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Effects of Date Palm Fibres on the Properties of Concrete

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Concrete is the most used building material across the world. Even though its production contributes to global warming, it will still be favorable in the construction industry for the next decade. From this perspective, there are many research efforts directed toward exploring more eco-friendly concrete mixes and new reinforcement solutions. This research examines potential use of date palm fibers as a natural reinforcement material for concrete. It investigates rheological, compressive, and flexural properties of fiber reinforced concrete mixes. Results have shown that fiber inclusion of 1 %, increases flexural strength by 11 %, however further increase in fiber content results in noticeable strength reduction.

1. Introduction

Nowadays, there is a huge demand for new construction materials (Oxford Business Group, 2022). The necessity to meet the demand is a crucial strategic goal allowing humanity to improve its well-being. In UAE, lots of efforts for sustainable future development have been made since the country's establishment (Al Sammani, 2011). For instance, Dubai Municipality actively takes the lead in global socio-economic and environmental changes encouraging to minimize air, land, and water pollution and shift to alternative energy usage. The Municipality established in 2016 its unique evaluation system "Al Safat", which implements strict rules for green building construction. "Al Safat" in Arabic means a date palm frond. The word was specifically chosen to draw attention to natural construction material that was readily available and widely used for roofing local houses in the past (Saseendran, 2016). Date palm trees have always played significant role in agricultural sector of Arabic speaking countries, especially in Middle east and North Africa regions. Globally, the trees yield more than 1 Gt of dates in a single year, as well as its by - products such as palm fronds, coir, and leaves (Labib, 2019). This requires developing of waste management practices which contributes to sustainability and economy of the regions by reusing the date palm by - products. Low manufacturing energy cost, as well as lifecycle and palm fibers renewability stimulate researchers to assess its potential industrial use and economic feasibility.

In the recent years multiple studies were conducted on advancements in construction materials for sustainable development that focused on: the reduction of cement in concrete by utilizing supplementary cementing materials and modifications (Klemm and Sikora, 2012) and spatially varying concrete performance (Liu et al., 2018), the reduction of concrete for construction by partial replacement (Richard et al., 2020) and total replacement with engineered natural materials (O'Ceallaigh et al. 2019) Nevertheless, only a few researchers tried to assess the potential of date palm fibers utilization for concrete. The focus was mainly on the effect of fibers inclusion into concrete mixes on workability of concrete mixes. Ismail and Hashim (2008) noted that an addition of date palm fibers significantly reduces the workability of the mix if the fiber length is greater than 5 cm. Shareef and Ramli (2009) concluded that the optimal fiber content in the concrete mix must not exceed 2 % of its volume.

Since a lack of knowledge exists in the area of palm fibers utilization in concrete, this paper assesses their effects on the mechanical characteristics of concrete.

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2. Methodology

2.1 Materials

The concrete mix includes five main ingredients:
- Ordinary Portland cement, grade: 42.5
- Sand (40 % of aggregate volume)
- Coarse aggregates (10 mm and 20 mm in size)
- Water, type: tap water
- Date palm fibers (3 cm in length, Figure 1).

This length of fibers has been chosen to achieve optimal mix consistency.
Palm species: Phoenixdactylifera.
Fibers are extracted from the palm crown. Cleaned up with tap water and dried in natural environment under the sun.

Figure 1: Date palm fibres

Concrete mixes were prepared according to fiber content and divided into 3 categories: with 0 % fibers, which serves as a reference for results comparison, and with 1 %, and 2 % fiber content of cement by mass.
All mixes were placed in beam molds for flexural test (dimensions: 0.1 x 0.1 x 0.4 m^3) and cubic molds for compressive test (0.15 x 0.15 x 0.15 m^3). While placing concrete into the molds it was tampered 25 times with a rod and vibrated for better distribution and compaction of the mix.
When concrete mix sat, it was removed and placed in the water for 28 d curing. To analyze how concrete gains its strength, flexural and compressive tests were performed on days 7, 14, and 28.
Quantities of materials for concrete preparation are presented in Table 1.

Table 1: Quantities of materials for concrete preparation in kg/m^3

Concrete mix M20 – (1:1.5:3)	kg/m^3
Cement (OPC)	1,440
Sand	1,650
Coarse aggregates	1,600
Water	997

2.2. Experimental techniques

The consistency was assessed by conducting a slump test. The procedure includes filling the cone with freshly made concrete up to the top and tampering with each of the three layers 25 times.

