Effect of Palm Fibers on Asphalt Pavement Properties

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Abstract. The continuous population growth around the world associated with industries development results in considerable amounts of waste materials. Therefore, a series concern has arisen to find environmentally safe treatment for these wastes. This research aims to study the possibility of using palm fibers locally available as waste materials in asphalt pavement industry. In particular, this work investigates the volumetric properties and tensile strength of asphalt mixtures manufactured with palm fibers. Asphalt mixtures were prepared with five contents of palms fibers (0.2, 0.4, 0.6, 0.8, 1.0) % by weight of aggregate passing sieve No. 4 to compare their properties with that of traditional mixtures. Marshall and indirect tensile strength (ITS) test methods were conducted to evaluate the volumetric and mechanical properties of asphalt mixtures. It can be concluded that adding this type of fiber to asphalt mixtures is possible. It was found that adding different contents of palm fiber has generally increased the density, voids filled with asphalt, and tensile strength and decreased the voids in mineral aggregate (VMA) of asphalt mixtures. However, no inflection points can be noticed on the curves of these properties. That might suggest investigating more palm fiber contents to find its optimum.

Keywords: Date palm fiber, fiber modified asphalt, synthetic fibers, natural fibers.

1. Introduction
Asphalt cement modifiers have been used in pavement technology to enhance the performance of flexible pavement. These modifiers have also used to reduce the occurrence of rutting, low temperature cracking, stripping, and fatigue cracking. Fiber is one of the modifiers used for this purpose. It was reported that fiber improved the performance of asphalt pavement mixtures more than other additives [1]. The main function of fibers is to increase the tensile strength and improve the fracture resistance of asphalt mixtures [2,3]. Moreover, it was found that the fibers improved the performance of paving mixtures against the anticipated most important distresses such as permanent deformation, fatigue cracking, and thermal cracking [4]. It was also stated that the investigated fibers can be incorporated in pavement design to reduce the thickness of pavement structures [5].

Using fibers as modifiers it is not a new concept, it has been attracted by many researchers to improve the performance of asphalt pavements. Some researchers used synthetic fibers such as glass fiber, carbon fiber, and polymer fiber. While other researchers used natural fibers such as hemp fiber,
coir fiber, jute fiber, sisal fiber, and flax fibers [6]. In 1984, Button and Hunter tested asphalt mixtures reinforced by synthetic and organic fibers and carried out field trials [7]. They found that a slight overall improvement such as a reduction of mixtures susceptibility to moisture damage. However, some positive effects were attributed to the higher binder content of asphalt mixtures produced with fibers. The observations also indicated that the field sections of asphalt pavement constructed with fibers showed a better resistance to crack propagation and in turn more resistance to fatigue cracking.

Recently, a composition of aramid-polyalphaolefin fibers has gained a significant attention. However, it was initially developed in 1982 as an asphalt modifier to increase the fatigue life of asphalt pavements [8]. It was found that the addition of aramid-polyalphaolefin fibers improved the resistance of asphalt concrete mixtures to low-temperature cracking. An increase of critical strain and flexural strength with a reduction of flexural stiffness modulus at -20ºC was observed throughout the bending beam tests [9]. More investigation of aramid-polyalphaolefin fibers was conducted by Kaloush et al. [10]. They found that mixtures produced with fibers showed better performance than control mixtures based on the optimum content of fiber. Fiber contents affected the final results of dynamic modulus and flexural strength tests.

Moreover, the natural fibers have been used in the production of stone matrix asphalt mixtures. The cellulose oil palm fiber (COPF) was used as one of SMA mixture modifiers. It was found that using this fiber type improved the fatigue cracking resistance of SMA mixtures [11]. Carbon fibers composite materials (CFCM) were reused to prevent the draindown of asphalt binder from the porous hot mixes asphalt (PHMA) at elevated temperatures. In addition to preventing the draindown, it was observed that the fine size of CFCM improved the mechanical properties of PHMA and rutting resistance [12]. It was also found that polypropylene fiber has significantly decreased the permeability and slightly increased the strength of PHMA [13].

