fibres. Fibres could be extracted from different parts of the date palm, namely, the leaves, spadix (inflorescence) and mesh [25]. The major constituent of date palm fibre is cellulose (glucose units) (46%), hemicelluloses ((polysaccharides) (18%), lignin (aromatic polymers and phenyl propane monomers) (20%) and ash (10.54%) [23, 26].

Recently, numerous types of agricultural fibres wastes have increasingly been used in non-structural civil applications, such masonry rendering systems [1], structural and bearing insulators [27], thin-sheet products for partitions, building envelopes and roofing tiles [22, 28, 29]. In addition to its traditional uses such as ropes, baskets, pillows and cleaning equipment [30], the employment of date palm waste (wood or fibres) in construction industry technology has received much attention in terms of improving the thermal insulation performance, particularly in desert area regions which may contribute in reduce the energy consumption [31, 32].

Several investigations have been carried out in order to characterise different types of agricultural fibres -reinforced cement based materials and take advantage of its high variability on their properties [33, 34].

Using coconut fibres as reinforcement material led to increases in the flexural and compressive strength of cement mortar, whereas reduced the toughness [35, 36]. In addition, an improvement in flexural strength and splitting tensile strength were obtained when cement matrix composite containing sisal fibres [6, 37]. A study by Banthia *et al.* [38] reported that the curling and cracking in concrete slabs was reduced due to incorporating 0.3% volume fraction of micro fine fibres structured from cellulose. According to Aggarwal [39] the mechanical and durability performance of cement-based composites reinforced with dry fibrous of sugarcanes met the requirements of BS 5669-4 and ISO 8335 standards as useful materials in building construction [40, 41].

A limited number of researches have been conducted to study the use of date palm fibre as reinforcement in cement-based materials. The compressive strength, flexural strength and cracking of concrete have improved when incorporating date palm mesh fibre (up to 1.5% by mass) while decreased the bulk density [42]. Furthermore, Labib [23] demonstrated that the date palm derived fibre has lower density and greater tensile strength as compared to polypropylene fibre.

Kareche *et al.* [31] indicated that the performance of the composites increases with the increase of date palm fibres content in the cement mortar. The obtained results showed also that adding date palm fibres contributes towards reducing drying shrinkage of the resulted mix, hence allows better shrinkage prevention, and consequently reduced the cracking problems.

Agoudjil *et al.* [43] emphasised that the date palm waste is an appropriate material in developing efficient and safe insulating materials. Moreover, gypsum based materials containing ground date palm fibres exhibited good thermal performances which allows for being suitable for thermal insulation in buildings [44]. In a similar way, Benmansour *et al.* [27] revealed that cement- based reinforced with date palm fibres reduces the thermal conductivity of the resulted composite.

Contrarily, other studies showed that the incorporation of agricultural fibres into cement-based materials have adverse or no significant effects on the performance of the resulted mix. Teo *et al.* [45] showed that the incorporation of oil palm shell into concrete has no effect on the flexural behaviour of the resulted composite. Additionally, the incorporation of bamboo fibre in cement matrix composites does not show significant effect on the both flexural_strength and fracture toughness values [46].

Filho *et al.* [12] shown that the drying shrinkage of cement-based materials increased with addition of sisal and coconut fibres. Agricultural fibres are weakened and become sensitive to deterioration when incorporated with cement-based materials (High alkaline environment). Consequently, the long term durability of the resulted composite will be negatively impacted [21]. Another study mentioned that the addition of date palm fibres in concrete reduces its compressive properties [30].

In fact, most cement based materials used for construction are significantly influenced by environmental conditions [47, 48]. The incorporation of date palm fibres into cement-based materials were found to decrease the compressive strength in hot dry curing [49]. Abbasi *et al.* [50] indicated that the compressive and the flexural strength of concrete decreased under hot-dry climate. Furthermore, concretes and mortars has been exhibited a high level of shrinkage and cracking in hot environments [51, 52]. Contrarily, other studies showed that the hot environment, reduced the shrinkage deformation and have little influence on the flexural strength of concrete [53, 54].

Generally, date palm wastes are either burned in farms or disposed of in the landfills, which can lead to harmful consequences on the environment and human health. As a result, it is recommended to utilise these wastes as reinforcement of cement-based composites to save the environment from pollution.

Overall, according to the previous literature, there are contradictory results regarding the effect of incorporation agricultural fibres on the performance of cement-based materials in terms of fresh and hardened properties. Therefore, further research is required into the properties of cement-based materials reinforced with date palm wastes. This work is a part of full project concerning the study of the potential of using date palm wastes as building materials.

