Effects of palm fronds fibers on properties of high-volume fly ash concrete

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Abstract. Portland cement concrete is considered as the most difficult product in environmental pollution, although it is the main construction material. One of the alternatives is high volume fly ash concrete which uses low cost binding material (waste material) as a high replacement to Portland cement. This type of concrete is brittle similar to traditional concrete. So, the aim of this research is to use organic fibres (palm fronds fibres), which is a waste material, in enhancing the tensile property of this concrete (that use 50 % and 60 % replacement of fly ash). The percentages of fibres used are 0.4, 0.8, 1.2, 1.6, and 2% by volume of concrete to find the optimum percentage of it. The effects of fibres were studied on dry density, compressive and tensile strength, and drying shrinkage upto 90 days age. Results indicate that the optimum percentage of palm fronds fibres that can be added to high volume fly ash concrete (with 50 or 60% replacement of cement by fly ash) is 1.2% by volume.

Keywords
high volume fly ash concrete, palm fronds fibers

1. Introduction
The demand for sustainable and low-cost building materials is gaining increasing interest as social, economic and environmental issues evolve in society today.

The urgent need to develop appropriate and affordable housing has been generated by the fact that more than 1.5 billion people in the world live in developing countries; the poor live in very low-quality housing.

Concrete is one of the most common construction materials in the world. It has high compressive strength but its tensile strength is relatively low. It also has negative effects on the environment due to CO₂ emissions during Portland cement manufacturing [1].

There are many agricultural and industrial waste materials which are available in huge quantities. These materials can play a major role in improving the mechanical properties of concrete.

This work intends to use fly ash, which is one of the waste industrial material, in High Volume Fly-Ash (HVFA) concrete containing (50 and 60%) as a replacement of Portland cement. HVFA concrete is a brittle material same as normal concrete [2]. The addition of any fibers to concrete mix improves its tensile strength, enhances its ductility and result in greater resistance to cracking [3]. While addition of
natural fibers to concrete can increase its greenness, it also contributes to a more healthy and sustainable environment [4]. This work aims to find the optimum percentage of palm fronds fibers that can be added to HVFA concrete.

2. Experimental Program

2.1 Materials

2.1.1 Cement. Sulfate resisting Portland cement was used throughout the research. Its C3S, C2S, C3A, and C4AF are 50.8, 24.3, 2.3 and 12.8%, respectively. Its physical properties conform to Iraqi specification No.5/1984 [5].

2.1.2 Fine aggregate. Al-Ekhaider natural sand was used for casting specimens. The fine aggregate had a fineness modulus, SO3, and specific gravity of 3.3, 0.1%, and 2.67 respectively. The grading zone of fine aggregate was zone (2) according to the Iraqi specification No.45/1984 [6].

2.1.3 Coarse aggregate. Crushed coarse aggregate was used from Al-Nibaee region. The maximum size of coarse aggregate (19 mm) and the specific gravity and SO3 of 2.7 and 0.07% respectively. Their grading and other properties were within the requirements of the Iraqi specification No.45/1984 [6].

2.1.4 Fly-ash. Fly ash meeting the requirements of ASTM C 618 (Class F) [7] was used. The chemical composition and physical requirement show that the fly ash conforms to the chemical and physical requirement of ASTM C 311 [8]. Where the compressive strength activity index at 7 and 28 days are 126.31 and 135.83%, respectively.

2.1.5 Natural fibers. Palm fronds fibers was used in this work. The diameter of palm fronds fiber range between (0.2-0.3) mm and length of nearly (2.5±5) mm with an aspect ratio (100-125) and density of 720 kg/m³.

2.1.6 High range water reducing admixture. High-range water reducing admixture, with commercial name GLENIUM 51, from BASF Company was used in the present work. It is a second generation superplasticizer based on polycarboxylic ether. It complies with ASTM C 494(type F) [9].

2.1.7 Treatment of palm fronds fibers. Fibers were washed with tap water several times in order to remove dust and soluble (sugar) substances. The alkali treatment was then performed in order to preserve the fibers inside the concrete and reduce their absorption. This treatment was done to remove hemicelluloses, lignin and all waste substances and produce a rough surface topography. The clean fiber with (25mm) length was soaked in 0.173% concentration Ca(OH)₂ solution for 14 hrs. At a controlled temperature of 20°C. After soaking, the fibers were drained and rinsed thoroughly with potable water to remove any excess Ca(OH)₂. The fibers were subsequently spread out on absorbent cotton sheets in loose bunches to dry at (20)°C for 48 hrs. This method of treating fibers was carried out based on earlier research [10].

2.2 Mix proportions.

Table 1. Indicates the mix proportions used throughout this work.

