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The Influence of Silica Fume on the Properties of Mortars Containing Date Palm Fibers

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Abstract: Natural fibers have recently been presented as a promising alternative for manufactured fibers. Date palm fibers showed interesting results when used as an inclusion in concrete and mortar. In this study, Sefri Date Palm Mesh Fibers (SDPMF) were used as an inclusion in mortars. Silica fume (SF) partially replaced the cement by 5%, 10%, 15%, and 20% by mass to improve the mechanical properties of SDPMF mortars. SDPMFs were collected from local farms. The fibers were then cleaned, dried, and cut to 50 mm, and added to mortars with 1%, 2%, and 3% by weight. Density, absorption, open porosity, workability, and compressive strength of mortars were investigated. A comparison with a previous study's results for mortars containing Sefri Date Palm Leave Fibers (SDPLF) is presented. The results showed that the incorporation of SF as part of cement may lead to improving the properties of the mixtures containing SDPMF fibers.

Keywords: agricultural waste; compressive strength; date palm fibers; mortar; natural fibers; silica fume

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1. Introduction

The construction industry is classified as one of the top industries responsible for carbon dioxide emissions [1,2]. Therefore, it is considered as a high threat to the environment [3–5]. Researchers around the world have been investigating and introducing new ways to reduce carbon dioxide emissions. For example, natural fibers could be an alternative promising solution to replace the manufacturing one. This will reduce the number of manufacturing processes in factories, energy consumption, and unlikely emissions. Besides, the natural fibers are low-cost, environmentally friendly, renewable, economic, and possess good physical and mechanical properties [6–10].

The agriculture sector produces million tonnes of waste annually and in most cases are dumped in landfills, causing environmental and fire hazards. For example, the annual world production of bamboo, jute, kenaf, and flax fibers is 30,000,000 tonnes, 2,300,000 tonnes, 970,000 tonnes, and 830,000 tonnes, respectively [6]. Recycling such wastes by introducing them as potential construction materials will contribute to a cleaner environment and help shifting to a "circular carbon economy". Studies on natural fibers such as coconut, jute, bamboo, sisal, and hemp showed a positive influence on properties of concrete and mortar [8,9,11–15]. Kesikidou and Stefanidou [8] reported improvements up to 28%, 24%, and 16% in flexural strength when kelp, coconut, and jute fibers are incorporated in the mortar, respectively. The thermal insulation of a small house of 42 m^2 area was investigated [11], where mortar coated by coconut fibers was used. The results showed an improvement in the thermal insulation by saving up to 16% of annual energy costs. Arshad et al. [16] conducted an experimental program to study the effects of basalt fibers on the mechanical properties of concretes containing 8% silica fume and different content of bagasse ash. Their results showed improvements up to 21.8% and 53.4% for compressive strength and modulus of rupture, respectively. Moreover, they found that when content of basalt fibers increases from 0.5% to 1.0%, the compressive strength and modulus of rupture marginally increase. Khan and Ali [17] conducted a study where 15% silica fume and different contents of fly ash (i.e., 0%, 5%, 10%, and 15%) were added to concretes containing 2% (by mass) of coconut fibers. They concluded that the compressive strength and modulus of elasticity improved up to 26.67% and 32.37%, respectively, as compared to the plain concrete. This improvement is corresponding to concretes having 10% fly ash. Khan et al. [18] conducted a study to investigate the effects of silica fume and coconut fibers on the thickness of concrete roads. For this reason, silica fume of 5%, 10%, 15%, and 20% by cement mass were incorporated to concretes containing 2% of coconut fibers with length of 50 mm. The compressive strength, flexural strength, and modulus of elasticity were improved up to 24.62%, 59.60%, and 33.60%, respectively, as compared to the plain concrete. This improvement is corresponding to concretes having 15% silica fume. The authors concluded that the thickness of concrete roads could be reduced up to 8% when 15% of silica fume is used in concrete containing 2% of coconut fibers.

According to [19], date palm is one of the high growing varieties around the world with 11.8 million ha. covered area. Date palm is planted in more than 94 countries especially in Asia and Africa with 8.18 and 1.66 million ha., respectively. In Saudi Arabia, for example, date palm trees are ranked the first among permanent crops, with an estimated 28.5 million date palm trees in 2015 [20]. The date palm waste generated annually by seasonal pruning and trimming can be estimated by 35 kg per tree on average [21]. As a result, million tonnes of waste could be produced and placed in landfills with no economic value and potential fire hazards.

