Engineering and Technology Journal 40 (11) (2022) 1365-1375

Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

Modifying the Properties of Open-Graded Friction Course by Adding Cellulose Fiber

Ahmed J. Muhammed*, Zaynab I. Qasim, Rasha H. Al-Rubaee

Civil Engineering Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: bce.19.79@grad.uotechnology.edu.iq

HIGHLIGHTS

- This paper aimed to enhance the properties of open-graded friction course mixtures.
- It investigates the effect of Cellulose Fiber as a modifier.
- A crushed aggregate of (19 mm MAS) gradation and (40-50) asphalt grade are used, and three percentages of Cellulose Fiber.
- Marshall Stability and flow, indirect tensile strength, and moisture susceptibility were evaluated.
- Cellulose Fiber indicated that mixtures' properties were improved. 6% was the optimum percentage of cellulose fiber that gave the best results.

ARTICLE INFO

Handling editor: Mahmoud S. Al-Khafaji

Keywords:
Modified Asphalt; Open-Graded Asphalt Mixture; Marshall Stability; Permeability; Cellulose Fiber.

ABSTRACT

In recent years, Open Graded Friction Course OGFC is becoming more common in some countries. It is applied to improve surface frictional resistance, minimize hydroplaning, reduce water spray, improve night visibility, and lower pavement noise levels. These functions are carried out primarily by removing water from the pavement surface during a period of rain. Also, it has many disadvantages which as poor resistance to permanent deformation, low fatigue strength, high stripping, and moisture susceptibility. The paper aims to investigate the probability of using Cellulose Fiber (CF) as a modifier to improve the properties of OGFC asphalt mixture. In this research, one type of asphalt grade (40-50) and one gradation (19 mm Maximum Aggregate Size MAS) were used. Three percentages of CF (2%, 4%, and 6%) were added to asphalt cement to obtain the modified mixtures. Optimum asphalt content was selected by evaluating the following criteria: air voids content, asphalt drain down, abrasion resistance, and permeability. Several laboratory tests such as Indirect Tensile Strength (ITS), moisture susceptibility, Marshall stability, and flow were evaluated for modified samples, and their results were compared to the original open-graded asphalt mixture. The outcomes indicated that cellulose fiber greatly enhanced the mechanical properties of OGFC mixtures, increasing moisture damage resistance by 19.4%. Furthermore, Marshall stability improved by 38.92 % as the abrasion loss is decreased by 15.85% with adding of CF for aged samples.

1. Introduction

A thin permeable layer of asphalt with a skeleton of homogenous aggregate size and a minimal fine value is known as the Open-Graded Friction Course (OGFC). A limited percentage of fine aggregate is used in these mixes, resulting in a significant number of air voids [1,2]. The OG pavement layer is mostly composed of a single coarse aggregate with a high amount of asphalt. The stone carries the weight, while the asphalt binds everything together. The main purpose of these mixtures is the rapid drainage of rainwater. Porous asphalt is designed to generate a surface with a porosity not less than 18 percent after laying and compaction [2,3,4].

Also, Porous asphalt is utilized for various objectives on roads, including management of stormwater and expressway wearing courses [5]. The whole pavement layer comprises porous asphalt put on top of an OG aggregate base course that works as a reservoir for stormwater before it infiltrates into the underlying soil when utilized for stormwater management. The amount of stormwater runoff is greatly decreased in these applications due to infiltration, and the porous pavement structure works as a filter during the process [6,7]. The porous asphalt consists almost of 85% coarse aggregate by weight, and the voids between them result in an open and hollow structure that increases the surface's ability to allow water to flow vertically or horizontally [8]. The interconnected air voids allow free water drainage through the mix so that traffic can minimize the water spray caused

http://doi.org/10.30684/etj.v40i11.1181
Received 30 March 2022; Accepted 07 July 2022; Available online 25 July 2022
2412-0758/University of Technology-Iraq, Baghdad, Iraq

by traffic. Also, provide a high level of skid resistance and reduce the reflection of light during wet and dark operation conditions. Because the surface texture is composed of many blown holes, it gives an even riding surface that produces less tire noise [9].

The load-carrying in open-graded depends mainly on interlocking and friction of aggregate. The traffic stress imposed on the surface is distributed by stone-to-stone contact, friction, and interlocking between the aggregate. Open-graded is featured by having a relatively high air void, and this matter increases from the surface area of texture so that asphalt material will be exposed to environmental elements such as oxidation and volatilization. These reactions cause gradual and permanent hardening and considerable loss of plastic characteristics of the material [10,11,12].

As mentioned previously, a naturally porous asphalt mixture has a small amount of fine aggregate, few fillers, and a relatively high percentage of asphalt compared with other types of mixtures. These factors will not give sufficient stability to the mixture [13,14]. Also, low filler leads to the asphalt binder draining from porous asphalt mix during transportation and construction procedures. As known that asphalt material has highly sensitive to temperatures, so over time, the durability gradually decreases rapidly, and due to traffic load and environmental factors, the aggregates will be lost from the mixture. As a result, problems such as raveling have become prevalent [15]. In addition, filler of various types gives stiffness to the mixture, and it affects mainly the cohesion and homogeneity of the mixtures somewhat. Thus, the decrease in fine materials affects negatively [16,17,18]. Therefore, this study aims to evaluate the performance of these mixtures with the addition of cellulosic fiber, known for its adherence capacity between the aggregates and the binder [19]. These will help to prevent binder loss by drainage, which is one of the main problems of porous asphalt since the loss of the fine aggregate is reduced.