The 4-point bending setup was used to record flexural strengths. The rate of loading is 0.03 kN/s. The load acts on a span of 300 mm, width - 100 mm, and height - 100 mm. A compression testing machine was used to obtain compressive strengths. Cubes were subjected to a load rate of 3.00 kN/s on the net area of 22,500 mm^2.

3. Experimental results

3.1 Slump test

Table 2 presents slumps test results. The addition of fibers contributes to the dryness of the mix. Low or almost zero slump occurs.

Table 2: Slump test results

0 % f.c.	1 % f.c.	2 % f.c.
9 cm	4 cm	0 cm

The slump test of concrete mix reinforced with 2 % fiber content is shown in Figure 2.

Figure 2: 0 cm slump (2% f.c.)

3.2 Compressive strength

Tables 3, 4 and 5 summarize mean strengths values for different ages, and Figure 3 presents its development. It was noticed that the compressive strength of 1 % fiber content concrete at 7 d reduces with the addition of palm fibers by 10 %; at 14 d reduces by 17.6 % and at 28 d - by 10 %. The trend and values for 2 % fiber content are similar. Compressive strength of 2 % fiber content concrete at 7 d reduces with the addition of palm fibers by 11 %; at 14 d reduces by 16 % and at 28 d - by 12.6 %. The highest compressive strength results were for concrete samples without any fibers.

Table 3: Compressive test results at 7 d

0 % f.c.	1 % f.c.	2 % f.c.
28.7 MPa	25.9 MPa	25.7 MPa

Table 4: Compressive test results at 14 d

0 % f.c.	1 % f.c.	2 % f.c.
34.6 MPa	28.5 MPa	29.1 MPa

Table 5: Compressive test results at 28 d

0 % f.c.	1 % f.c.	2 % f.c.
36.6 MPa	33.1 MPa	32.0 MPa

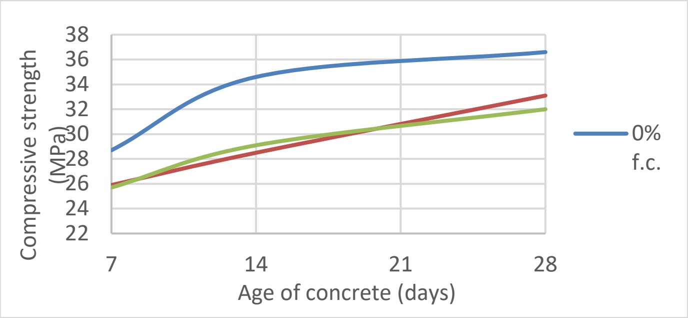

Figure 3: Concrete compressive strength development

3.3 Flexural strength

Tables 6, 7 and 8 summarize flexural strength values and Figure 4 illustrates flexural strength development of concrete.