The utilization of date palm fibers in concrete and mortar was studied. According to [22,23], the density of mortars containing date palm fibers could be slightly reduced, with a reduction ranging from 1% to 8%. However, with a high volume of date palm fibers inclusion, a significant reduction in density could be observed. For example, the inclusion of 21% and 51% by volume could yield a reduction in the density up to 16% and 39%, respectively [24–27]. Water absorption and porosity of mortars containing date palm fibers were studied [23,27,28]. It was found that the water absorption and porosity increase when the content and length of fibers increase. However, the pretreated fibers with $Ca(OH)_2$ showed lower water absorption. This is due to the effects of the alkali pre-treatment that removes the hemicellulose and lignin from the fibers. The ability of date palm fibers to improve the thermal conductivity of mortar and cement-based composites was also investigated [24–26,29–32]. These authors concluded that date palm fibers could be classified among the best construction materials in terms of thermal insulation. For example, the thermal conductivity of mortars containing date palm fibers of 21%, 27%, 31%, 35%, 48%, and 51% by volume was studied [30]. They concluded that the thermal conductivity could be improved up to 70% for mortars containing 51% date palm fibers. Similar results were obtained by [26] where a reduction in the thermal conductivity up to 75% was observed for 51% date palm fibers inclusion. Braiek et al. [31] conducted an experimental study to evaluate the thermal insulation capacity of gypsum plaster containing different contents of date palm fibers (i.e., 5%, 10%, 15%, and 20% by weight). The authors concluded that the thermal conductivity decreases when the content of date palm fibers increases. For example, the thermal conductivity decreases up to 14.38%, 37.17%, 52.88%, and 61.50% for date palm fibers inclusion of 5%, 10%, 15%, and 20%, respectively. Benmansour et al. [24] investigated the thermal conductivity of mortars containing 5%, 10%, 15%, 20%, 25%, and 30% by weight date palm fibers. The date palm fibers used were composite of crushed petiole and rachis with different diameter of 3 mm and 6 mm. The results showed significant improvements in terms of thermal conductivity up to 92.5% and 87% for mortars containing 30% inclusion of date palm fiber with 6 mm and 3 mm diameter, respectively.

Mortars and cement-based materials containing date palm fibers showed lower compressive and flexural strength as compared to plain ones [24,28,30,33–35]. It was noticed that the compressive and flexural strengths decrease when the length and content of date palm fibers increase. Date palm fibers which were pre-treated by boiling in water, immersing in alkalis, and coating with oil were used to improve the mechanical properties of mortars containing date palm fibers [33,36,37]. However, to the best of the author's knowledge, no study has been reported on the incorporation of pozzolanic materials into mortars containing date palm fibers. Such incorporation may lead to overcome the main drawback of the mechanical strength of mortars containing date palm fibers due to the pozzolanic reaction. Besides, the use of date palm fibers in mortars and concretes could lead to clean and green environment by eliminating the date palm waste. In this study, the physical and mechanical properties of mortars containing Sefri Date Palm Mesh Fibers (SDPMF) were investigated. Silica fume (SF) was incorporated as part of cement in the mortars containing SDPMF fibers.

2. Experimental Program

2.1. Materials

In this study, Portland cement type I was used. The sand was obtained from the Wadi Bisha rainfall stream with a specific gravity of 2.67, and particle size distribution as shown in Figure 1. Sefri Date Palm's (a type of date palm in Saudi Arabia) trunk mesh Fibers (SDPMF) were collected from a local farm at Bisha. The SDPMFs were cleaned, dried, manually separated, and then cut to specified lengths of 50 ± 5 mm (Figure 2). SDPMFs were incorporated into the mixtures by 1%, 2%, and 3% by weight. In order to investigate the effects of silica fume (SF) on the mechanical properties of SDPMF mortars, the cement was partially replaced by silica fume with 5%, 10%, 15%, and 20% by weight. The chemical composition and physical properties of SF are presented in Table 1.

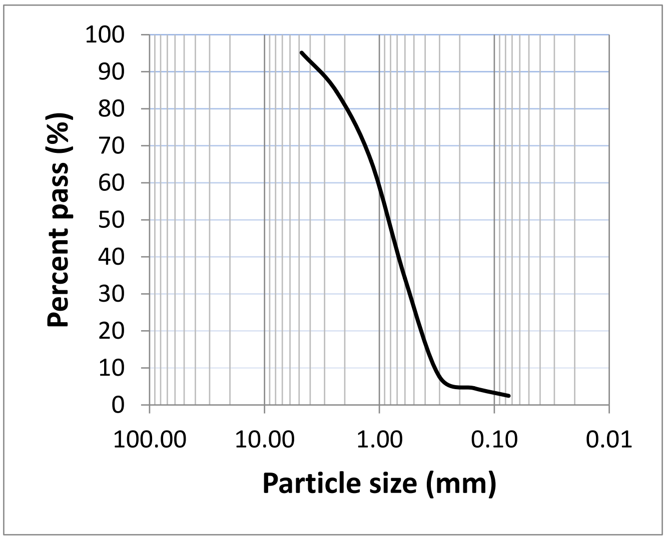

Figure 1. Particle size distribution of the used sand [23].