To increase the ability of asphalt material to resist weathering and improve other physical properties, the loss and drain down of asphalt during storage and transportation should be decreased. This aim is achieved by the addition of cellulose fiber. Adding cellulosic fibers also increases the asphalt content and allows for greater asphalt retention and aggregate coating. Consequently considerable mixture durability occurs [20,21].

Cellulose fibers are added to improve the physical properties and durability of the mixture and maintain its functional properties. However, the desired percentage of asphalt is relatively high as it reduces the drain down, which is the important problem that the mixture suffered. In the previous research, cellulose fibers were used as a percentage by weight of the total mixture as it is mixed with aggregates, and this case may cause burning and damage of cellulose due to direct heat. In addition, cellulose may not be coated with asphalt correctly during mixing, as the cellulose material alone is considered an organic material that absorbs moisture and causes damage to the mixture [22,23].

Mixing cellulose fiber with asphalt using a propeller mixer is the best way, as the temperature distribution is homogeneous and regular. Also, the materials are not exposed to intense direct heat that causes burning, and the mixing is more homogeneous [24].

Afonso et al. [25] studied the addition of cellulose fiber and evaluated the performance of the mixture, and found that drain down was decreased with an increase in cellulose fiber percent also significant improvements in Indirect Tensile Strength (ITS) happened. The permeability was not affected by the addition of cellulose fiber. Gupta et al. [26] found that cellulose fiber slightly reduced the air voids content and permeability. Also, have a positive influence on Cantabro abrasion tests in aged and un-aged conditions. In addition, the outcomes of the indirect tensile test have improved significantly. Wu et al. [27] indicated that drain down was significantly decreased with the addition of cellulose fiber, in addition to a substantial decline in the result of the Cantabro abrasion test. Also evolved in resistance to moisture damage occurred. Suresha et al. [28] reported that the use of cellulose fiber gives positive outcomes appreciably, so it contributed to decreasing the drain down and Cantabro abrasion results. Also, the moisture susceptibility was improved, but it led to a decrease the permeability.

This research aims to investigate the possibility of using cellulose fiber as a modifier to enhance OGFC asphalt mixture properties of volumetric, mechanical, and permeability characteristics. Many Laboratory tests are conducted to achieve the objective, including abrasion (Cantabro) loss resistance, drain down test, permeability test, Marshall stability, indirect tensile strength, and moisture susceptibility. A considerable enhancement in results by adding cellulose in both treated and untreated situations, increasing moisture damage resistance.

2. Experimental Work

The experimental work of this research consists of modifying the 40/50 asphalt binder with cellulose fiber and comparing the results of the modified OGFC mixture with the original mixture for the volumetric, mechanical properties, and Permeability.

2.1 Materials

2.1.1 Asphalt cement

Asphalt cement of penetration grade (40-50) was used in this research. It was provided from the Daura Refinery, southwest of Baghdad. The physical properties of the used asphalt cement are shown in Table 1. The results of the asphalt cement tests revealed that its properties comply with the Iraqi standards (SCRB/ R9-2003) [29].

2.1.2 Aggregate

The crushed aggregates used in this study were obtained from Al-Nibaie Quarry. Table 2 shows the physical properties of the coarse aggregate (retained on sieve No.4), while the fine aggregates used in this research are 75 % fractured sand and 25% by-weight river sand. Table 3 shows the physical properties of fine aggregates.

2.1.3 Mineral filler

Ordinary Portland Cement, obtained from local markets, was used as mineral filler in this study. Table 4 illustrates the physical characteristics of ordinary Portland cement.

Table 1: Asphalt Binder's Physical Characteristics

Test	Value	Scrb Specification Of 40/50 Asphalt
Penetration @25°C With 100 Gm-5 Sec	43	(40-50)
Ductility @25 °C , 5 Cm/Min, (Cm)	145	>100
Flash Point (°C)	295	>232
Fire Points (°C)	305	……
Softening Point (4±1) °C /Min, (°C)	51.5	……
Specific Gravity	1.031	(1.01-1.05)

Table 2: Coarse Aggregate's Physical Characteristics

Properties	Astm Specification	Coarse Aggregate			
Specific Gravity	(Astm C127-128-15)	***Sieve Size (Mm)***	***G_{sb}****	***G_{sa}*****	***Abso.%***
		12.5	2.651	2.674	0.32
		9.5	2.585	2.591	0.09
		4.75	2.570	2.582	0.18
Fractured Pieces, 95% Min	Astm (D5821-13)	98			
Los Angeles Abrasion, 30% Max	Astm (C131-14)	21.72			

* Bulk specific gravity
** Apparent specific gravity

Table 3: Fine Aggregate's Physical Characteristics

Property	Astm Specification	Fine Aggregate			
Specific Gravity	(Astm C127-128-15)	***Sieve Size (Mm)***	***Bulk Specific Gravity, G_{sb}***	***Apparent Specific Gravity, G_{sa}***	***Abs. %***
		2.36 , 0.075	2.588	2.774	2.6
Clay Content By Sand Equivalent% 45min	Astm (D2419-14)	51			

Table 4: Physical Properties of Ordinary Portland Cement

Properties	Results
Passing Sieve No. 200, (%)	97
Bulk Specific Gravity	3.20

Figure 1: Cellulose Fiber used in the study

2.1.4 Cellulose fiber

The cellulose fiber utilized in this study was brought from the local market to prepare modified asphalt. Three different percentages of cellulose fiber were used to investigate its effect on the mechanical properties of the asphalt mixes. The percentages were (2, 4, and 6) %, respectively, by weight of the bitumen. Figure 1 illustrates the utilized cellulose fiber, and Table 5 presents its physical properties. According to previous studies, the mixing process was done by a mixer at 1000 rpm with a temperature of 160°C for 0.5 hours [24].

