Utilisation of date palm fibres in cement-based composites: A feasibility study

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Abstract. The renewed interest in the preservation of non-renewable resources has made the use of plant-based natural fibres as an environmentally friendly replacement to their synthetic counterparts in construction materials a necessity. This is due to the ability of plant-based natural fibres to enhance the mechanical properties of building components, their relatively low cost, and their derivation from a renewable resource. In this paper, the feasibility of using date palm fibres in cement composites as a replacement for synthetic fibres is reported. This study has reported on the production, types, and comparison between the chemical and mechanical properties of date palm fibres and synthetic fibres.

1. Introduction

Three main types of natural fibre are derived and based on different materials, such as animal, mineral, and plant fibres that can be used for cement-based composites [1]. Animal-based fibres constitute proteins, such as wool, silk, and hair fibres. Similarly, fibres derived from minerals comprise wollastonite, palygorskite, and asbestos. Lastly, fibres based on plants include flax, cotton, jute, hemp, sisal, palm, bagasse, ramie, and processed speciality fibres derived from wood.

Date palm fibres are a natural alternative reinforcement that is considered a principal agricultural product in the arid and semi-arid regions of the world, especially the Middle Eastern and North African regions. More than 120 million date palm trees worldwide yield several million tons of dates per year, apart from secondary products including palm midribs, leaves, stems, fronds, and coir. The majority are in the Kingdom of Saudi Arabia (KSA), Egypt, Iraq, Iran, Algeria, Morocco, Tunisia, the United Arab Emirates, Pakistan, India, Australia, and the United States. The KSA is a land famous for date production, and its palm tree is regarded as one of the oldest trees in the world. A recent estimate shows that the kingdom has more than 23 million date palm trees, which produce about 1 million tons of dates per year. Date palm trees produce a huge amount of agricultural waste in the form of dry leaves, stems, pits, seeds, etc. A typical date tree can generate as much as 20 kilograms of dry leaves per annum, as the date pits account for almost 10% of the date fruits [2]. As indicated in [3], the KSA alone generates more than 200,000 tons of date palm biomass each year. Biomass has generally been described as all organic matters or compounds either produced from crops, forestry, or marine life. In addition to the availability of the date palms in the KSA in huge quantities, date palms have the advantage of being considered a renewable natural resource because they can be replaced in a relatively short period [4]. Usually, date palm waste is burned on farms or disposed of in landfills, which causes environmental pollution in date-producing nations, and can cause environmental...
hazards, such as fire, bait for insects, and diseases [2,3,5-7]. Normally, the date palm waste is left outdoors, which could provide a good environment for certain pests, such as rodents and insects.

Therefore, from environmental and economic points of view, this research aims to study the feasibility of using date palm waste for producing a fibre cement-based composite as an alternative to synthetic fibres. The paper compares the chemical and mechanical properties, eco-friendliness, and cost-effectiveness characteristics of date palm natural fibres and polypropylene synthetic fibres.

2. Types of Date Palm Fibres
Most common types of natural-based plant fibres are stem, leave, and seed that is further categorized like seed-fibres, bast-fibres, and leave-fibres [1]. The extraction of the blast-fibre takes place to form the plant stems outer bark. Figure 1 has shown that the tree stem in the date palm is surrounded by the mesh made from single fibre. Generally, the fibre is used for the creation of different diameters from the natural crossed fibres woven mat. Based on the traditional practices, the annual removal of the mat from the trees takes place for the removal of the ropes. The general properties of bast-fibres are represented as the high tensile strength in the bundles made of long fibre.

![Figure 1](image1.png)

Figure 1. (a) tree of date palm (b) Fibres of date palm encircling stems.

3. Fibre Production
The estimated production volumes of the commonly used plant-based on natural fibres have been shown in Figure 2 [8, 9]. Figure 1 has shown that date palm possesses the largest yield of more than 4 million tons per year, followed by Bamboo and Jute fibres that have increased yield every year like the Herrera-Franco and Valadez-González [10] study results. Considering the high production yield of date palm fibres, these serve as enough sources to be utilized in the construction industry.
Date palm is reflected upon as a renewable natural resource, which production can take place in a short-run [11]. The time required for the date palm for bearing fruit varies from four to eight years when it is replaced, whereas the time for the commercial harvesting is said to range from seven to ten years. The presence of 120 million trees of the date palm is expected to increase its fibre production, where the input from the Arab countries is expected to be significant i.e. more than two-thirds (Figure 3) [8]. An average of 20 kilograms of waste can be produced by a date palm tree every year. Generally, the waste of the date palm is either disposed of in the landfills and sometimes by burning into farms, which can lead to detrimental consequences on the bait for insects, fire, and other diseases [12-15]. Therefore, it is recommended to utilize such wastes in producing fibre composite concrete to save the environment from pollution.