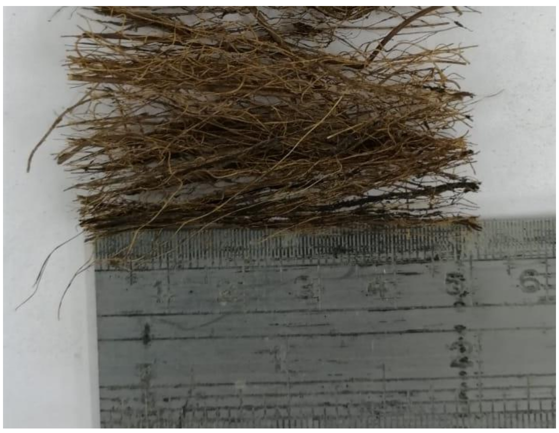

Figure 2. SDPMFs after preparation.

Table 1. Chemical composition and physical properties of SF.

Compound Composition	Content (%)
SiO_2	91.6
Al_2O_3	1.65
Fe_2O_3	0.99
CaO	0.22
MgO	0.30
SO_3	0.07
Cl	0.01
Na_2O	0.25
K_2O	0.17
LOI	3.75
Relative density	2.27
Color	Grey dark

2.2. Mix Proportion

This study aims to investigate the mechanical properties of mortars due to (a) incorporation of 1%, 2%, and 3% SDPMF fibers, (b) incorporation of 1%, 2%, and 3% SDPMF fibers, and 10% of SF, and (c) incorporation of 1% SDPMFs and 5%, 10%, 15%, and 20% of SF. Thus, a total of ten mixtures of mortars were prepared, including the control mixture. Table 2 shows the mix proportions and SDPMF and SF ratios for all mixtures.

Table 2. Mix proportion of mortars.

Mixture	SDPMF (%)	SF (%)	*w*/*c*	Binder:Sand
M0S0(CR)	0	0	0.5	1:2
M1S0	1	0	0.5	1:2
M2S0	2	0	0.5	1:2
M3S0	3	0	0.5	1:2
M1S10	1	10	0.5	1:2
M2S10	2	10	0.5	1:2
M3S10	3	10	0.5	1:2
M1S5	1	5	0.5	1:2
M1S15	1	15	0.5	1:2
M1S20	1	20	0.5	1:2

Figure 3 shows the flow chart of the mixing procedure. The sand, cement, and SDPMFs were put together into the mixer, and the mixer was operated for about one minute to ensure the SDPMFs are equally distributed among the mixture. The mixing water was then gradually added, and the mixer was run for about 3 min. The mortar was then placed in the molds and properly compacted as per ASTM C192. The specimens were left in the molds for 48 h, then demolded and placed in water tank until the day of the test. M1S10 is a mixture where the percentage of SDPMF is 1% and the content of SF is 10%.

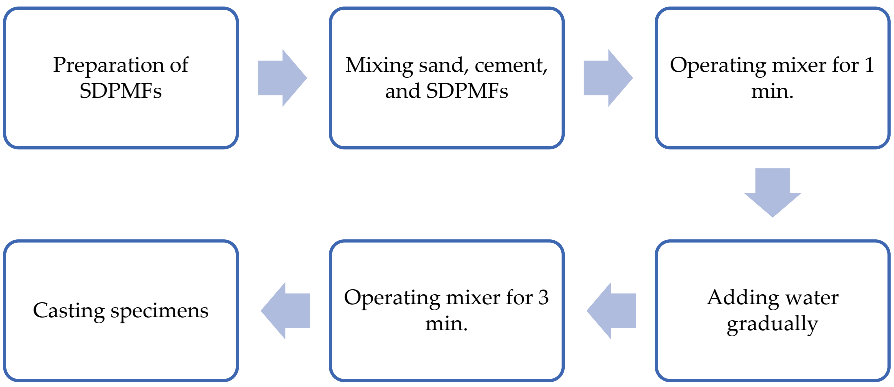

Figure 3. Mortars mixing procedure.

2.3. Tests

2.3.1. SDPMF Properties

The density and absorption of SDPMF were determined by Equations (1) and (2), respectively. The procedure of the test was adopted from ASTM C127. A sample of SDPMF was dried in an oven at 110 °C until a constant weight was obtained; this weight was recorded as oven-dried weight (*Wo*). The sample was then immersed in water for 18 h. The water on the SDPMF was wiped and the weight was recorded as saturated surface dry (W_{SSD}). The weight of the SSD specimens in water (submerged weight W_i) was also determined.