2.2 Selected aggregate gradation

For best performance, the OGFC mixture must have a coarse aggregate skeleton with stone-on-stone contact. The voids in coarse aggregate (VCA_{DRC}) for the crushed aggregate are calculated using ASTM (D7064-13) [30]. When the dry–rodded density of the coarse aggregate fraction has been calculated, the VCA_{DRC} can be determined using the equations below:

$$VCA_{DRC} = \frac{G_{CA}\,\gamma w - \gamma s}{G_{CA}\,\gamma w}\,100 \tag{1}$$

Where: VCA_{DRC}: the voids in coarse aggregate in dry-rodded condition (percentage), γs: the unit weight of the coarse aggregate fraction in the dry-rodded condition; (kg/m^3), γw: the unit weight of water; (998 kg/m^3), G_{CA}: the bulk specific gravity of the coarse aggregate.

$$VCA_{MIX} = 100 - \left(\frac{G_{mb}}{G_{CA}} . P_{CA}\right) \quad (2)$$

Where:G_{mb}: is the bulk specific gravity of the compacted mixture, P_{CA}: is the percent of coarse aggregate in the mixture, and G_{CA}: is the bulk specific gravity of the coarse aggregate

In this research, one selected blend of aggregate gradation of maximum aggregate sizes (MAS 19 mm) was employed following ASTM (D7064-13), as given in Figure 2. The selected blend has the desired requirements, where the VCA ($VCA_{MIX} < VCA_{DRC}$) is necessary to ensure stone-on-stone contact, as shown in Table 6.

Table 5: Physical properties of Cellulose Fiber

Property	Value
Tensile strength (N/mm^2)	500-800
Average length, (mm)	1.7
Diameter, (μm)	14
Denier, (g/9000 m)	2.4
Surface area, (cm^2/g)	25000
Specific gravity	1.1

Table 6: Properties of OGFC mixture for Marshall design Samples

Trial blend for OGFC wearing Course	γs, (Kg/m^3)	VCA_{DRC}	VCA_{MIX}
	1543.98	40.267	39.3

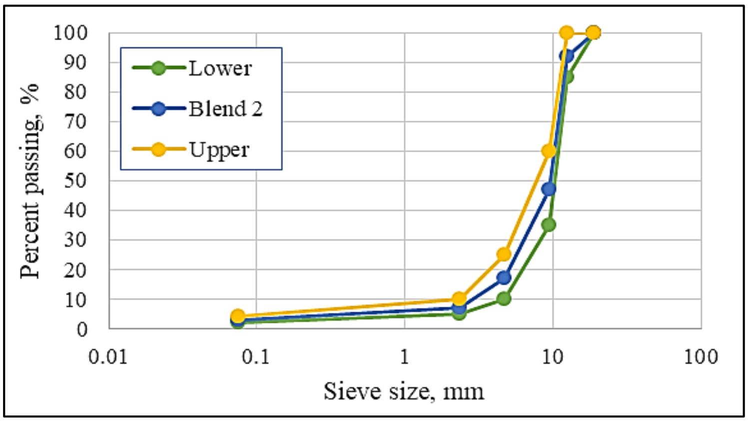


Figure 2: Asphalt mixture gradation with ASTM specification limits

2.3 Preparation of Compacted Marshall Specimens

Marshall specimens are produced according to ASTM (D6926-10) [31] specification, with a (101.5) mm diameter and a (63.5) mm height. To prepare an open-graded asphalt mix, aggregates, cement filler, and asphalt were mixed in a metallic container with five different asphalt binders (4, 4.5, 5, 5.5, and 6%). The mold component was placed on the compaction base, and a 4.535 kg compaction hammer with a movable weight and an 18-inch free fall was used to provide 50 blows to the top and bottom of a specimen (457.2 mm). Allow the specimen in the mold to cool for 24 hours at room temperature before removing it with a mechanical lever. The sample weighs 1200 gm.

2.4 Temperatures for Mixing and Compaction

The Asphalt Institute (2003) advises determining the temperatures of compaction and lab mixing for the asphalt binder when the viscosity-temperature line intersects viscosity intervals of 0.170± 0.020 Pas (range of the mixing temperature) and 0.280± 0.030 Pas (range of the compaction temperature), as described in Figure 3. To ensure that the asphalt binder is one of the efficient fluids for pumping and mixing, the viscosity of the asphalt binder is evaluated using an RV (i.e., rotational viscometer) or Brookfield viscosity at two temperatures (135°C) and (165°C). The results show that the mixing temperature is about (155°C), and the compaction temperature is approximately (144°C) for control or non-modified asphalt.

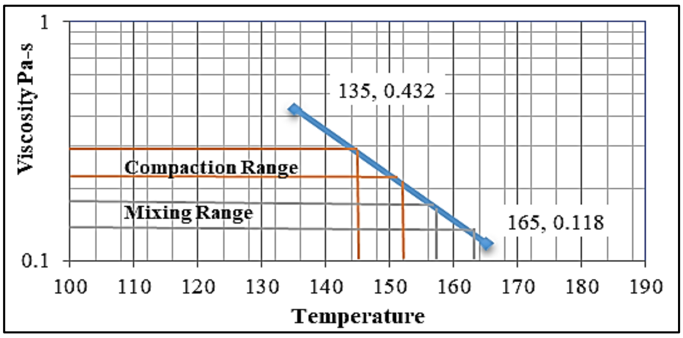


Figure 3: Viscosity-Temperature Relationship Plot of Asphalt Grade (40-50)

2.5 Selection of Optimum Asphalt Content

Five distinct asphalt content percentages (4, 4.5, 5, 5.5, and 6 %) are used to find the optimum asphalt content using the Marshall mix design method based on the standard specification (ASTM D7064–13). Marshall mix design curves for optimum asphalt content are shown in Table 7 and Figure 4, and it is found to be 5.4%. It is determined by averaging the values shown below:

- Air Void: 5.5% was found as the best value in the curve graph of binder content.
- Cantabro Abrasion Loss: 5.5% was found as the best value in the curve graph of binder content.
- Drain down: The best value of the bitumen binder content was (5) %.
- Permeability: The best value of the bitumen binder content was (5.5) %.
- The optimum asphalt content (5.4%) will be used for the control or non- modified asphalt mix.

