Research Article

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Using papyrus fiber ash as a sustainable filler modifier in preparing low moisture sensitivity HMA mixtures

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Abstract: In this study, a sustainable filler made from papyrus fiber ash (PFA) is used as a partial cement replacement in hot mix asphalt mixtures (HMA). The replacement levels used are 0, 5, 10, and 15% by weight of ordinary Portland cement. The hot mix asphalt samples were subjected to Marshal volumetric properties (stability, flow, and air voids) and service tests (tensile strength ratio test and immersion compression test) to predict the influence of the used filler modifier on the moisture sensitivity of blended HMA. Best results have been achieved by using 10% of PFA, whereas all the prepared samples with the mentioned percentage of the filler modifier showed a lower sensitivity to moisture in comparison with the control samples, which contained 0% of PFA. The used technique proved to be very efficient in keeping the pavement safe from deformation caused by moisture. At the same time, using sustainable filler materials proved to be an environmentally eco-friendly method.

Keywords: sustainable filler, moisture sensitivity, modified filler, papyrus fiber ash

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1 Introduction

Flexible pavement represents the most popular type of pavement since it is highly durable, resistant to water damage at some levels, and has very low flexural strength. The rising volume of traffic is causing continuous damage to the road pavement. Therefore, pavements need to be modified to resist such loading conditions and to provide a smooth, high-quality surface that is cost-effective and has a long service life [1].

Papyrus is a thick, paper-like material that was employed as a writing surface in ancient times. It was produced from the papyrus plant's pith and used by the ancient Egyptians to make reed boats, mats, rope, sandals, and baskets, in addition to being used as a writing material [2].

Water can penetrate the flexible pavement from its surface, causing different types of failure. Therefore, a strengthening process must be carried out by using different types of additives, such as the ash of papyrus fibers, to increase the resistance of the pavement to moisture effects and make it more durable [3].

The main parameter controlling the performance of the pavement is its ability to prevent water from remaining underneath its layers. Moisture damage in the flexible pavement is mainly caused by a chemical reaction inside the pavement between aggregate, asphalt binder, and water. As a result of the chemical reaction caused by moisture, the adhesive power between the aggregate and the asphalt binder has decreased, as has the cohesive power of the binder. In addition, the rising dynamic loading of traffic under water saturation conditions can create a pore water pressure that leads to pavement moisture failure [4].

Modification processes of asphalt binder lead to a long life for pavement depending on the type of fillers such as cement, lime, quarry dust, *etc*., and its percentage. Papyrus fiber ash (PFA) can be used as a filler modifier since it is generally inexpensive when compared to others and has a unique composition that enables the pavement to resist moisture failure by increasing its durability [5].

Moisture damage in the flexible pavement can lead to permanent deformation, cracking, reduction in the load-carrying capacity of pavements, and excessive settlement. As a result, moisture damage represents the condition of the pavement following the occurrence of several distresses, which may occur concurrently or individually [6].

As a result, the adhesion and cohesion powers inside the pavement are naturally weakened by time or as an effect caused by moisture. Effectively, the chemical composition and surface tension of the filler, aggregate, and asphalt binder are the main factors that affect the adhesion and cohesion powers of flexible pavement [6].

In the case of water entrapment inside the voids of flexible pavement, it can cause high internal pressure and stresses, which can be called pore water pressure. That kind of pressure leads to fracture of the binder film around the particles of filler and aggregate. High pressure from traffic loading can accelerate the diffusion process of water in the layers of pavement [7].

Ali Adili *et al.* [2] have examined the use of papyrus fibers in soil stabilization and proved that using such an additive has improved the failure deviator stress and shear stress of soil.

Abdulhussein *et al.* [8] investigated the effects of adding papyrus fibers on the physical characteristics of concrete, whereas the compressive strength and split tensile strength of concrete have both increased as a result of this technique.

In this study, PFA has been used as a filler modifier in a hot mixed asphalt mixture (HMA) to produce an efficient, flexible pavement with the aid of resistance to moisture damage.

2 Experimental work

Certain factors were selected to evaluate the moisture sensitivity of various HMA mixtures, such as the type and content of the filler modifier, aggregate gradation, and the type of asphalt.

2.1 Materials

2.1.1 Asphalt cement (bitumen)

A type of asphalt cement was used with 40–50 penetration grade brought from Al-Nassiriya refineries. Table 1 shows the physical characteristics and tests of the asphalt cement.

2.1.2 Aggregate

The used course aggregate was crushed stones brought from Al-Najaf quarry, which is widely utilized in the south and middle parts of Iraq in asphalt paving projects. The aggregate particles are generally off-white with sharp surfaces.