$$density\ (OD)\left(\mathrm{kg/m^3}\right) = \frac{Wo}{W_{SSD} - W_i} * 997.5 \quad (1)$$

$$Absorption\ (\%) = \frac{W_{SSD} - Wo}{Wo} * 100 \quad (2)$$

2.3.2. Mortar Properties

To investigate the effects of SDPMF and SF on mortar's properties, density, absorption, open porosity, workability, and compressive strength were investigated. A flow table test was conducted in accordance with ASTM C230 for each mixture to investigate the workability of the mortars. After 25 drops of the flow table, the diameter of the mortar was measured in four directions. The average of the measured diameters was used to interpret the results. The apparent density, absorption, and open porosity of mortars were determined at age of 180 days using Equations (3)–(5), respectively. The procedure of the test is adopted from ASTM C642. Three cubes of 100 mm length for each mixture were used in this test. The oven-dried weight was determined after drying the specimens at 110 °C for more than 24 h. The weight of saturated surface dry was determined after immersing the specimens for more than 24 h. in the water and wiping the surface water with a piece of cloth. The weight of saturated surface dry specimens in water (submerged weight) was also determined.

$$Apparent\ density\left(\mathrm{kg/m^3}\right) = \frac{Oven\ dried\ mass}{Oven\ dried\ mass - submerged\ mass} * 1000 \quad (3)$$

$$Absorption\ (\%) = \frac{Saturated\ surface\ dry\ mass - Oven\ dried\ mass}{Oven\ dried\ mass} * 100 \quad (4)$$

$$Open\ porosity(\%) = \frac{Saturated\ surface\ dry\ mass - Oven\ dried\ mass}{Saturated\ surface\ dry\ mass - submerged\ mass} * 100 \quad (5)$$

Six cubes of 100 mm were cast and cured to determine the compressive strength of mortar at 7, 28, and 180 days in accordance with ASTM C192 and ASTM C109. A compression test machine of 3000 kN capacity was used to test the cubes with a stress increment of 0.15 MPa/s.

3. Results and Discussion

3.1. Physical Properties of SDPMFs

The density and absorption of SDPMFs were determined as the average of two samples. Figure 4 shows the SDPMFs during testing. The results are summarized in Table 3. As compared to other natural fibers, the SDPMFs could be lighter than cotton, jute, flax, hemp, abaca, ramie, and sisal [6,38]. This property could lead to lighter construction materials. Several researchers concluded that the addition of date palm fibers to the mortar decreases its density up to 39% for inclusion of 51% of date palm fibers [23,26,30]. It is obvious that SDPMFs have high porosity with an absorption capacity of 122.53%. The high porosity structure comes from the small canal and the huge number of pores inside the fibers [34]. Such high absorption capacity could affect the workability and mixing water of the mixture; therefore, causation needs to be exercised during mix design. As compared to

SDPLFs, it can be seen that SDPMFs have lower density and higher absorption capacity, which may lead to different effects on mortars.

Figure 4. SDPMFs in SSD condition.

Table 3. Physical properties of SDPMF.

SDPMF Property	Value Range
Density (OD)	951.78 ± 20.78 kg/m^3
Absorption	$122.53 \pm 8.24\%$

3.2. *Workability of Mortars*

3.2.1. Effects of SDPMF Content

Figure 5 shows the workability test procedure. The results of the workability test are illustrated in Figures 6–8. As shown in Figure 6, the workability of mortars decreases as the content of SDPMF increases. The reductions of 11.37%, 21.07%, and 24.25% for M1S0, M2S0, and M3S0, respectively, were observed. This reduction is expected due to the high porosity and absorption of SDPMFs, which lead to the loss of mixing water. Similar results were reported, where a reduction in workability up to 7.6% was recorded when date palm leaves (SDPLF) up to 3% are incorporated in the mortars [23]. The higher loss of workability for mortars containing SDPMFs compared to mortars containing SDPLFs, could be attributed to the higher absorption capacity of SDPMFs (i.e., 122.53%) compared to SDPLFs (i.e., 94.74%). Thus, researchers suggest submerging date palm fibers in water before mixing process [22].

Figure 5. Workability test.

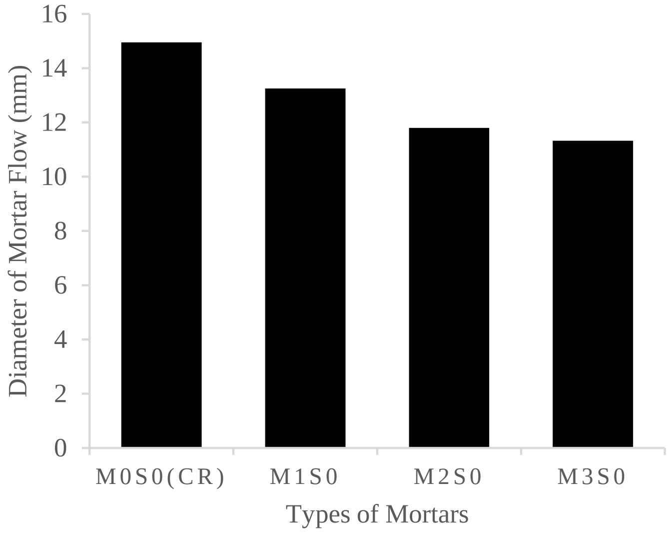

Figure 6. Effects of SDPMF content on the workability.