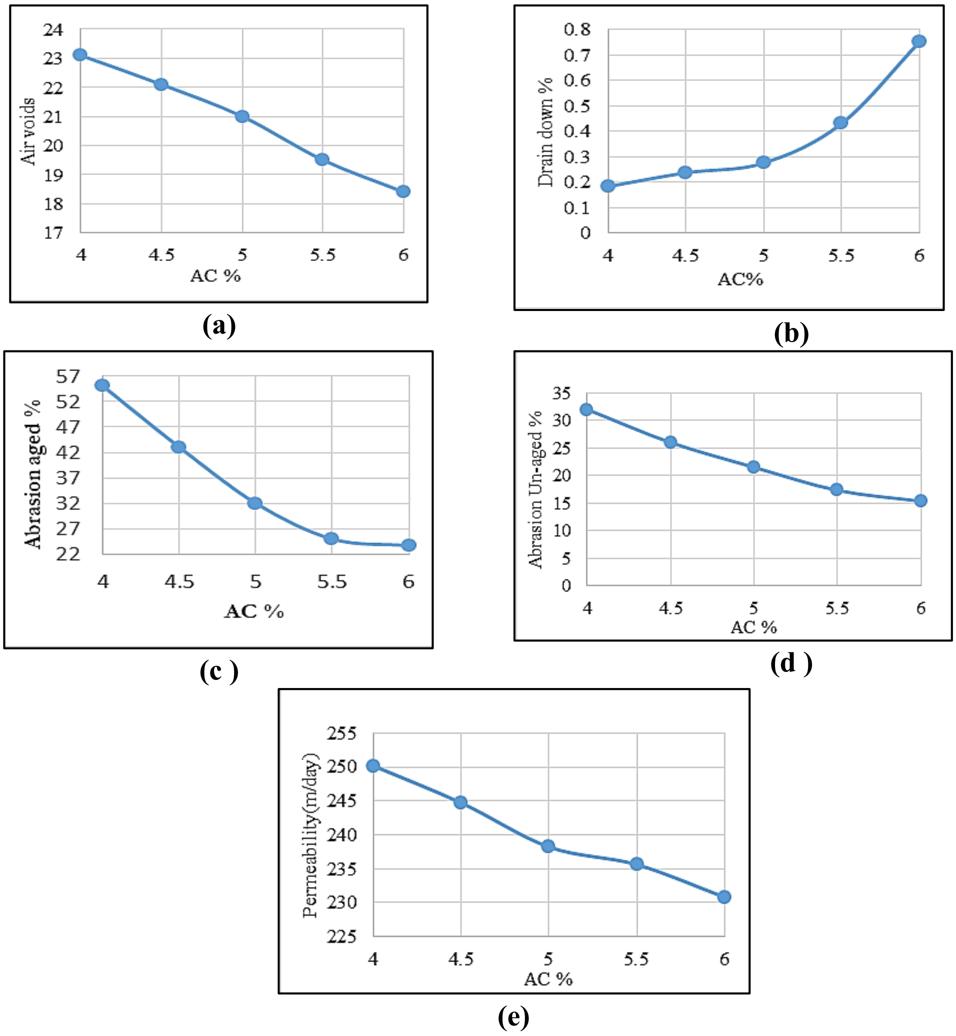


Figure 4: Selection of Optimum Asphalt Content (a) Relationship between Air voids and asphalt content (b) Relationship between drain down and asphalt content (c) Relationship between abrasion aged and asphalt content (d) Relationship between abrasion un-aged and asphalt content (e) Relationship between permeability and asphalt content

Table 7: Results of Optimum Asphalt Content

	Ac%	Air Void,%	Drain Down, %	Abrasion Un-Aged,%	Abrasion Aged,%	Permeability, M/Day
Asphalt Binder Content,%	4	23.1	0.183	32	55	250.15
	4.5	22.1	0.237	26	43	244.7
	5	21	0.275	21.5	32	238.2
	5.4	20.1	0.37	18.3	28	240.8
	5.5	19.5	0.43	17.3	25	235.6
	6	18.4	0.75	15.34	23.7	230.8

3. Properties of Open-Graded Asphalt Concrete Mixtures

3.1 Air Voids (V_a%)

According to ASTM (D3203-11) [31], and ASTM (D 7064-13) [30], the percentage of air pockets in compacted open-graded pavement mixtures was estimated. The percentage of air void content is calculated using the equation below.

$$V_a = \left(1 - \frac{G_{mb}}{G_{mm}}\right) 100 \quad (3)$$

Where: Va: air voids; (%), G_{mb}: Bulk specific gravity; of the compacted open-graded pavement mixtures; which was estimated using the geometrical measurements of specimens, following ASTM test method (D3203-11) [32]; and, G_{mm}: Theoretical max. Specific gravity; of the un-compacted mixtures; was calculated according to ASTM (D2041-11) [33].