Fine aggregate was also brought from Al-Najaf quarry. The combined aggregate was sieved and recombined in proper proportions to meet the Iraqi specifications of SCRB, R/9 for the base course.

Table 2 presents the physical properties of the selected coarse and fine aggregate, whereas the selected gradation for the base course is presented in Table 3. The results of the tests indicated that the selected aggregates met the Iraqi specifications (SCRB, R/9).

Aggregate gradation for the base course was chosen in this study since the mentioned layer is very important in distributing the loads from the upper layers to the underneath ones and also shapes the hard structural support for the pavement surface layer. Thus, such a layer should be modified to endure the loading conditions.

Table 1: Physical properties and tests of asphalt cement

Test	Unit	Result	SCRB specification
Penetration (25 C, 100 g, 5 s) ASTM Ds	1/10 mm	46	40–50
Kinematic viscosity at 135°C ASTM D2170	CST	370	
Ductility (25°C, 5 cm/mm) ASTM D113	cm	110	>100
Flash point (Cleveland open-cup) ASTM D92	°C	268	Min. 232
Specific gravity at 25°C ASTM D70		1.04	1.01–1.05

Table 2: Physical properties of the aggregate

Property	ASTM designation	Coarse aggregate	Fine aggregate
Apparent specific gravity	C-127 C-128	2.65	2.54
Bulk specific gravity	C-127 C-128	2.36	2.35
Angularity	D 5821	95%	—
% Wear (Los Angeles)	C-131	25% Max 35%	—
% Water absorption	C127 C-128	1.42	2.8

Table 3: Asphalt mixture grading

Sieve size (inch)	Sieve size (mm)	Base course	
		Sp. limits	Gradation
1 1/2	37.5	100	100
1	25.0	90–100	97
3/4	19.0	76–90	86
1/2	12.5	56–80	71
3/8	9.5	48–74	61
No. 4	4.75	29–59	44
No. 8	2.36	19–45	36
No. 50	0.3	5–17	12
No. 200	0.075	2–8	6

2.1.3 Mineral filler

Ordinary Portland cement was utilized as mineral fillers with the aid of its physical properties as shown in Table 4.

Table 4: Filler's physical properties

Property	Test result
Fineness (cm^2/g)	3,045
Specific gravity ($g/cm^{2)}$)	3.15
% Passing sieve No. 200	95

2.1.4 Filler modifier

The papyrus was collected from the southern marshes of Iraq to prepare the PFA. It is usually pretreated for extracting the required fiber ash as follows:

- Burning it in the air to reduce its size at a temperature of 100°C.
- Grinding the burned papyrus using the lab grinder (Los Angeles abrasion machine), then passing it through sieve number 200.
- Heating the filler which passed through sieve number 200 in a special oven at a temperature from 350 to 450°C to produce the requested ashes as shown in Figure 1.

2.2 Lab tests

2.2.1 Immersion compression test

The test procedure is conducted according to AASHTO T167 to predict the loss of strength due to the effect of water on compacted hot asphalt mixtures. The index of retained strength (IRS) is determined by comparing the compressive strength of new compacted specimens with the compressive strength of replicated specimens immersed in water under specific conditions [9]. The compression apparatus is shown in Figure 2.

2.2.2 Tensile strength ratio (TSR)

The used technique for the indirect tensile strength (AASHTO T 283) (TSR) test is by preparing two groups of asphalt samples. The first group is freeze–thaw conditioned samples and the second group is unconditioned samples at 60°C. By dividing the calculated tensile strength of the conditioned samples by the tensile strength of the unconditioned asphalt samples we get the percentage of TSR; higher values of TSR lead to the production of

Figure 1: Production stages of PFA.

Figure 2: The setup of compression apparatus.

Figure 3: The setup of indirect tensile strength apparatus.

hot asphalt mixtures with high resistance to moisture damage [9]. The maximum load was recorded using the following formula for calculating the tensile strength:

$$S_t = \frac{2,000 \times P}{\pi \times t \times D}, \quad (1)$$

where S_t is the indirect tensile strength (kPa), P the maximum load (N), t the specimen thickness (mm), and D the specimen diameter (mm).

After conducting the indirect tensile strength for both conditioned and unconditioned samples, the ratio of TSR is calculated as follows:

$$\text{TSR} = \frac{S_2}{S_1}, \quad (2)$$

where TSR is the tensile strength ratio, S_2 the average indirect tensile strength of conditioned samples, and S_1 the average indirect tensile strength of unconditioned samples.

The indirect tensile strength apparatus and the tested specimens are shown in Figure 3.

3 Results and discussions

The volumetric properties for the prepared asphalt samples are shown in Table 5.

The levels of stability, flow, stiffness, density, and air voids for all the prepared samples are demonstrated in Figure 4.