Finally, Iraq is well known as one of the main suppliers of date palm in the world. Therefore, there are considerable amounts of cellulose date palm fibers are generating annually as waste materials. Therefore, this study is an effort to explore the possibility of using date palm cellulose fiber as a sustainable modifier in asphalt pavement industry. Pavements during service life will be exposed to different traffic loading and climatic conditions. This exposure requires evaluating the volumetric and tensile strength for each asphalt mixture used in construction which becomes increasingly more important. Loading incorporating environmental conditions results in a progress of tensile stresses within the asphalt pavement resulting in different types of cracking. In particular, if volumetric and tensile properties could not meet the target design. Therefore, this study aims to evaluate these properties of asphalt mixtures before and after adding the waste palm fiber. This evaluation will help to give an indication about the possibility of using the palm fiber in asphalt pavement construction.

2. Material Characterization

In this study, the investigated materials of this study are locally available and currently used in road construction in Iraq while cellulose date palm fiber is locally available as waste materials.

2.1 Asphalt Cement

One penetration grade bitumen, 40-50 pen was used in this work from Daurah refinery. It was used at different contents (4.3, 4.6, 4.9, 5.2, and 5.5) % by the weight of total mix. The physical properties are presented in table 1.

2.2 Aggregate

The aggregate characteristics are one of the major factors to design high quality paving mixtures used in asphalt pavement industry [14]. It forms about 80% of the volume of asphalt pavements and almost 95% of their weight [15]. In this research, crushed quartz aggregate from Al-Nibaay quarry with a top size of 19 mm was used according to the State Corporation of Roads and Bridges, SCRB [16]. The specification limits and selected gradation of manufactured asphalt mixtures are presented in figure 1 and table 2 respectively.
Table 1. Properties of asphalt cement.

| Asphalt properties                                      | ASTM designation | Test Result | SCRIB Specification [16] |
|--------------------------------------------------------|------------------|-------------|---------------------------|
| Penetration at 25°C, 100gm,5sec., (1mm)               | "D5"             | 41          | 40-50                     |
| Softening point (°C)                                  | "D30"            | 50          | -------                   |
| Ductility at 25°C, 5cm/min, (cm)                      | "D113"           | >100        | >100                      |
| Flash Point (°C)                                      | "D92"            | 288         | Min.232                   |
| Specific Gravity                                      | "D70"            | 1.042       | ----                      |
| Residue from thin film oven test                      |                  |             |                           |
| Retained Penetration % of original                    | "D1754"          | 59          | 55+                       |
| Ductility at 25°C, 5 cm/min(cm)                       | “D113”           | 81          | 25+                       |

Figure 1. Aggregate gradation curve.

2.3 Mineral Filler
The hydrated lime was used as a mineral filler. The properties are shown in table 3.

2.4 Cellulose Date Palm Fibers
The date palm fronds were collected from some plantations in Baghdad. The collected fronds were dried and cut manually into small pieces with a thickness of 3 mm and a length of 2.5 cm. From the sieve analysis, it was found that fibers passed from sieve No. 4 (4.75 mm) and retained on sieve No. 8 (2.36 mm). Therefore, it was classified and added to the designed asphalt mixture in terms of passing No. 4.
Moreover, the chemical composition of the date palm fronds is presented in table 4. figure 2 also presents a sample of date palm fronds fibers.
Table 2. Aggregate physical properties.

| No. | "Lab. Test" | ASTM Designation | Result | Specification |
|-----|-------------|------------------|--------|---------------|
| 1   | Apparent specific gravity | "C127" | 2.672 | ------ |
| 2   | "Bulk specific gravity" | "C127" | 2.631 | ------ |
| 3   | "Water Absorption%" | "C127" | 0.483 | ------ |
| 4   | "percent wear by (Los Angeles Abrasion %)" | "C131" | 20.2 | 35-45 Max. |
| 5   | "Soundness Loss by sodium sulfate solution%" | "C88" | 3.11  | 10-20 Max. |
| 6   | "Fractured Pieces%" | "D4791" | 95%  | 95 min. |

"Coarse Aggregate"

"Fine Aggregate"

| No. | "Lab. Test" | ASTM Designation | Result | Specification |
|-----|-------------|------------------|--------|---------------|
| 1   | Apparent specific gravity | "C128" | 2.68  | ------ |
| 2   | "Bulk specific gravity" | "C128" | 2.626 | ------ |
| 3   | "Water Absorption%" | "C128" | 0.726 | ------ |
| 4   | "Sand equivalent, %" | "D2419" | 55 | 45 Min. |

Table 3. Mineral filler properties.

| Test Property | Result |
|---------------|--------|
| Specific gravity | 2.41 |
| Present of passing from sieve No. 200 | 100% |

Table 4. Chemical composition of date palm fronds.

| Component | % |
|-----------|---|
| Cellulose | 43 |
| Hemicelluloses | 25 |
| Lignin | 30 |
| Ash | 2 |

Figure 2. Date palm fronds fibers.
3. Testing Method
In this work, the following tests were performed on the prepared laboratory specimens:
- Resistance to plastic flow (Marshall Method, ASTM D 1559).
- Standard test method for the percent of air voids in compacted dense graded mixtures, ASTM D 2041.
- Indirect tensile strength, ASTM D 4123.