3.2.2. Effects of SDPMF Content and 10% SF

Figure 7 shows the effects of SDPMF content and 10% SF on mortar workability. The workability losses of 30.43%, 35.28%, and 40.55% were recorded for M1S10, M2S10, and M3S10, respectively. With the 10% SF partial replacement of cement, the workability became lower as compared to SDPMF's mortars containing no SF. This is due to the micro size and high fineness of SF that demands high content of water, leading to mixing water loss [39,40].

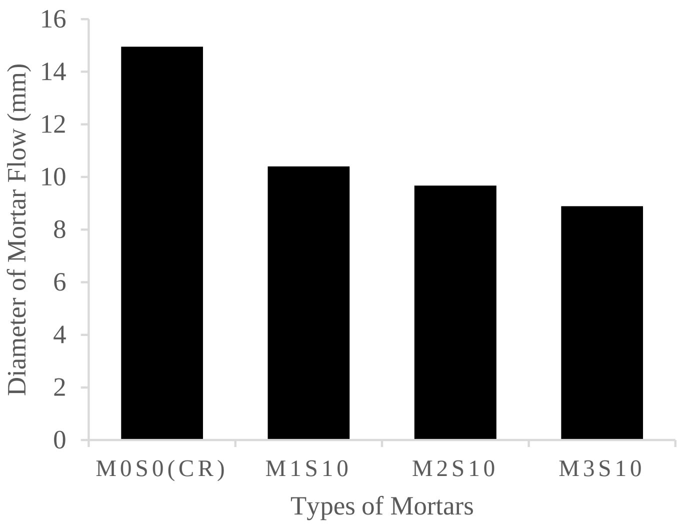

Figure 7. Effects of SDPMF content and 10% SF on the workability.

3.2.3. Effects of SF Content

Figure 8 shows the effects of SF content on mortars containing 1% SDPMFs. SF content of 5%, 10%, 15%, and 20% were tested. The workability of mortars decreases when the content of SF increases, recording a reduction of 24.25%, 30.43%, 30.94%, and 33.11% for M1S5, M1S10, M1S15, and M1S20, respectively. Even though the content of SF is doubled from 10% for M1S10 to 20% for M1S20, the loss in workability is increased by only 2.68%. This refers to an insignificant loss that could be occurred when higher content of SF up to 20% is incorporated into the mortars.

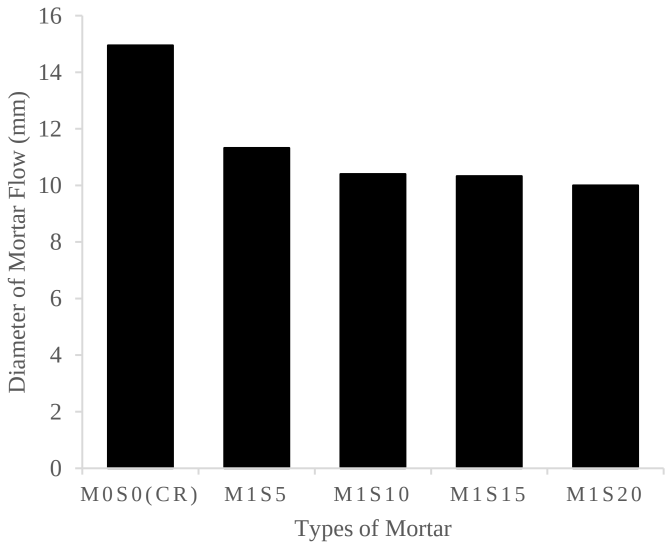

Figure 8. Effects of SF content on the workability of mortars containing 1% SDPMFs.

3.3. Water Absorption and Open Porosity

Table 4 shows the results of water absorption, open porosity, and apparent density of all mixtures except for M0S20 which is not included in these tests. The standard deviations for all tests are also presented. With respect to water absorption, it can be seen that the mortars containing SDMPF fibers showed higher absorption than the control one. Similarly, the open porosity of the mortars containing SDPMFs is higher than the control one. Even though the content of SDPMFs increases from 1% to 3% in the mortars. However, no significant increments in water absorption and open porosity were observed. This could be attributed to a) the presence of SDPMFs and b) the fibers with aging were not significant in the water absorption of the mortars [41].

Table 4. Physical properties of the mixtures.