The physical properties of the generated mixtures which contain PFA as partial filler replacement is discussed below.

Stability levels increase as the PFA content in the mix increases, especially at 10%, then it starts to decrease gradually when PFA content reaches 15%. The reasons for such an increase owing to enhancing the friction forces between aggregate particles and achieving the best particle interlock [10]. The stability level starts to drop at 15% of PFA because the mixture has reached a critical point, whereas the combined filler at a high level of PFA tends to absorb more asphalt binder in comparison with the control mixture [11]. Therefore, friction power between aggregate particles starts to decrease, leading to a gradual decrease in the level of stability.

Table 5: Marshall volumetric properties (ASTM D6927-06)

(PFA)% in HMA mixtures	Stability (kN)	Flow (mm)	Stiffness (kN/mm)	Bulk density (g/cm^3)	Air void (%)
	Min. 8 kN	2–4 mm	–	–	3–5
0	6.7	2.7	2.48	2.320	4.2
5	8.5	3.1	2.74	2.311	3.7
10	10.6	2.9	3.66	2.297	4.1
15	7.8	3.2	2.44	2.225	4.5

The air content in the generated mixtures tends to have a stable level in comparison with the control mixture, although it begins to increase slightly at 15% of PFA owing to the absorption process of asphalt binder by the combined filler at a high percentage of PFA [11].

Flow levels increase as the PFA content in the mix increases due to the increased air content in the modified mixtures in comparison with the control mixture.

All the modified asphalt mixtures have the most satisfying Marshall properties, and all the levels are within the Iraqi specifications (SCRB, R/9). The optimum percentage of adding PFA as a replacement to Portland cement is 10%. The best physical properties (stability, flow, and air voids) and service tests (TSR and IRS) of the generated mixtures are achieved at 10% of PFA (Figure 5).

The results of the moisture sensitivity tests are tabulated in Table 6. The levels of the TSR test and the IRS are demonstrated in Figures 6 and 7.

The following points were concluded depending on the analysis process of the results:

- Using 10% of PFA as a replacement for Portland cement within asphalt mixtures, proved to be the optimum percentage of filler modifier due to its effect in enhancing the volumetric properties and moisture sensitivity of asphalt.
- Using PFA as a replacement for Portland cement within asphalt mixtures has increased the values of TSR and IRS

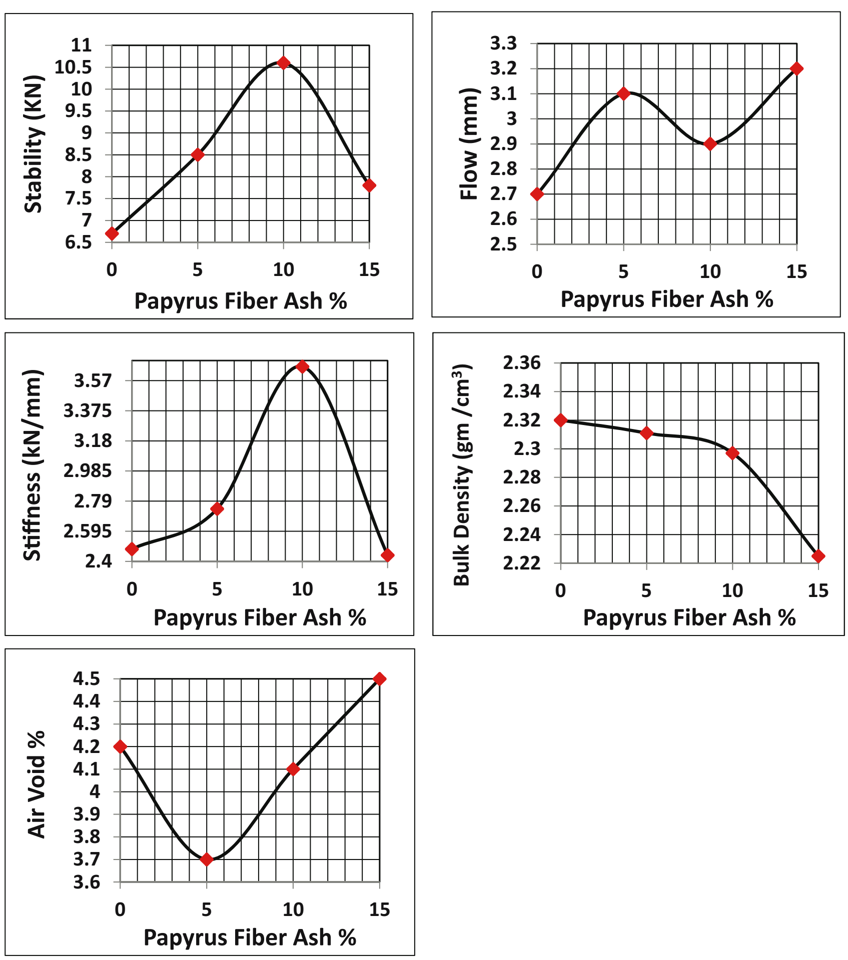

Figure 4: Curves represent the Marshall volumetric properties.