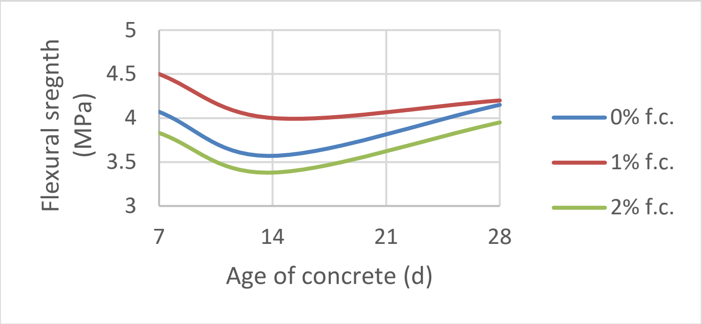

Figure 4: Concrete flexural strength development

Table 6: Flexural test results at 7 d

0 % f.c.	1 % f.c.	2 % f.c.
4.07 MPa	4.50 MPa	3.83 MPa

Table 7: Flexural test results at 14 d

0 % f.c.	1 % f.c.	2 % f.c.
3.57 MPa	4.00 MPa	3.38 MPa

Table 8: Flexural test results at 28 d

0 % f.c.	1 % f.c.	2 % f.c.
4.15 MPa	4.20 MPa	3.95 MPa

4. Discussion

In general, there was no significant strength increase for all three mixes after 7 d, but results differ for various fiber content. It was observed that flexural strength of 1 % fiber content concrete at 7 d increases with the addition of palm fibers by 10.6 %; at 14 d it increases by 11 % and at 28 d increases by 1.2 %. Flexural strength of 2 % fiber content concrete at 7 d decreases with the addition of palm fibers by 6 %; at 14 d decreases by 5 % and at 28 d by 5 %. The highest flexural strength performance was achieved by adding 1 % of fiber content to the concrete mix. It was observed that beams containing 0 % f.c. were broken into two halves while fiber reinforced concrete (FRC) beams presented only a small, tiny crack (see Figure 5). It indicates that addition of date palm fibers provides better bonding to the mix.
The presence of randomly oriented fibers in FRC changes its structural unity. It also affects permeability of concrete mix preventing it from excessive water bleeding. Based on experimental outcomes, short thin date palm fibers increase the degree of crack control but do not substantially increase its strength. This means that they cannot fully substitute traditional moment resisting reinforcement. Having such properties FRC can be used in various construction works, for example, in construction of pavements.

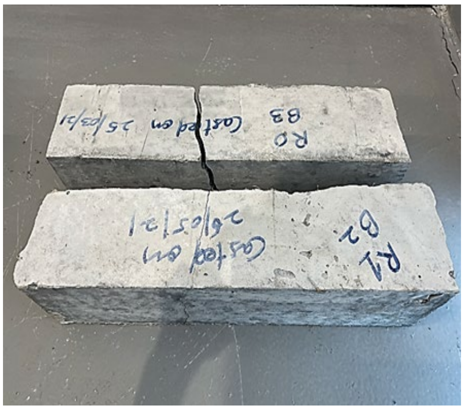

Figure 5: Broken parts of specimens without (top) and with fibers (bottom)

Basically, there are two main aspects that play crucial role when choosing fibers for concrete reinforcement. Those aspects represented by tensile strength and Young' modulus. Date palm fibers display sufficient degree of strength (tensile strength - 300 MPa) and they can be used in combination with other types of reinforcement. There are other natural fibers which can be utilized in cement - base mixes. To illustrate this, Figure 6 provides comparison of tensile strength values of different plant fibers, including palm.

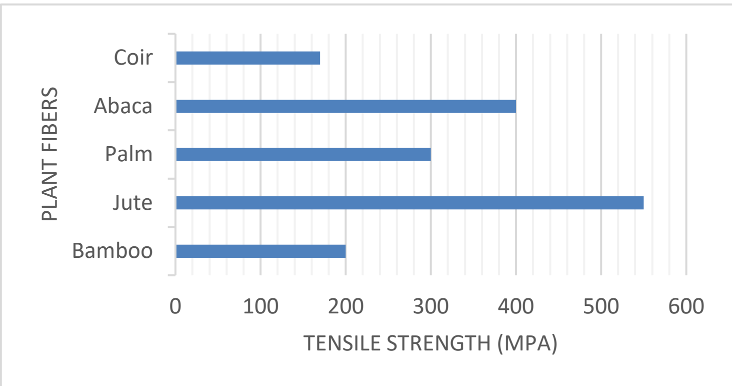

Figure 6: Tensile strength of different plant fibres (Labib, 2019)

5. Conclusion

After investigating the workability and strength of concretes with palm fibers the following can be concluded:

- The addition of fibers contributes to the dryness of the mix. The degree of workability of mixes, containing date palm fibers can be considered as low.

- Addition of fibers reduce compressive strength to similar level regardless of the fibers content. The strength is reduced by 10 % and 12.6 %, at 28 d with 1 % and 2 % fibers content.
- Addition of 1 % of fiber to the concrete mix improves flexural strength. It was observed that the addition of 1 % fibers to the concrete mix increased its flexural strength by 11 %, while 2 % fiber content decreases the strength by 5 % for 14 d mixes.

As can be seen, addition of date palm fibers doesn't provide substantial strength increase, and at this early stage this material cannot be suggested as potential concrete reinforcement. However, due to the limited number of research works on date palm fiber utilization further investigation is required. Considering that cement – base composites will still need synthetic fibers, renewable materials obtained from natural environment can potentially replace them. Recommendations for further research consider new methods of fibers treatment and fiber extraction. Fibers can be extracted from other parts of the palm tree such as leaflets. Properly treated, fibers extracted from the leaflets may have better tensile properties. Percentage of fiber inclusion is another aspect of study. The tendency shows that lesser fiber content (up to 1 %) provides better mix consistency, material bonding, and strength results.

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