3.2 Cantabro Abrasion Loss Resistance

The Cantabro abrasion loss test (un-aged and aged situation) is conducted based on ASTM (D7064-13) [30], and the goal of this test is to measure the compacted sample's abrasion resistance. The samples for every percent of the binder have been categorized into two or three, with each group having a comparable average void content (20%). The Los Angeles machine test technique ASTM (C131-14) was used to test one set in the unaged state while the other was aged at 140 °F (60 °C) for seven days [34]. The aged group was left for 24 hours to cool at the room's temperature before testing after 7 days. The initial mass of a sample was calculated to assess the abrasion resistance of the open-graded samples.

Figure 5 shows specimens before and after the abrasion loss test. The equation was used to find out how much abrasion loss there was. Ai and Af indicate the specimen's initial and final masses, respectively.

$$\text{Abrasion loss\%} = \left[\frac{Ai - Af}{Ai}\right] \times 100 \quad (4)$$

Figure 5: Samples during and after (Cantabro) Abrasion Loss Resistance Test

3.3 Drain Down Test

Un-compacted samples (mass of sample 1200±200g) were produced following (ASTM D6390-11) [35] such that the maximum permitted drain down should not exceed 0.30 percent. The assembly was then placed in an oven for one-hour ± 5 min at a degree of temperature equal to the predicted plant production temperature plus 15°C. Finally, the assembly was taken after the specified time from an oven and left to cool to the room's temperature, as illustrated in Figure 6. The following formula is used to obtain the amount of drain down percentage:

$$\text{Drain down } (\%) = \frac{(D - C)}{(B - A)} \times 100 \quad (5)$$

Where: A: mass of the empty wire basket; (gm), B: mass of the wire basket and sample; (gm), C: mass of the empty catch plate; (gm), and D: mass of the catch plate plus drained material; (gm).

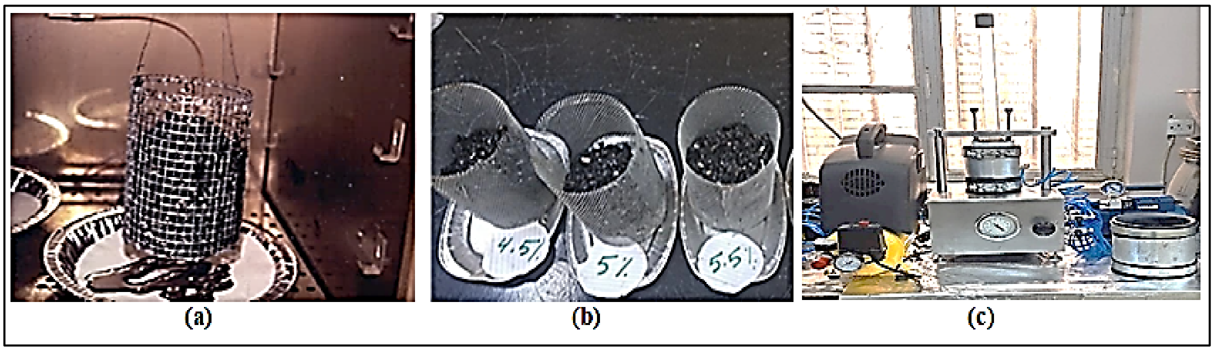


Figure 6: (a) and (b) Samples during and after Drain down Test (c) Permeability Test

3.4 Hydraulic Conductivity Test (Permeability Test)

Permeability is one of the essential characteristics utilized in assessing the open-graded asphalt mixes. The asphalt's minimal permeability coefficient is 100m/day. (based on the Florida method and ASTM D-7064-13) [30] [36]. The falling-head test device has been utilized to evaluate the flow rate of water through the Marshall specimen in this study. Figure (6b) depicts the equipment. The compacted paving mixture's permeability coefficient (K) was calculated using Darcy's law and the following eq.:

$$K = \frac{a\,L}{A\,t} \ln\left(\frac{h_1}{h_2}\right) .tc \tag{6}$$

Where: K: coefficient of water permeability; (cm/s), a: inside cross-sectional area of inlet standpipe; (cm^2), L: the thickness of test specimen; (cm), A: cross-sectional area of test specimen; (cm^2), t: average elapsed time of water flow between timing marks; (sec), ln: natural logarithmic function, h_1: hydraulic head on the specimen at time t_1; (cm), h_2: hydraulic head on the specimen at time t_2; (cm), and, tc: temperature correction for the viscosity of water.

4. Results and Discussion

4.1 Effect of Cellulose Fiber on Air Voids

Figure 7 illustrated that a reduction in air voids occurred when cellulose fiber was added to the OGFC mixture. The addition of cellulosic fibers reduced the drain and preserved the asphalt and fine materials from loss, thus gradually decreasing the air voids content. As known, it is directly affected by the amount of asphalt and fine materials. The results indicated that air voids values of specimens containing (2, 4, and 6) % cellulose fibers are decreased by (0.6, 1.54, and 3) %, respectively. The reason is that the cellulose acts as a stabilizer as it reduces the viscosity of the asphalt material because it works to absorb the hydrocarbon materials in its composition, thus reducing the lost fine material and increasing the coating around aggregates. This leads to a decrease in the surface area of the specimen, which means a decrease in the air voids content, the results agree with that reported by James et al., [20].