Mixture	Apparent Density (kg/m^3)		Absorption (%)		Open Porosity (%)	
	Value	Dev.	Value	Dev.	Value	Dev.
M0S0	2331.00	8.00	5.86	0.37	12.01	0.70
M1S0	2354.05	63.55	8.12	0.07	14.99	2.18
M2S0	2342.80	25.16	8.13	0.57	16.00	1.07
M3S0	2357.41	9.32	8.15	0.35	16.11	0.63
M1S10	2347.31	20.60	9.03	0.96	18.14	1.70
M2S10	2352.84	2.99	9.34	0.86	17.53	1.28
M3S10	2322.99	6.39	10.91	1.35	20.19	2.06
M1S5	2279.33	46.00	8.74	0.31	14.77	3.48
M1S15	2331.34	42.03	9.21	0.32	17.11	1.32

The mortars with 10% SF showed higher water absorption and open porosity as compared to mortars containing SDPMFs only. The hydrophilicity of the fibers, as well as the heterogeneous dispersion of silica fume in the mixture, may have contributed to the mortars' increased porosity [41]. The mortars with 1% SDPMFs and different content of SF showed higher water absorption and open porosity as the content of SF increases. Increments of 22.98%, 51.06%, and 42.45% in open porosity were recorded for the mortars M1S5, M1S10, and M1S15, respectively, as compared to the control mortar. Such increments could be attributed to the presence of SF where agglomeration could have occurred with a degree proportional to the content of SF [41–43]. When the addition of SF is presented in the mortar, low dispersion of particles is occurred forming large particle sizes and reducing the hydration process [41,44].

3.4. Density

The apparent density of all mortars is shown in Table 4. As can be seen from Table 4, positive effects, but not significant, were observed in the density of the mortars containing SDPMF fibers. Increments ranging from 0.51% for M2S0 to 1.13% for M3S0 were recorded. These insignificant increments could be attributed to (a) the possibly high compaction between SDPMFs and cement matrix that leads to enhanced homogeneity [28,45], (b) the very small inclusion dosage and diameter of SDPMFs may prevent the agglomeration of the fibers. With respect to the study carried out by [23], the mortars containing SDPLF leave fibers showed an insignificant reduction in the density up to 0.8%. In contrast, the findings of this study showed improvement in the density of the mortars containing SDPMFs up to 1.13%. The large tuft of SDPLF leave fibers (which is about 5 mm) may lead to disturbing the compaction between the fibers and matrix creating more pores resulting in an insignificant reduction in the density.

With regard to the mortars containing 1% SDPMF and 10 SF, M1S10, and M2S10 showed insignificant improvements while M3S10 showed insignificant reduction as compared to the control mortar. Similarly, M1S5 showed a small reduction while M1S15 showed almost the same density as the control one. Previous studies have concluded that the density of mortars may be insignificantly decreased/increased when the cement is partially replaced by SF [46,47]. The reduction in the density in the mortars containing SF may be due to the lower density of SF that replaces the cement. However, the insignificant improvement in the density of the mortars containing SF could be attributed to the aging of the mortars (180 days) that may develop additional C-S-H products.

3.5. Compressive Strength

Table 5 shows the average compressive strength of two specimens at 7, 28, and 180 days for all mortars.

Table 5. Compressive strength results.

Mixture	7 Days	28 Days	180 Days
M0S0(CR)	11.56	20.63	23.76
M1S0	8.51	14.65	15.76
M2S0	7.52	10.90	11.55
M3S0	5.29	8.74	10.24
M1S10	5.08	8.62	16.26
M2S10	3.55	8.24	15.61
M3S10	2.97	8.03	11.71
M1S5	5.47	7.39	13.27
M1S15	4.13	8.93	16.75
M1S20	3.44	9.84	17.60

3.5.1. Effects of SDPMF Content

Figure 9 illustrates the effects of SDPMFs on the mortars' compressive strength. It is obvious that, with the increase in SDPMF content, the compressive strength decreases. At 28 days, a reduction of 29.01%, 47.16%, and 57.66% for M1S0, M2S0, and M3S0, respectively, was observed. The reduction in the compressive strength is attributed to the SDPMF itself as it is highly porous structure [2,7]. At 180 days, a larger reduction was noticed with 33.67%, 51.39%, and 56.90% for M1S0, M2S0, and M3S0, respectively. Kriker et. al. [33] conducted an investigation on the effects of pretreated date palm fiber with $Ca(OH)_2$, and observed that the pretreated fibers become weaker. Thus, the authors concluded that the durability of date palm fibers in concrete and mortar may be affected, due to calcium hydroxide released during the hydration process.

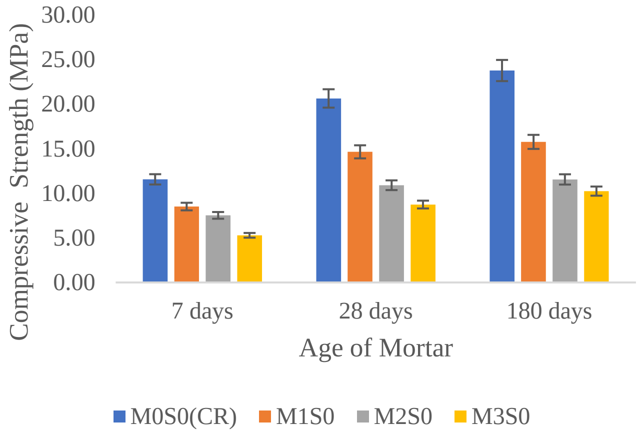

Figure 9. Effects of SDPMF content on mortars' compressive strength.