It has been reported by a UN organization (i.e. FAO) that majority of these trees exist in Egypt, Iran, Algeria, KSA, Iraq, Morocco, Tunisia, United Arab Emirates, Pakistan, India, Australia, and United States. The reason behind such huge production is the increased positive acceptance of the tree socially, along with the support provisioned at governmental level. This extent of government support is provided to the date palm trees because they produce valuable food for human beings. These trees
are also used as an ornament for the garden and are recognized as well as appreciated for the increased health as well as social benefits to the individual in most individual residential buildings in KSA.

In addition to their environmental advantages, date palm fibres possess the economic advantage, as the cost of raw materials is recognized as the major stimulant affecting the performance of the industry. It is because the industries performance and production capability are heavily dependent on the cost associated with the acquiring of the raw material impacting its cost-benefit plans. The factor that adds value to the goods or company property is the low cost which directs the construction industry for the adaptation of the fibres produced naturally as compared to other synthetic material. The production of huge amounts of date palm waste ensures the availability of date palm fibres at a relatively low cost. Ghosh et al [16] and Lewin [17] stated that the date palm fibres are considered the cheapest among several natural fibre’s types.

The variation in the raw material cost is based on its type; however, the cheapest of the fibres among the various types is date palm fibres. This further draws the attention towards the utilization of the date palm fibres as an alternative for being reinforced in cement based composites. A significant energy quantum is required for the synthetic fibre (also known as polypropylene) production in the manufacturing process to be produced from non-renewable recourses, unlike the production of date palm fibres.

Moreover, it generates pollution and health risk when inhaled as it requires the use of compounds of phenol such as ultraviolet stabilizer (i.e. amines and antioxidants). It acts like flame retardant, which characteristics vary from the sustainable materials [18]. Consequently, the integration of the activities pertaining to the synthetic material recycles and production causes pollution which causes a negative influence on the environment [19]. One of the natural alternative reinforcements to the synthetic complements is date palm waste which can be used for producing fibre cement composites. These composites could provide a good mechanical performance of cement composites.

4. Fibre Chemical Structure and Mechanical Characteristics

Fibre based on natural plant induces in such properties both mechanical as well as a chemical which allows it to be utilized in numerous applications within the building industries using these fibres [20-22]. Table 1 has highlighted the components of plant-based natural fibres including cellulose (glucose units), hemicelluloses (polysaccharides), lignin (aromatic polymers and phenyl propane monomers), extractives, and ash. It clearly shows that major part of the plant fibre is made from hemicellulose, cellulose, and lignin. The plant fibres are collectively termed as lignocellulosic fibres because of the presence of three major organic constitutes [23]. It has been depicted in Table 1 that the three constituents possess different content due to variance in their types. The fibres derived from plant exhibit different mechanical characteristics when used in cement composites, because of their variety in molecular structure and composition.

Table 1. Chemical compositions of the most popular plant-based fibre used in cement composites (adopted from [8, 24-29]).

| Fibre | Cellulose | Hemicellulose | Lignin | Extractives | Ash | Reference |
|-------|-----------|---------------|--------|-------------|-----|-----------|
| Abaca | 62.5      | 21            | 12     | -           | -   | Jawaid & Abdul Khalil [24] |
| Flax  | 72.5      | 14.5          | 2.5    | -           | -   | Jawaid & Abdul Khalil [24] |
| Fiber Type   | Density | Water Absorption | Strength | Modulus | Source                           |
|-------------|---------|------------------|----------|---------|----------------------------------|
| Jute        | 33.4    | 22.7             | 28       | -       | Ramakrishna & Sundararajan, [25] |
| Hemp        | 81      | 20               | 4        | -       | Jawaid & Abdulkhali [24]        |
| Kenaf       | 53.5    | 21               | 17       | -       | Jawaid & Abdulkhali [24]        |
| Ramie       | 72      | 14               | 0.8      | -       | Jawaid & Abdulkhali [24]        |
| Bamboo      | 34.5    | 20.6             | 26       | -       | Jawaid & Abdulkhali [24]        |
| Hibiscus    | 28      | 25               | 22.7     | -       | Ramakrishna & Sundararajan, [25]|
| Banana-trunk| 31.48   | 14.98            | 15.07    | 4.46    | Arsene et al [26]               |
| Banana      | 60-65   | 6-8              | 5-10     | -       | Reddy & Yang, [27]              |
| Sisal       | 38.2    | 26               | 26       | -       | Ramakrishna & Sundararajan, [25]|
| Sisal       | 73.11   | 13.33            | 11       | 1.33    | Arsene et al, [26]              |
| Sisal       | 43-88   | 10-11            | 3/8-9.9  | -       | [Li, 2000; Agopyan & John, [28]|
| Banana      | 25.65   | 17.04            | 24.84    | 9.84    | Reddy & Yang, [27]              |
| Pineapple   | 70-82   | 18               | 5-12     | 0.7-0.9 | Reddy & Yang, [27]              |
| Corn        | 38-40   | 28               | 7-21     | 3.67    | Reddy & Yang, [27]              |
| Date Palm   | 46      | -                | 20       | -       | AL-Oqla & Sapuan [8]            |
Plant-based natural fibre mechanical characteristics are significantly affected due to their chemical composition. The induced cellulose is recognized as the most strengthening and strongest organic compound supplementing the stiffness, strength, and stability in the fibre [30]. The study has demonstrated positive association between the cellulose and the tensile strength, Young’s modulus and specific strength [30]. Whereas, the sturdy shows that there is a correlation between the hemicellulose with the moisture gain, specific strength, and Young’s modulus. The negative correlation is observed between the microfibril angle, tensile strength, density, and natural fibre strain failure. The moisture gain is found to have a sturdy positive correlation with the Lignin. Subsequently, specific strength, the strength of the tensile, density, and specific Young’s modulus has a negative correlation with lignin [30].