2.3 Mixing, casting and curing

All materials (with or without fibers) were mixed homogeneously in a pan mixer of 0.1 m³ capacity. The compaction was carried out by means of a vibrating table for a duration of 20 seconds/ layer. After 24 hours, the samples were de-molded from the casting. Then concrete samples were moist cured at 25°C until testing age.
3. Results and discussion

3.1 Workability

The slump of concrete mixes were fulfilled according to ASTM C143/C143M-00[11]. The slump of concrete mixes was kept constant by changing the amount of superplasticizer added. The results of the slump test are shown in the table 1, which demonstrate the following:

1. The inclusion of fiber in the concrete mix reduced its workability. The amount of HRWR_A increase with increase of the fiber content in mix. This may be due to the distribution of palm fronds fiber that obstacle the flow of the concrete [12]. Also the high surface area/volume ratio of the fibers increase the demand to water. So, the increase of fibers in concrete mix requires more HRWR_A to attain the required slump (125±10) mm.

2. It can be noticed that the maximum percentage of fibers with RF1 mix is 1.2% by volume which is less than that used with RF2 mix i.e. 2%. This is because it was difficult to have a homogeneous and workable RF1 mix when incorporating fibers more than 1.2% with it. While the increase of fly ash in RF2 mix to 60% enhances the homogeneity of concrete and permits inclusion higher percentage of fibers in the mix.

3. RF2 mix use a lower dose of HRWR admixture than mix RF1 for the same workability. This could be due to the increase of fly ash particles that have a spherical shape, which reduces the internal friction between the aggregate and between the aggregate and paste interface by producing a ball bearing effect at the point of contact [13].

3.2 Compressive strength

The compressive strength test was carried out according to BS EN (12390-3:2002) [14] using100 mm cubes. The test machine used is an ELE machine with 2000kN capacity with the rate of loading of 0.3 N/mm²/s. Figure (1) indicates that the addition of fibers by 0.4, 0.8 and 1.2% by volume to mix RF1, which incorporated fly ash by 50 percent cement replacement, increased its compressive strength by 7.1, 11.2, and 14.7%, respectively. This may be due to densifying the matrix and reducing shrinkage of concrete by addition of those fibers. Results shown in figure (2) indicate that the compressive strength

| Concrete mix | Cement kg/m³ | Fly ash kg/m³ | Fine aggregate kg/m³ | Coarse aggregate kg/m³ | w/c ratio | S.P L/m³ | % of fibers | Slump mm |
|--------------|--------------|---------------|----------------------|------------------------|-----------|----------|------------|---------|
| RF1 (50% fly ash substitution) | 200 | 200 | 840 | 800 | 0.37 | 2.6 | --- | 125 |
| RF1PF0.4 | 200 | 200 | 840 | 800 | 0.37 | 2.8 | 0.4 | 130 |
| RF1PF0.8 | 200 | 200 | 840 | 800 | 0.37 | 3.2 | 0.8 | 125 |
| RF1PF1.2 | 160 | 240 | 840 | 800 | 0.37 | 3.4 | 1.2 | 125 |
| RF2 (60% fly ash substitution) | 160 | 240 | 840 | 800 | 0.37 | 2.4 | --- | 130 |
| RF2PF0.4 | 160 | 240 | 840 | 800 | 0.37 | 2.8 | 0.4 | 135 |
| RF2PF0.8 | 160 | 240 | 840 | 800 | 0.37 | 3 | 0.8 | 130 |
| RF2PF1.2 | 160 | 240 | 840 | 800 | 0.37 | 3.2 | 1.2 | 130 |
| RF2PF1.6 | 160 | 240 | 840 | 800 | 0.37 | 3.4 | 1.6 | 125 |
| RF2PF2 | 160 | 240 | 840 | 800 | 0.37 | 3.6 | 2 | 120 |
increase by 4.9% when fibers added to the RF2 mix by 0.4% by volume. But, when fiber addition increases to 0.8, 1.2, 1.6 and 2% the compressive strength of RF2 mix decreases by 9, 14.1, 21.1, and 23.6%, respectively. This decrease in compressive strength might be due to the formation of voids with the incorporation of those fibers in the mix.

Figure 1. Effect of addition of fibers on the compressive strength of RF1 concrete mix.

Figure 2. Effect of addition of fibers on the compressive strength of RF2 concrete mix.

3.3 Splitting tensile strength
The splitting tensile strength was determined according to ASTM C496-04\cite{15}, using (100 x 200) mm cylinders. The test was conducted with a rate of loading 0.1 N/mm$^2$/sec.

Figure (3) indicates that the addition of 0.4, 0.8 and 1.2% by volume of fibers to mix RF1 causes an increase of splitting tensile strength by 18.2, 29.5 and 40.4% respectively. While figure (4) indicates that the addition of 0.4, 0.8, 1.2, 1.6 and 2% by volume of fibers to mix RF2 cause increase of splitting tensile strength by 9.7, 17.5, 21.6, 11.1 and 5.9%, respectively. This means that the optimum percentage of fiber addition is 1.2% by volume. Zhou et al\cite{10} indicate that the treatment of natural fibers (they used hemp fibers) with calcium chloride solution roughen their surface and increase the bond with the matrix and so increase the tensile strength. Also, the pozzolanic reaction between fly ash and calcium hydroxide used in the fibers treatment might increase this bond strength, and so increase the tensile strength.