The relationship between the compressive strength (Y) and the SDPMF content (x), for the mortars containing SDPMFs is shown in Figure 10. It may be expressed using a best fit polynomial equation (Equation (6)) with correlation coefficient R^2 = 0.9499

$$Y = 9550x^2 - 680.8x + 20.597 \quad (6)$$

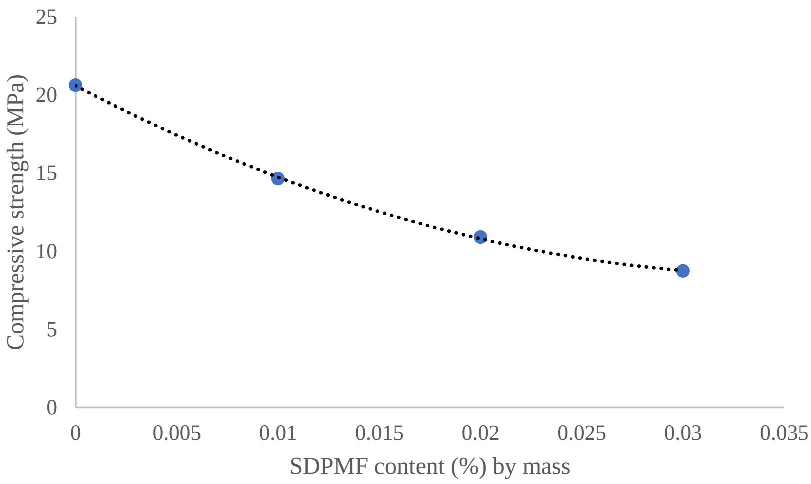

Figure 10. Best fit curve of SDPMF mortars' compressive strength.

Compared to mortars containing SDPLF leaves, SDPMF mortars showed better performance. Mortars containing 1% and 3% SDPMF showed lower loss of compressive strength with 29.01% and 57.66%, respectively, compared to 50.30% and 83.91% for mortars containing 1% and 3% SDPLF leaves, respectively. These results could be attributed to the larger tuft of SDPLF leaves (5 mm) that weakening the bonding of the mortar matrix.

3.5.2. Effects of SDPMF Content and 10% SF

As Figure 11 shows, the compressive strength decreases when the content of SDPMFs increases for mortars containing 10% SF. At 7 and 28 days, mortars with SDPMFs and 10% SF showed higher losses as compared to mortars containing SDPMFs only. This is because of the low content of cement due to its replacement with SF, and due to the fact that the pozzolanic reaction needs time to launch. However, at 180 days, the loss in compressive strength became lower as compared to ages of 7 and 28 days. M2S10 mortar showed the best behavior, where the addition of 10% SF yields a ceasing of compressive strength loss by 33.25%. This behavior could be attributed to the pozzolanic reaction that took place in the mortars. The pozzolanic reaction results in additional C-S-H gel and consuming $Ca(OH)_2$ that might degrade the mechanical strength of SDPMFs.

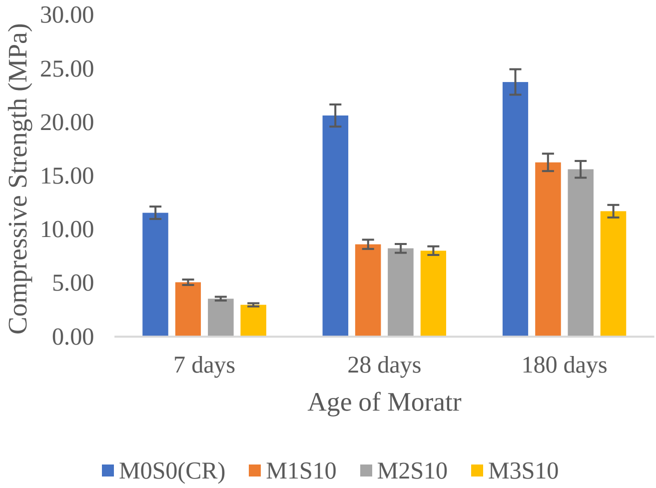

Figure 11. Effects of SDPMF content and 10% SF on mortars' compressive strengths.