4.2 Effect of Cellulose Fiber on (Cantabro) Abrasion Loss Resistance

Figure 8 shows the effect of the Cellulose Fiber on Un-aged and Aged Samples. The results show that an increase in the percentage of cellulose fiber causes a decrease in abrasion loss for aged and un-aged samples. For example, 6% of CF caused a decrease of (15.85% and 13.6%) for aged and un-aged samples, respectively, as shown in Figure (8). The reason back to the addition of cellulose maintains the proportion of the asphalt causing sufficient bonding between the aggregate and asphalt and preserving the fine materials that increase the stiffness of the mixture. In addition, it increases the cohesion between the asphalt and aggregate particles. Also, it produces a remarkable effect on the abrasion loss resistance of modified aged and un-aged open-graded mixtures. The results agree with that obtained by Ma et al., [17]. However, there is a large discrepancy in abrasion loss values between the aged and un-aged specimens. The percentage value of abrasion loss for the aged was (28%) which is greater than the un-aged value, which is equal to (18.3%). The reason is due to the exposure to oxidation conditions and asphalt lightweight volatilization.

4.3 Effect of Cellulose Fiber on Drain Down

The results showed that when cellulose fibers were added in the percentage of (2, 4, and 6%) by weight of asphalt, drain down values decreased by (22.7, 67.3, and 75.4%), respectively, as shown in Figure 9. The cellulosic fibers increase the cohesion of the asphalt material and maintain the fine materials. They work together to absorb hydrocarbon materials, increasing the asphalt's viscosity. Therefore, the specimen resistance to thermal effect is increased. In addition, the bond is strengthened between the aggregate and the asphalt. Thus, it leads to the reduction of drain down results deal with that found by Tayh et al., [24].

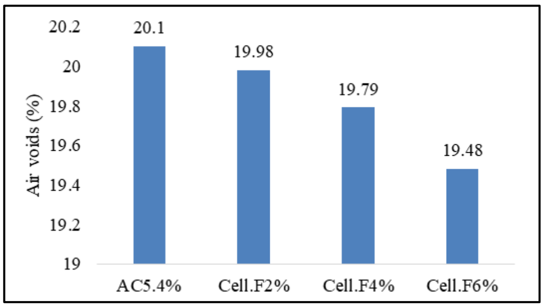
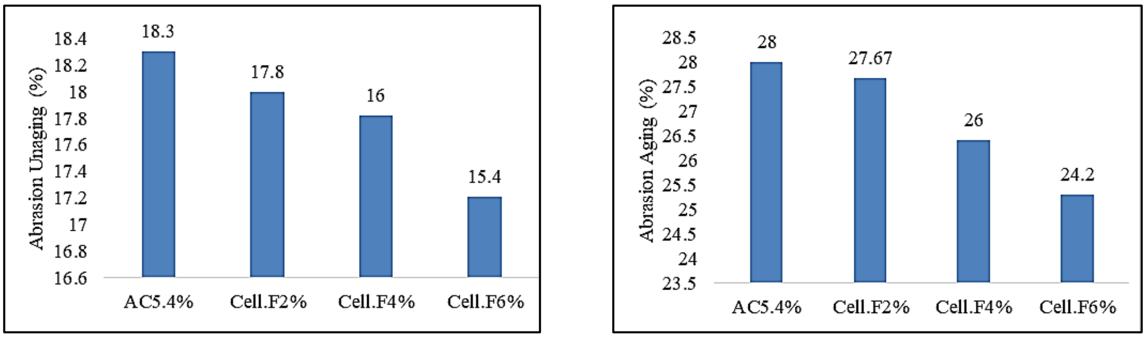


Figure 7: Effect of the Cellulose Fiber on Air voids



(a) (b)

Figure 8: Effect of the Cellulose Fiber on (a) Un-aged Samples (b) Aged Samples

4.4 Effect of Cellulose Fiber on Permeability

As explained earlier, the falling head test method was used to estimate the permeability of open-graded asphalt. Most researches and specifications specify the permeability coefficient to a maximum value of 100 m/day, ASTM (D7064–13) [30]. The addition of cellulose fiber reduces the coefficient of permeability by (0.33, 1.16, and 1.41%), respectively, from the original asphalt mixture, as shown in Figure 10. Mostly, the increase of the cellulose fibers keeps the asphalt material from losing because of increasing its cohesion in addition to maintaining the fine materials and thus affects the air voids directly as it gradually decreases and thus leads to a decrease in permeability.