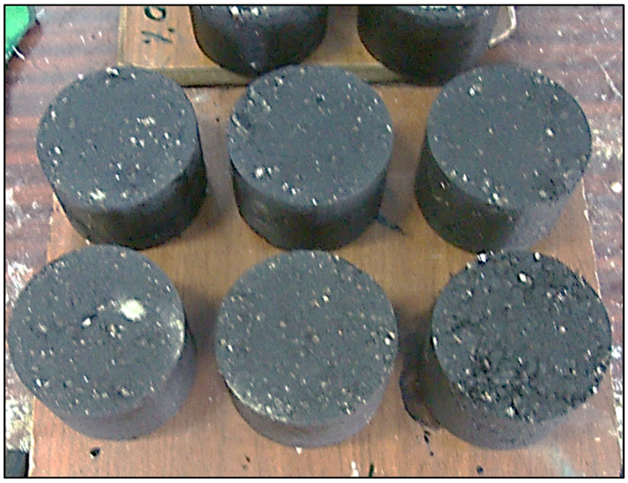

Figure 5: Photo represents the generated asphalt samples.

Table 6: The results of TSR and IRS tests

(PFA)% in HMA mixtures	TSR (%)	IRS (%)
0	68	66
5	76	71.3
10	84	73
15	82.5	69.6

regularly, and this leads to enhancing the characteristics of the mix against moisture effects. The enhancement of the asphalt mixtures in mechanical and service levels is applied due to the eventual reaction between the asphalt cement and the added filler modifier. Consequently, as a result of that reaction, the bond between the asphalt cement and the coated aggregate becomes relatively stronger [12].

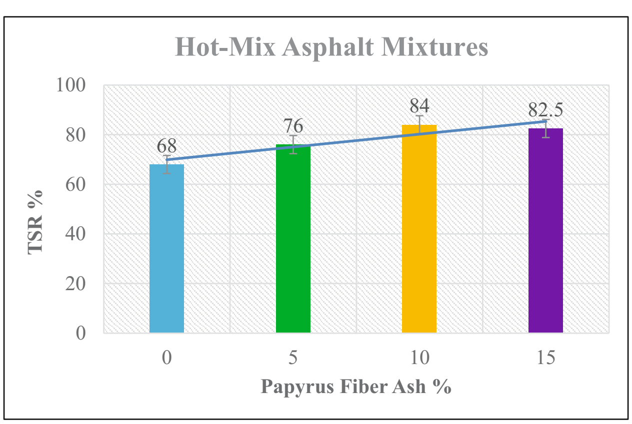

Figure 6: Graph represents the results of the TSR test.

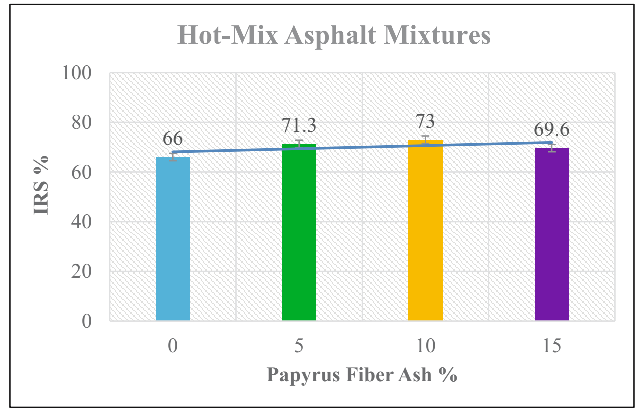

Figure 7: Graph represents the results of the IRS test.

4 Conclusions

1. The modified HMA samples have the highest TSR and IRS values in comparison with control specimens.
2. The estimated cost of the pavement which has been modified with PFA was lower than the cost of conventional pavement, owing to the reduction in the quantity of the virgin materials which are used in preparing the asphalt mixtures, and taking into consideration the cost of maintenance every 5–6 years of the service life of the pavement.
3. Using the PFA as a filler modifier in HMA mixtures is highly recommended because it can reduce the failure of the pavement due to cracking or rutting caused by heavy traffic loads.
4. The use of sustainable materials as a modifier in HMA mixtures, such as PFA, can provide an economical, cost-effective, environmentally friendly, and mechanical aspect.

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