3.5.3. Effects of SF Content

The effects of SF content on the compressive strength of 1% SDPMF mortars are presented in Figure 12. At age of 7 days, the loss in compressive strength ranges from 52.68% for M1S5 to 70.24% for M1S20. However, at age of 28 days, the reduction in compressive strength becomes lower. Besides to the presence of SDPMFs in the mortars, the replacement of cement by SF content could be the reason behind the large compressive strength loss at early ages. The positive effects of SF content in 1% SDPMF's mortars are observed by substantially ceasing the loss of compressive strength. For example, the compressive strength of M1S15 mortar improved by 54.10% at age of 180 days as compared to the age of 7 days. Similarly, an improvement of 63.10% was noticed for M1S20 mortar at age of 180 days against the age of 7 days. The improvement in compressive strength for the mortars at age of 180 days as compared to the early ages could be attributed to the presence of SF that induces the pozzolanic reaction and produces more C-S-H gel. The improvement in compressive strength for mortars containing SF and 1% SDPMF at 180 days age against early ages (7 and 28 days) increases when SF content increases with the best performance accredited to M1S20 mortar. Therefore, it can be concluded that the negative effects of date palm fibers on the compressive strength of the mortars could be reduced by the addition of SF content up 20%.

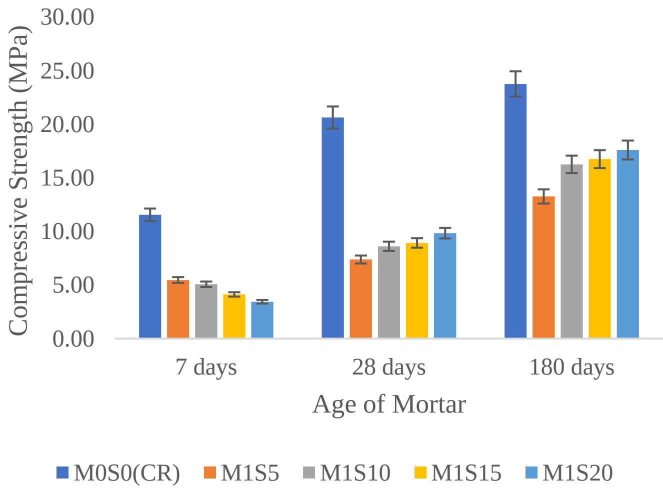

Figure 12. Effects of SF content on the compressive strength of 1% SDPMF mortars.

4. SDPMF Mortar's Applications

Based on the above discussion, it is obvious that the incorporation of SDPMFs into mortars lead to decrease the compressive strength. However, the compressive strength is still high enough to be used in several construction applications. For example, according to RILEM functional classification of lightweight concrete [48], all studied mortars could be classified as "Class II:. compressive strength is higher than 3.5 MPa", which can be acceptable for use in structural applications of lightweight construction. Thus, it can be concluded that mortars containing SDPMFs up to 3% by weight could be produced with acceptable compressive strength for use as structural materials in buildings and lightweight construction.

5. Conclusions

The effects of incorporating SDPMF and SF on the physical and mechanical properties of mortars were experimentally studied. A comparison between mortars containing SDPMF mesh fibers and mortars containing SDPLF leave fibers is presented. A total of ten mixtures were prepared and tested. SDPMFs were collected, cleaned, dried, manually separated, and then cut to specified lengths of 50 ± 5 mm. Physical properties of SDPMFs and workability, density, water absorption, porosity, and compressive strength of mortars were investigated. The following conclusions can be drawn:

- The low density (951.78 kg/m^3) and high absorption capacity (122.53%) of SDPMFs classify them as lightweight fibers, which might produce light mortars towards green construction materials.
- The workability of mortars was affected and reduced due to the inclusion of SDPMFs and reduced more as SF partially replaced the cement. With changing the content of SDPMFs and SF, the workability was reduced up to 24.25% and 33.11%, respectively, as compared to the control mortar.
- The density of mortars was insignificantly affected by the presence of SDPMFs and SF, with improvements up to 1.13% as compared to the control mortar. However, some mortars showed insignificant reduction up to 2.21%.
- All mortars showed higher water absorption and higher open porosity as compared to the control mortar. With changing the content of SDPMFs and SF, the water absorption and open porosity were increased up to 86.18% and 68.11%, respectively.
- The mortars containing SDPMFs showed a loss in compressive strength up to 57.66% at 28 days for 3% SDPMF inclusion. The loss in compressive strength at early ages becomes higher when SF is introduced to the mortars.
- The loss in compressive strength due to the inclusion of SDPMFs could be compensated by incorporating SF. A substantial improvement in compressive strength up to 63.10% at age of 180 days could be observed when 20% SF is incorporated to a mortar containing 1% SDPMFs.
- Mortars containing SDPMFs could be produced with acceptable strength for use in structural applications.

As the inclusion of SDPMFs to mortars showed promising results especially with the addition of SF, it is recommended to invest more time and resources to expand the research in this topic. For example, deep studies are recommended to understand the bonding mechanism between fibers and matrix, bridging mechanism, and incorporation of natural pozzolanic materials. In addition, the long-term durability of date palm fibers is still a matter of concern which needs more investigations.

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