4. Test Results

4-1 Resistance to plastic flow
Marshall Methodology for mix design was used as an indicator of resistance to plastic flow. Stability and flow were tested for prepared specimens using ASTM D 1559 after calculating their air voids and other volumetric properties. The results are presented in Figure 3 to find the optimum asphalt content. By using at least three properties. It was found that the optimum asphalt content (OAC) was 5.0%.

Table 5 shows the asphalt mixtures properties at this optimum which meet the SCRB, R/9 2003 [16].

![Figure 3. Marshall properties for investigated asphalt mixtures.](image-url)
Table 5. The properties of asphalt mixture at the OAC with the standard values.

| Marshall property | result | Specification requirements, SCR, [16] |
|-------------------|--------|----------------------------------------|
| Stability, kN     | 10.3   | 8 min.                                 |
| Flow, mm          | 3.50   | 2-4                                    |
| Percent air voids | 4.40   | 3-5                                    |
| Percent VMA       | 18.3   | 14 min.                                |

4.2 Effects of date palm fiber on Marshall volumetric properties

The results of the palm fiber contents influence on volumetric properties are presented in Figure 4-7. It is obviously that adding different contents of palm fiber has generally increased the density, voids filled with asphalt, and it has rationally reduced the air voids and voids in mineral aggregate of asphalt mixtures. However, no inflection point can be seen on the curves of these evaluated properties. That might suggest increasing the investigated palm fiber contents to find its optimum. The increased density of investigated mixtures shown in Figure 4 might be attributed to an increase in their cohesion due to the increase of fiber contents from 0.2 to 1.0%. On the other hand, these contents of palm fiber have rationally reduced the air voids to the half as presented in Figure 5. Adding palm fiber to more than 0.8% might be a possible reason of bleeding because the air voids decreased to less than 3% (The minimum standard value as shown in Table 5). In addition, it can also be noticed from Figures 6 and 7 that the reduction of VMA values and the increased values of VFA are generally still within their standard values, 14 min for VMA and 70-85% for VFA.

![Figure 4](image1.png)

Figure 4. Influence of date palm fiber contents on the density of asphalt mixtures.

![Figure 5](image2.png)

Figure 5. Influence of date palm fiber contents on the air voids of asphalt mixtures.
Figure 6. Influence of date palm fiber contents on the voids in mineral aggregate (VMA) of asphalt mixtures.

Figure 7. Influence of date palm fiber contents on the voids filled with asphalt (VFA) of asphalt mixtures.

4-3 Indirect tensile strength test results
Asphalt mixture specimens were prepared by Marshall mix design method with five contents of palms fibers (0.2, 0.4, 0.6, 0.8, and 1.0) by the weight of aggregate passing sieve No. 4. ASTM D 4123 was applied to these specimens to find the indirect tensile strength (ITS). After extracting the specimens from their molds, these specimens were left to cool at the room temperature for 24 h. Then immersed in a water bath at 25°C for 30 minutes before testing. The specimens tested by Versa-Tester using a 1/2 inch-wide curved, loading strip on the top and the bottom of the specimen parallel to the axis which are diametrically loaded at a constant rate of 2 inch/minute. Three specimens for every mix were tested using the compression machine shown in Figure 8. The ultimate loading resistance was reported and the ITS was calculated using Equation 1. The results of ITS versus different palm fiber contents was presented in Figure 9.

\[
\text{ITS} = \frac{2 \text{Pult}}{\pi \text{t} \text{D}} \tag{1}
\]

Where:
\( \text{Pult} \) = Ultimate load up to failure (N).
\( \text{t} \) = Thickness of specimen (mm), and
\( \text{D} \) = Diameter of specimen(mm).

The results indicated that adding the date palm fiber to asphalt mixtures improved their tensile strength in comparison with the control mixture (zero fiber content). The strength gradually increases with
fiber increase as shown in Figure 9. This might be related to the role of palm fiber in improving the tensile properties of asphalt mixtures. It is well known that this type of fiber has good tensile properties.