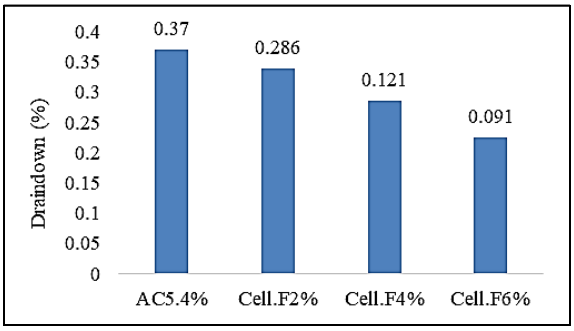


Figure 9: Effect of the Cellulose Fiber on Drain Down

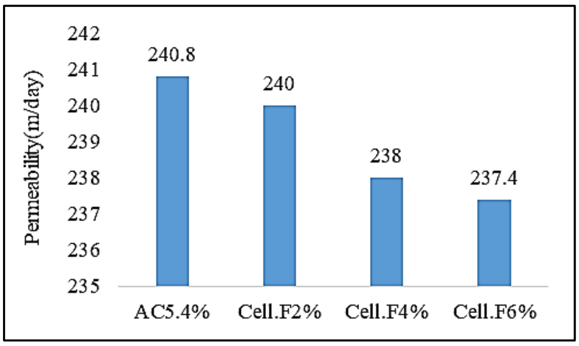
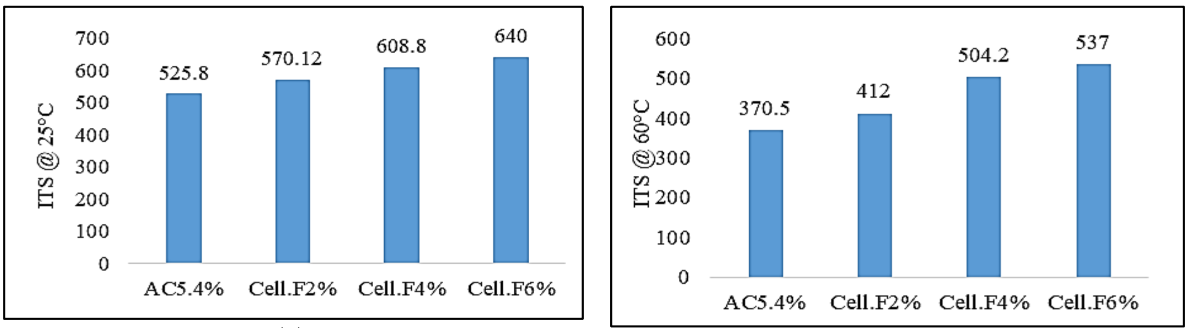


Figure 10: Effect of the Cellulose Fiber on Permeability



(a) **(b)**

Figure 11: Effect of the Cellulose Fiber on ITS (a) Dry samples @ 25 °C, (b) Wet samples @ 60 °C

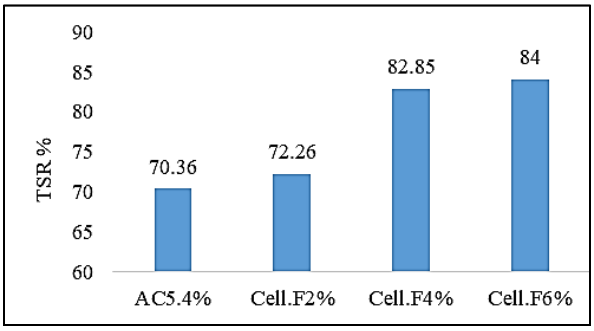
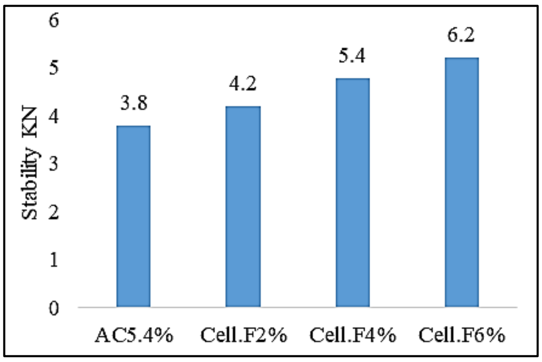
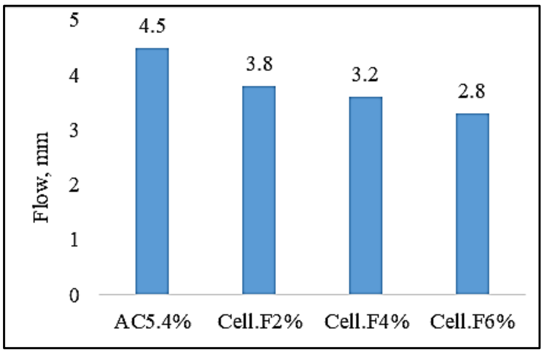


Figure 12: Effect of the Cellulose Fiber on TSR%



(a)



(b)

Figure 13: Effect of the Cellulose Fiber on (a) Marshall Stability (b) Marshall Flow

4.5 Effect of Cellulose Fiber on Indirect Tensile Strength (ITS)

Figure 11 illustrates the results of the indirect tensile strength (ITS) for dry samples at a temperature of 25 °C and wet samples at a temperature of 60°C, respectively. It can be noticed that the loss in ITS for conditioned mixtures is lower than for un-conditioned mixtures. Also, the ITS values for dry and wet samples increased with increased CF. On the other hand, Figure 12 illustrates the relationship between the indirect tensile strength ratio TSR and the content of cellulose fiber. It is indicated that TSR% increased with increasing cellulose fiber. The high TSR value occurred at (4% and 6%) of CF, respectively. The reason is that decreasing air voids resulting from the increase of cellulosic fibers means a decrease in the area exposed to climatic conditions and thus increases the durability of the asphalt mixture, the result deals with that reported by Afonso et al., [25].

4.6 Effect of Cellulose Fiber on Marshall Stability and Flow

To determine the Marshall properties, three open-graded asphalt mixtures specimens of un-modified and modified binders were prepared at the optimum asphalt content of 5.4%. Figure 13 shows that the addition of cellulose fiber by (2, 4, and 6%) increased Marshall stability by (9.52, 29.63, and 38.92) % from the original mixture, respectively. Also, a decrease in flow values was noted with the addition of the same percentages of cellulose fiber by (15.56, 28.88, and 37.77%), as shown in Figure 13 b. As mentioned previously, the cellulose fibers increase the cohesion of the asphalt material and maintain the fine materials that increase the hardness of the mixture; therefore, these factors increase the stability of the mixture and reduce the flow.