The main objective of this study is to evaluate the suitability of date palm mesh fibre as alternative reinforcements in composite materials. In addition to study their effects on physical and mechanical properties, the influence of hot-dry climate also has been examined.

2. Experimental methodology and design

2.1 Materials

Cement

Al Mosalah cement CEM I (Arabian Cement Company) which meets GPC requirements BS EN 197-1 [55] was used to produce the mortars. General purpose cement has been chosen as the observation of mortar properties can be done during the normal hydration process; thus the effects of date palm mesh fibre in the mortar can be noticed.

Sand

The fine aggregate used was locally available silica sand collected from Awjilah town and called Awjilah sand with an absorption capacity of 0.20%, specific gravity of 2.60. Prior to use, the fine aggregate was dried in ambient conditions to eliminate any free water.

Water

Drinking grade tap water (TW) (pH 7.4; 2.29 µS/cm) was used and conditioned at 22±2 °C prior to use.

Date palm mesh fibre

The date palm mesh fibres used in this study are obtained from Saidi date palms trees (local name) from Awjilah town which is located in the Al Wahat district in the Cyrenaica region of north-eastern Libya.

The fibre meshes are the part of the tree which surrounds the trunk and after removing the leaves, the fibre meshes are removed in the form of nearly rectangular meshes (300-500 mm length and 200-300 mm width) formed with three superposing layers. Subsequently, the mesh sheets were washed with fresh water several times to avoid the absorption of mix water by the fibres due to its porous and rough surface [21]. Finally, the fibres meshes were dried at room temperature for one week and chopped manually by scissor to achieve the required length, that is, 7 – 10 mm. Table 1 shows the physical properties of date palm mesh fibre [47, 56].

Table 1: Physical properties of date palm mesh fibre [47, 56].

Property	Range
Diameter (mm)	0.1 - 0.8
Density (kg/m^3)	1089
Natural moisture content (%)	9.5 - 10.5
Water absorption after 5 min (%) under water	60 - 84
Water absorption to saturation (%)	97 - 203

2.2 Mortar composition and mixing procedure

The composition of control mortar was in accordance with ASTM C270 [57] with the mix proportions being 1 part of cement and 3 parts of sand (by mass) at a fixed water/cement ratio (w/c) of 0.50. Each mortar batch comprised cement (450 g), fine aggregate (1350 g), water (225 g). The fractions of date palm mesh fibres were calculated by weight of the cement in the composite (0%, 0.5%, 1%, 1.5%, 2% and 2.5%).

The mixing process followed the procedure described in ASTM C305 [58] using the Hobart mixer (model N-50 G). In the case of adding date palm mesh fibres to the mixes, the adopted ASTM C305 test method was modified with additional steps.

Immediately, after the finishing of mixing mortar, the required masses of date palm mesh fibres were added manually in the mixing bowl for 2 to4 minutes by using a spatula to ensure thorough mixing. The Hobart mixer was then turned up to a high speed and left to mix for 60s. At this time, the Hobart mixer was turned off and the mixing bowl removed. The mortar was then subjected to several performance tests as detailed later.

2.3 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 cured until the day of test in two types of environment. Firstly, mortar specimens were placed in a curing tank filled with water saturated with lime ASTM C511 [59] for up to 28 days at a temperature of 23-26 ºC (LSW method). Water not saturated with calcium hydroxide (high-calcium hydrated lime) may affect test results due to leaching of lime from the test specimens. Secondly, all the specimens were placed in a humidity cabinet (HC method) at 31ºC and 37.5% RH to simulate hot-dry climate in the Al Wahat regions in Libya as shown in Table 2.

Table 2: The characteristics of the climatic data in the Al Wahat regions in Libya [60]

Month	Min. Temp. (Av) °C	Max. Temp. (Av) °C	Average temperature °C	Relative humidity (Av) %
May	21.4	36.1	28.8	31
June	25.1	38.6	31.9	33
July	25.1	38.9	32	38
August	25.1	37.5	31.3	41
September	22.9	37.9	30.4	45

2.4 Test methods

Determination of the fresh mortar properties were through measuring flow (ASTM C1437) [61], wet density (ASTM C138) [62] and air content (TESTING Bluhm & Feuerherdt GmbH) (ASTM C231) [63]. The hardened mortar properties were determined through the measurements of compressive and flexural strength.

Mortar specimens (50 x 50 x 50 mm) were tested at the age of 7 and 28 days for compressive strength following the listed procedures of the test method (ASTM C109/C109M) [64]. 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.