The variation in mechanical properties of lignocellulosic fibres is a great challenge for designing of components in a specific industry as the engineers are adapted to the reproducible and precise properties of synthetic fibres. In the hydrophobic polymer matrix, low moisture resistance and incompatibility results from the lignocellulosic fibres hydrophilic nature. As a result of the incompatibility, the deficiency occurs in the fibre interface which mitigates the mechanical characteristics present in the bio composites. It clearly depicts the significance of matrix bonding with fibres essential for improving mechanical strength. The existence of the hydroxyl group induced in hydrophilicity in the fibres which form poor interfacial bonding of hydrophobic polymer matrices with hydrophilic fibres derived naturally.

The content of the three polymers is highly variable between the plant fibres. Figure 3 has shown the content of the three main components in the majority of the common natural fibres. Figure 4 exhibits that cellulose content of date palm fibres is greater than the majority of the common plant-based fibre naturally, including bamboo, hibiscus, sisal, and jute. Therefore, their higher strength of the tensile and Young's modulus is observed, which is considered as an added value for date palm fibres. The natural fibres tensile strength and Young's modulus increase with the increase in cellulose content. The content increase in the cellulose impacts the alignment of fibrils, resulting in a decline of angles of micro-fibril as reported by Li and Ye [31].

![Figure 4](image-url)  
Figure 4. Natural fibre three main components content.

The key mechanical properties for selecting suitable reinforcing fibres in cement composites are two named as tensile strength and Young modulus. Figures 5 and 6 have shown that date palm fibres have an acceptable degree of tensile strength (300 MPa) and Young’s modulus (9 GPa). The date palm derived fibre holds low position based on the Young modulus and strength of the tensile occupy a low position, as compared to other fibre obtained naturally. The date palm fibre strength of tensile (32 MPa) and Young modulus are extremely high as a synthetic counterpart, as compared to polypropylene. This increases its utilization prospects as reinforcement in the cement composites.
The fibre mechanical characteristics are regarded as crucial parameters which improve the capability for selection of the appropriate fibres as reinforcement in cement composite. Ramakrishna and Sundararajan [25] and Reddy and Yang [27] reported that the determination of the concentration and its components is substantially impacted by the fibre type, its growth, position on the plant, age, dimensions, extraction, and ways adopted for its processing. Therefore, there is a difference in the mechanical characteristics of the same type of fibre obtained through various sources. It has been illustrated in Table 2 that the fibres of the date palm comprising of the mechanical properties are acquired through different sources, which lead to different mechanical properties when used in cement-based composites. Similarly, Table 3 has highlighted the most observed mechanical characterizes of the natural fibres derived from the plant which are incorporated in the composites of
the cement, which are then contrasted with the mechanical properties of polypropylene fibres as their synthetic counterpart.