It can be seen from the results that introducing a percentage higher than 1.2% in RF2 mix causes a reduction in tensile strength. This might be due to the difficulties in producing a homogeneous and well distributed fibers in the mix when using those higher fiber percentages.

Figure 3. Effect of fibers addition on the splitting tensile strength of RF1 concrete mix.
3.4 Dry density

Dry density test was carried out according to ASTM C 642-13[16]. 100 mm cubes of concrete were prepared to determine the dry density at 28 days age. Table (4) indicates that incorporation of treated palm fronds fibers causes reduction of 28-day dry density of reference mixes (RF1 and RF2). This is because of the low density of incorporated fibers. But this decrease in density of this type of concrete doesn't make as lightweight concrete. Results also indicate that inclusion of 1.6 and 2% by volume of fibers with mix RF2 causes a large reduction in density of 8.3 and 10.5% respectively. This is because of the voids that are formed through inclusion fibers with those percentages in the concrete[17].

Table 2. Effect of palm fronds fibers addition on the dry density of concrete mixes.

| Concrete Mix                  | Dry density, kg/m3 |
|-------------------------------|-------------------|
| RF1                           | 2340              |
| (50% fly ash substitution)    |                   |
| RF1PF0.4                      | 2280              |
| RF1PF0.8                      | 2260              |
| RF1PF1.2                      | 2180              |
| RF2                           | 2290              |
| (60% fly ash substitution)    |                   |
| RF2PF0.4                      | 2260              |
| RF2PF0.8                      | 2235              |
| RF2PF1.2                      | 2120              |
| RF2PF1.6                      | 2100              |
| RF2PF2                        | 2050              |
3.5 Drying shrinkage

Prismatic (25*25*285) mm specimens were used to measure the length change of the hardened concrete. The specimens dimension was adopted according to ASTM C490-05\(^{[18]}\). This test was carried out according to ASTM C157/C157 M-05\(^{[19]}\). The drying shrinkage was measured by using a mechanical strain gauge. Two dermic points were fixed on samples at a standard distance using epoxy. The specimens were moist cured till 28 days age and then left in ambient environment for 90 days.

Figures (5) and (6) indicate that the drying shrinkage for mix RF2 was higher than that for mix RF1. This is may be due to the effectiveness of the Pozzolanic material contained by the fly ash which reacts slowly, causing a reduction in the volume of the reaction and causing increased shrinkage\(^{[20]}\). It is indicated from the test results presented in figure (5) that the addition of treated palm fronds fibers reduced drying shrinkage, at 90 days period of ambient environment exposure, by 13.6, 17.7, and 24.5% when fibers were added by 0.4, 0.8, and 1.2% to mix RF1. While figure (6) shows that this reduction is 8.2, 16.7, 28.1, and 30.1% when fibers are added by 0.4, 0.8, 1.2, 1.6, and 2%, respectively to mix RF2.

4. Conclusions

Based on the results of this study, the following conclusions are drawn:

1. The optimum percentage of palm fronds fibers that can be added to high volume fly ash concrete (with 50 or 60% replacement of cement by fly ash) is 1.2% by volume.
2. The addition of fibers by 0.4, 0.8, and 1.2% by volume to mix RF1, (which incorporated fly ash by 50 percent cement replacement) increased its compressive strength by 7.1, 11.2, and 14.7%, respectively. While the compressive strength increases by 4.9% when fibers are added to RF2 mix (which incorporated fly ash by 60 percent cement replacement) by 0.4% by volume. But, when the addition of fibers increases to 0.8, 1.2, 1.6, and 2% the compressive strength of RF2 mix decreases by 9, 14.1, 21.1, and 23.6%, respectively.
3. The addition of 0.4, 0.8, and 1.2% by volume of fibers to mix RF1 cause an increase of splitting tensile strength by 18.2, 29.5, and 40.4%, respectively. While the addition of 0.4, 0.8, 1.2, 1.6, and 2% by volume of fibers to mix RF2 causes an increase of splitting tensile strength by 9.7, 17.5, 21.6, 11.1, and 5.9%, respectively.
4. Incorporation of palm fronds fibers causes a reduction of 28-day dry density of reference mixes (RF1 and RF2).
5. The addition of palm fronds fibers reduced the drying shrinkage, at 90 days period of ambient environment exposure, by 13.6, 17.7, and 24.5% when fibers were added by 0.4, 0.8, and 1.2% respectively to mix RF1. While this reduction is 8.2, 16.7, 28.1, and 30.1% when fibers were added by 0.4, 0.8, 1.2, 1.6, and 2% to mix RF2.
Figure 5. Effect of fibers addition on the drying shrinkage of RF1 concrete mix.

Figure 6. Effect of fibers addition on the drying shrinkage of RF2 concrete mix.

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