In addition, the flexural strength of the prism mortar specimens (160 x 40 x 40 mm) was examined at the age of 28 days curing using three-point bending method according to the BS EN 1015-11 [65] using 10 kN single lever flexural testing machine (ELE International, UK). The load vertically applied by means of the loading roller to the opposite side faces of the prism of the prism and increase it smoothly at the rate of 0.05 ± 0.01 kN/s until fracture. The automatic horizontal jolting table was used instead of tamper at a rate of 60 jolts per minute to compact the fresh cement mortar in the three gang moulds instead of tamper.

3. Results and discussion

3.1 Influence of DPMF on flow and wet density

The flow was found to decrease when the mass fraction of DPMF increases (Fig. 1). A reduction in flowability was between 5-33% compared to the control mortar. Studies show that increase in fiber content decreases the workability due to a high specific surface area of the fibres [66-68].

The shape of DPMF could be another factor in reduction the flowability because of their ability to stretch out and creating rubbing that gives to the mixture an artificial cohesion [42]. This decreases in flow for mixes containing reinforcement materials is a similar to other studies reported in literature [69-71].

According to the Figure 2, it can be noted that the wet density decreases as the percentage of DPMF increase. This could be due to the porosity of the DPMF which affect the weight of the mortar mixes and then their density. Moreover, this slight reduction can be attributed to the control mortar (2242 kg/m^3) being replaced by lower density DPMF (1089 kg/m^3) when it placed in a mould of a fixed volume.

Previous studies showed that the incorporation of agricultural fibre into cementitious –based materials contributes towards reducing wet density of the resulted mix [23, 31, 42, 72].

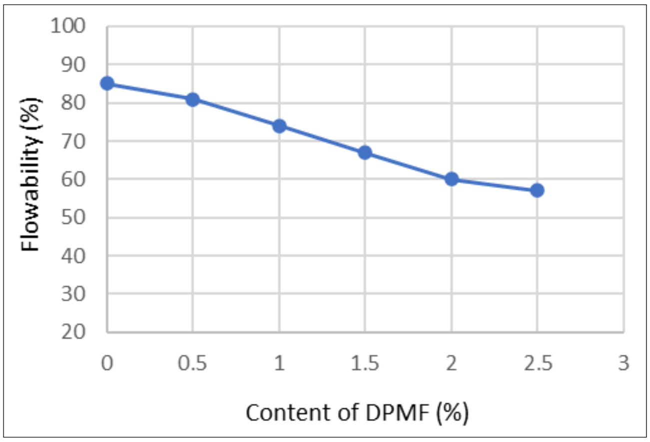

Fig 1: Effect of DPMF on flow of mortar mixes

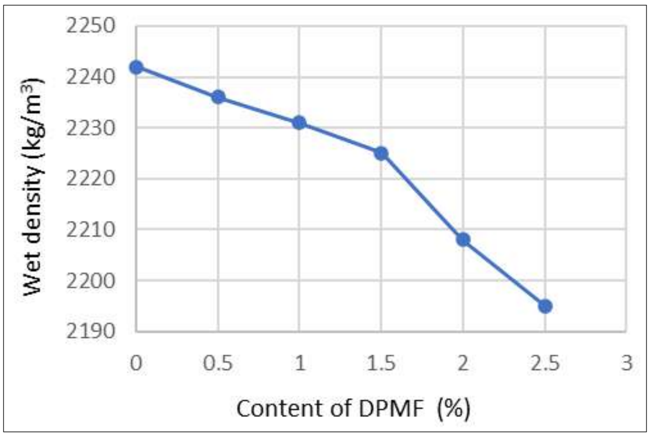

Fig 2: Effect of DPMF on wet density of mortar mixes

3.2 Influence of DPMF on air content

It can be seen that the percentage of air content of the tested mixes increases with the increasing DPMF content compared to control mix which showed the lowest value (6.6%) (Fig. 3). This increase in the air content can be attributed to the porosity of the DPMF and also the inter-particle spaces created between DPMF [31, 73]. Furthermore, it is possible that the air content increases with the increasing DPMF because of mixing related phenomena. However, this is still speculative and requires further work [4]. The increased voids of cement mortar as a result of date palm addition has been observed previously [27, 72, 74].