**Table 2.** Date palm fibre mechanical characteristics from different references and polypropylene fibres [14, 32-36].

| Length (mm) | Diameter (µm) | Tensile strength (MPa) | Young modulus (GPa) | Break elongation (%) | Density (g/cm³) | Water absorption (%) | Origin |
|-------------|---------------|------------------------|---------------------|----------------------|-----------------|----------------------|--------|
| 100–1000    | 58–203        | 2-7.5                  | 5-10                | -                    | -               | -                    | Saudi Arabia |
| 100         | -             | 170+40                 | 4.74+2              | 16+3                 | 0.5-1.08        | 97-203               | Algeria   |
| 60          | -             | 240+30                 | 5.00+2              | 12+2                 | 0.5-1.08        | 97-203               | Algeria   |
| 20          | -             | 290+20                 | 5.25+3              | 11+2                 | 0.5-1.08        | 97-203               | Algeria   |
| 20-100-1000 | -             | -                      | 7                   | 2-19                 | 0.9-1.2         | -                    |          |
| 250         | -             | 107.36                 | 2.57                | 4.5                  | 1.08            | 75                   | Algeria   |
| -           | -             | 125-200                | 70                  | -                    | 0.46            | 60-65                | Iraq     |
| -           | -             | 70-170                 | 70-800              | -                    | 0.85-0.01-0.035  | 60-84                |          |
| Polypropylene | 21-40       | 0.5-2.4                | 50-800              | 0.85                 | 0.01-0.035      | 0.95                 |          |
The determination of the adequate fibre for reinforcing in terms of cement composite is significantly dependent on the induced density in the natural fibre. The fibre low level of density emerges because of low composite weight. Elongation at break plays a significant role in selecting suitable reinforcing fibres in cement composites. Figure 7 has shown the highest value (13%) of the elongation is observed at the break in the date palm fibre and it occupies the third highest position after coir (29%), and pineapple (14%), as compared to other plant-based natural fibres. The comparison of it with polypropylene concerning break elongation, it is observed to be low showing value of 410% (Figure 8). However, the moderate value of elongation at break of date palm fibre is considered suitable for application in different industries from the mechanical perspective incorporating the concrete industry.

Table 3. Mechanical properties of most common plant-based natural fibres used in cement composites and polypropylene fibres.

| Fibre source | Tensile strength MPa | Young modulus GPa | Elongation at break % | Density g/cm³ |
|--------------|----------------------|-------------------|-----------------------|--------------|
| Abaca        | 400                  | 12                | 3-10                  | 1.5          |
| Flax         | 345-1035             | 27.6              | 2.7-3.2               | 1.5          |
| Jute         | 393-773              | 26.5              | 1.5-1.8               | 1.3          |
| Hemp         | 690                  | 70                | 1.6                   | 1.48         |
| Kenaf        | 930                  | 53                | 1.6                   | -            |
| Ramie        | 560                  | 24.5              | 2.5                   | 1.5          |
| Bamboo       | 140-230              | 11-17             | -                     | 0.6-1.1      |
| Sisal        | 511-635              | 9.4-22            | 2-2.5                 | 1.5          |
| Pineapple    | 400-627              | 1.44              | 14.5                  | 0.8-1.6      |
| Coir         | 175                  | 4-6               | 30                    | 1.2          |
| Polypropylene| 21-40                | 0.5-2.4           | 50-800                | 0.85-0.95    |
Figure 7. Concrete industry elongation at break comparison of date palm and other natural fibres.

Figure 8 has compared densities of various fibers derived from nature and polypropylene fibres using their average values as depicted in Table 3. The density value of the date palm fibre is found to be lowest amongst palm fibres that make it competitive to produce lightweight composites as compared with polypropylene fibres and other types of natural based fibres (Figure 9). This present study has recommended the utilization of the fibre obtained from the date palm to be used as reinforcement within the concrete industry.

Figure 8. Comparison between densities of natural fibres and polypropylene fibres.
Figure 9. Comparison between elongation at break of different types of natural fibres used in concrete industry and polypropylene synthetic fibres.

5. Conclusions
The focus of the modern world is on the development of materials that are environmentally friendly and renewable. Plant-based fibres have become a common topic for discussion regarding the replacement of their synthetic counterparts. This is due to the ability of these fibres to reduce the weight of a building along with sustaining composite effective mechanical properties and feasible economic advantages. Cement-based composites still extensively use synthetic fibres obtained from non-renewable sources. However, several advantages are achieved with the utilisation of natural fibres.

This study discussed the potential of using date palm fibres to replace polypropylene synthetic fibres. Thus, the study reports different types, production, and chemical and mechanical properties of date palm fibres and polypropylene synthetic fibres. The increased inclination towards using the date palm fibre is due to the economic and environmental advantages providing usable structural properties, low manufacturing energy requirements, derivation from a renewable resource, and ease of disposal upon completion of their lifecycle. The chemical structure of the fibre and its associated characteristics assist in determining its resistance, degradability, and recyclability, which determine how its integration assists in the reinforcement of satisfactory cement composites. In addition, mechanical characteristics allow the assessment of its applications within the building industry. These properties make it a potential competitor for synthetic fibres, particularly polypropylene.

The comparison of the date palm fibre as a natural fibre to polypropylene as a synthetic fibre indicates that strength, eco-friendliness, and cost-effectiveness characteristics are greater in natural fibres. They can be obtained from renewable resources and help to achieve sustainable construction.

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