![Indirect tensile test by using a compression machine.](image)

**Figure 8.** Indirect tensile test by using a compression machine.

![Influence of date palm fiber contents on the indirect tensile strength (ITS) of asphalt mixtures.](image)

**Figure 9.** Influence of date palm fiber contents on the indirect tensile strength (ITS) of asphalt mixtures.

5. **Conclusions**

According to the findings of this study, the main conclusions that can be drawn as following:

- The addition of different percentages of date palm fiber has affected the tensile and volumetric properties of asphalt mixtures.
- The density and VFA of asphalt mixture increased while the VMA decreased with increasing the percentage of date palm fiber content. However, no inflection point can be noticed on the curves of these properties. That might suggest to investigate more palm fiber contents to find its optimum.
- Increasing the percentage of date palm fiber has rationally reduced the air voids to the half. Adding palm fiber to more than 0.8 % might be a possible reason of asphalt binder bleeding because the air voids decreased to less than the minimum standard value (3%).
- In addition, it was also observed that the reduced values of VMA (18.4 to 16.6) % and the increased values of VFA (76 to 86) % are generally still within their standard values, 14 min for VMA and 70-85 % for VFA.
• The indirect tensile strength of the asphalt mix has gradually improved up to 40% with increasing the date palm fiber content from 0 to 1.0%. That might improve the cracking resistance of asphalt mixtures.

6. Recommendations

Based on these conclusions, it would be tentatively suggested to use this type of fiber as a sustainable material in asphalt mixtures production. However, this work needs further investigation. It would be great to examine the influence of palm fiber on fatigue cracking resistance, rutting, and moisture induced damage of asphalt mixtures.

REFERENCES

[1] Brown E R and Mallick R B 1994 Stone matrix asphalt- properties related to mixture design No. NCAT 94-2 National Center for Asphalt Technology

[2] Mahrez A, Karim M and Katman H 2003 Prospect of using glass fiber reinforced bituminous mixes Journal of the Eastern Asia Society for Transportation Studies 5 pp 794-807

[3] Moghadas Nejad F, Vadood M and Baeetabar S. 2014 Investigating the mechanical properties of carbon fibre-reinforced asphalt concrete Road materials and pavement design 15 (2) pp 465-475

[4] Kaloush K E, Biligiri K P, Zeiada W A, Rodezno M C and Reed J X 2010 Evaluation of fiber-reinforced asphalt mixtures using advanced material characterization tests. Journal of Testing and Evaluation 38 (4) pp 400-411

[5] Singh R R and Mittal E S 2014 Improvement of local subgrade soil for road construction by the use of coconut coir fiber Int. J. of Research in Engineering and Technology 3 (5) pp 707-711

[6] Abiola O S, Kupolati W K, Sadiku E R and Ndambuki J M 2014 Utilisation of natural fibre as modifier in bituminous mixes: A review Construction and Building Materials 54 pp 305-312

[7] Button J W and Hunter T G 1984 Synthetic fibers in asphalt paving mixtures Federal Highway Administration Report FHWA/TX-85/73+319-1F

[8] Sturtevant J 2012 Forta-fi- fibre reinforcement for asphalt NW Pavement Management Conference p 44

[9] Jaskula P, Stienss M and Szydlowski C 2017 Effect of polymer fibres reinforcement on selected properties of asphalt mixtures Procedia Engineering 172 pp 441-448

[10] Muniandy R and Huat B 2006 Laboratory diametral fatigue performance of stone matrix asphalt with cellulose oil palm fiber. American Journal of Applied Sciences 3 (9) 2005-2010

[11] Zhang K, Lim J, Nassiri S, Englund K and Li H 2019 Reuse of carbon fiber composite materials in porous hot mix asphalt to enhance strength and durability Case Studies in Construction Materials 11 e00260

[12] Al-Kaissi Z A and Mashkoor O G 2016 Durability of porous asphalt pavement Journal of Engineering and Sustainable Development 20 (4) pp 53-70

[13] Taih S A 2011 The effect of additives in hot asphalt mixtures. Journal of Engineering and Sustainable Development 15 (3) pp 132-151

[14] Witczak M W, Kaloush K, Pellinen T, El-Basyouny M and Von Quintus H 2000 Simple performance test for superpave mix design NCHRP Report 465 National Re-search Council Transportation Research Board Washington DC

[15] SCRB/R9 2003 General specification for roads and bridges section R/9 Hot-mix asphalt concrete pavement revised edition State Corporation of Roads and Bridges Ministry of Housing and Construction Republic of Iraq
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