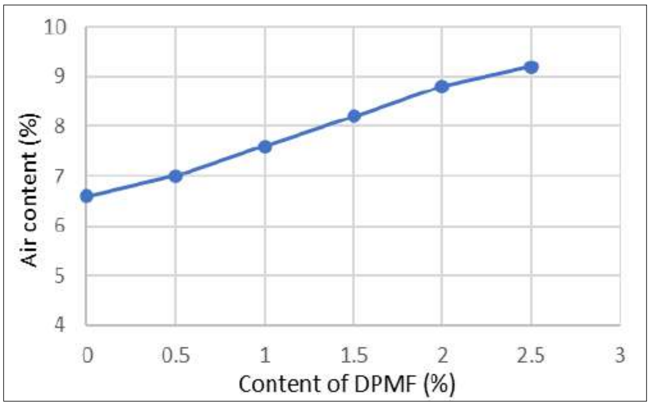

Fig 3: Effect of DPMF on air content of mortar mixes

3.3 Influence of DPMF on compressive strength

Regardless of the curing method, all the mixes follow a similar trend whereby a higher content of DPMF in mortars resulted in decrease compressive strength (Fig.4). The decrease was nearly linear rather than a step change at specific DPMF content.

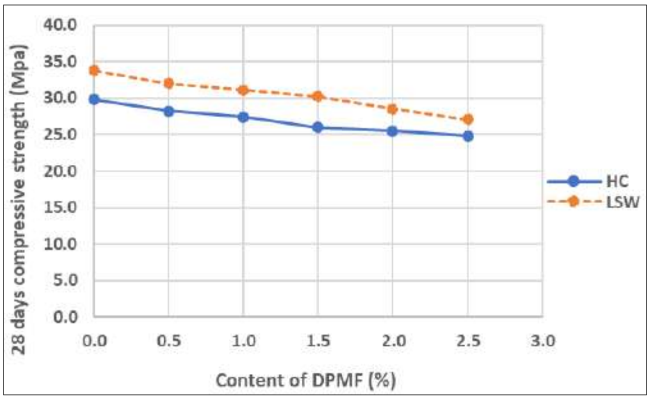

Fig 4: Variation in compressive strength at 28 days for mortar mixes containing DPMF using LSW and CH curing methods

The reduction of compressive strength of cement based materials due to incorporating DPMF can be attributed to the low mechanical strength of the inclusions and poorer DPMF/cement matrix adhesion [27, 31]. Furthermore, the addition of fibres interrupts the mineral skeleton of the resulted mix, creating voids inside the matrix and increasing its porosity with minimal strength [72]. Moreover, the poor resistance of agricultural fibres to the high alkaline environment (cement-based composites) could be also having contribution [21, 22, 75]. The deterioration of agricultural fibres in cement composites can be assigned to the dissolution of lignin and hemicellulose linking individual fibre cells by the alkaline pore solution [21, 35]. In addition, when mixed with cementitious materials, unsaturated plant fibres absorb a considerable amount of water and reduce water required for the hydration of cement. This lead to a lower degree of cement hydration

and, as a result, poor mechanical performance of cement composites [76].
Although the compressive strength continues to increase with age in the both curing methods, even when the fraction of DPMF was increased, the compressive strength observed for mixes cured in CH are remarkably lower than for those subjected to LSW curing (Fig.5).

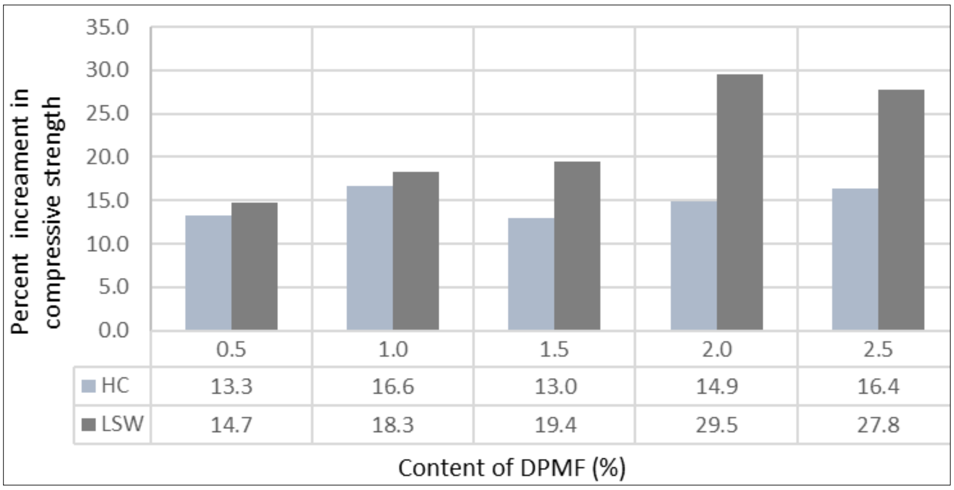

Fig 5: Percentage increment in compressive strength from 7 to 28 days of mortar mixes containing DPMF using LSW and CH curing methods

The principal elements responsible for this difference could be assigned to the hydrophilic_behaviour of agricultural fibres [77]. Agricultural fibres are cellulose-based materials which make them to absorb and loss water under varying humidity conditions. The absorption phenomenon of agricultural fibres as a result of hydrogen bonding of water molecules of hydroxyl (OH) groups present in the cellulose molecules [78]. Therefore, lack of hydration products due to evaporation of water from the specimens conserved in a hot dry environment has a detrimental effect on the compressive strength [47, 48].
Previous study utilised scanning electron micrograph indicated that the percentages of C_3S and C_2S remain very high in the dry environment, which confirms the low level of cement hydration processes. The incorporation of date palm fibres into cement-based materials were found to decrease the compressive strength in hot dry curing [49].
From the point of view of stability, results suggest that the cement-based mortar reinforcing date palm mesh fibres yields adequate compressive strength for non-structural civil applications.
Although with the addition of 1.5% of DPMF, the compressive strength at 28 days (LSW method) reduced to 30.2 MPa, 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. Indeed, the incorporation of 2.5% of DPMF leads to a compressive strength at 28 days of 24.8 MPa (CH method) and 27.1 MPa (LSW method). Even through these strengths are 16.7 and 20%, respectively that of the control mix, it remains at an acceptable level to be used in masonry rendering systems [1]. Furthermore, the obtained values remain compatible with the use of these materials as structural and bearing insulators [27].

3.4 Effect of DPMF on flexural strength

Irrespective of the methods used for curing, a notable decrease in the flexural strength was observed with increasing dosage of DPMF showing quite similar trends to those of compressive strength (Fig.6).

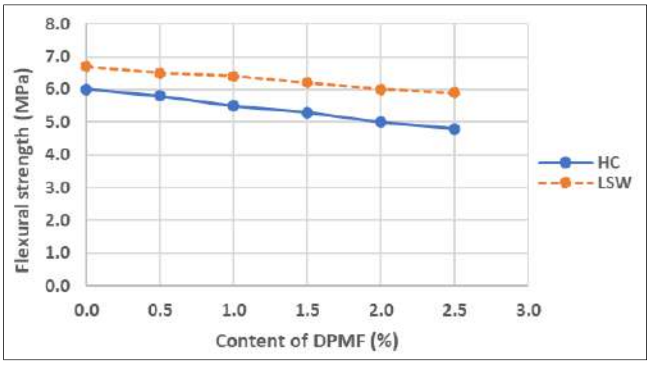

Fig 6: Variation in flexural strength at 28 days for mortar mixing containing DPMF using LSW and CH curing methods

Water absorption of plant fibre breakage of hydrogen bonds between fibers or between fibers and cementitious matrix. Therefore, weakens the fiber-cement matrix bond and consequently, it reduces flexural strength [76]. Moreover, due to poor interfacial bonding between the hydrophilic fibers and the hydrophobic matrices, the failure mode of the fibers is mostly by pullout [79, 80].
Although, samples with both curing methods showed reduction in flexural strength with increasing PDMF content, however, the samples cured in LSW achieved the best results compared with samples cured in CH. This difference can be attributed to the fact that when moisture is removed from the matrix due to dry atmosphere, more voids will be created inside the matrix as well as more inter particles spaces between PDMF leading to additional reduction in flexural strength [31, 73, 76].
The visual inspections on the broken specimens revealed that even though of the rupture the broken specimens were not fully split as the mesh of date palm still held for the pieces together, hence protecting the samples from totally splitting. A similar trend was observed by [47, 81].

4. Conclusion

The growing concerns regarding the environmental impact generated by the use of inorganic materials in different field applications increased the interest in the use of agricultural fibres as an alternative for conventional reinforcements in cementitious composites. This paper reports the results of an experimental investigation 0f the physical and mechanical properties of the mortar reinforced with DPMF. The investigations were performed by exposing the samples to various environments: immersion in water saturated with lime (LSW) and controlled hot-dry climate using humidity chamber (HC).

The results revealed that mortar reinforced with DPMF was found to reduce the flow, whereas there was an increase in the air content with increasing DPMF content. Furthermore, the increase of DPMF content allows lightens the mortar by decreasing its density. Additionally, it was concluded that the addition of DPMF produced slight variations on their flexural and compressive strength. Regardless of curing method used, compressive and flexural strength of mortar specimens proportionally decreased with the increase of the DPMF content. However, it was found that specimens cured in LSW presented, on average, higher values of their mechanical properties than specimens cured in HC. The principal elements responsible for this difference could be attributed to the hydrophilic behavior of DPMF. From the point of view of stability, results suggested that the cement-based mortar reinforcing with DPMF produced acceptable strength for non-structural civil applications and/or could be used for finis

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