5. Conclusions

The study conclusions can be stated as follows:

1) CF significantly modifies the OGFC asphalt mixtures due to the decrease in air voids values. It is decreased by about 3% when 6% CF is added. CF acts as a stabilizer and reduces the asphalt viscosity, thus reducing the lost fine material and increasing the coating around aggregates.
2) Cantabro abrasion loss for aged and un-aged samples decreases with the addition of CF, indicating higher resistance to abrasion due to increasing the cohesion between the asphalt and aggregate. For example, 6% of CF caused a decrease of 15.85% and 13.6% for aged and un-aged samples, respectively.
3) The addition of CF to OGFC asphalt mixtures improved drain down values due to increasing the asphalt viscosity and strengthening the bond between the aggregate and the asphalt.
4) It can be concluded that the permeability coefficient decreased with increasing the cellulose fiber. This is because it keeps the asphalt material from losing, increases its cohesion, and maintains the fine materials. For example, the permeability coefficient decreased by 1.41% when 6% CF was added.
5) CF- modified mixtures have higher indirect tensile strength, and TSR results in higher resistance to the environmental condition of the asphalt mixture.

6) The addition of CF results in modified asphalt mixtures with better stability and flow values than the original mixture, especially for high content of CF means that the cellulose fibers increase the cohesion of the asphalt material and maintain the fine materials leading to an increase in the hardness of the mixture.
7) Finally, cellulose fiber indicated that the mechanical properties of OGFC mixtures were improved. 6% was the optimum percentage of cellulose fiber that gave the best results.
8) For future works, it is suggested to investigate the influence of other waste materials, Nano materials, and other types of additives on the properties of OGFC asphalt mixture besides implementing a combination of two or more materials as additives in the modification process.

Acknowledgment

The authors would like to thank the Civil Engineering Department, University of Technology-Iraq, for their assistance.

Author Contribution

All authors contributed equally to this work.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability Statement

Statement the data that support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that there is no conflict of interest.

References

[1] G. J. Taylor, Open graded friction Courses (OGFC), Course No: C02-058, Continuing Education and Development, Inc. 22 Stonewall Court Woodcliff Lake, NJ 07677, 2014.

[2] M. M. Namaa, Z. I. Qasim , K. H. Al Helo, Study of the Properties of Open Graded Asphalt Mixtures with the addition of SBS, IOP Conf. Series. Mater. Sci. Eng., 1090 (2021). https://doi.org/10.1088/1757-899X/1090/1/012002

[3] C. Engineer, D. Eyl, and O. C. Eng, Orous sphalt, Porous Asph., 2003.

[4] C. A. Gemayel , M. S. Mamlouk, Characterization of hot-mixed open-graded asphalt mixtures, Transp. Res. Rec., (1988) 184–192.

[5] N. C. Jackson, Design, construction and maintenance guide for porous asphalt pavements, National Asphalt Pavement Association, 2003.

[6] J. J. Sansalone , S. G. Buchberger, An infiltration device as a best management practice for immobilizing heavy metals in urban highway runoff, Water Sci. Technol., 32 (1995) 119–125. https://doi.org/10.1016/0273-1223(95)00546-Y

[7] B. O. Brattebo, D. B. Booth, Long-term stormwater quantity and quality performance of permeable pavement systems, Water Res., 37 (2003) 4369–4376. https://doi.org/10.1016/S0043-1354(03)00410-X

[8] N. A. Hassan, M. Z. H. Mahmud, K. A. Ahmad, M. R. Hainin, R. P. Jaya, N. Mashros, Air voids characterisation and permeability of porous asphalt gradations used in different countries, ARPN J. Eng. Appl. Sci., 11 (2016) 14043–14047.

[9] L. N. Antunes, E. Ghisi, L. P. Thives, Permeable pavements life cycle assessment: A literature review, Water , 10 (2018). https://doi.org/10.3390/w10111575

[10] N. J. Garber , L. A. Hoel, Traffic and Highway Engineering, Fourth Edition, 2009.

[11] S. Shuler , D. I. Hanson, Improving durability of open-graded friction courses, Transp. Res. Rec., 1259 (1990) 35–41.

[12] M. H. Sadd, J. Cardin, P. Daly, K. Park, C. Tanaka, Performance Improvement of Open-Graded Asphalt Mixes,Univ. Rhode Isl. Transp. Cent. Proj. 536144 (2003) 1–38.

[13] A. A. A. Molenaar, E. T. Hagos, and M. F. C. van de Ven, Effects of Aging on the Mechanical Characteristics of Bituminous Binders in PAC, J. Mater. Civ. Eng., 22 (2010) 779–787. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000021

[14] M. Ameri and M. A. Esfahani, Evaluation and Performance of Hydrated Lime and Limestone Powder in Porous Asphalt, Road Mater. Pavement Des., 9 (2008) 651–664. https://doi.org/10.1080/14680629.2008.9690143

[15] K. R. Opara, M. Skakuj, M. Stöckner, Factors affecting raveling of motorway pavements - A field experiment with new additives to the deicing brine, Constr. Build. Mater., 113 (2016) 174–187. https://doi: 10.1016/j.conbuildmat.2016.03.039

[16] V. Ranieri, K. J. Kowalski, N. Berloco, P. Colonna, and P. Perrone, Influence of wax additives on the properties of porous asphalts, Constr. Build. Mater. 145 (2017) 261–271. https://doi.org/10.1016/j.conbuildmat.2017.03.181

[17] X. Ma, Q. Li, Y. C. Cui, A. Q. Ni, Performance of porous asphalt mixture with various additives, Int. J. Pavement Eng., 19 (2018) 355–361. https://doi.org/10.1080/10298436.2016.1175560

[18] S. Eskandarsefat, B. Hofko, C. Sangiorgi, A comparison study on low-temperature properties of Stone Mastic Asphalts modified with PmBs or modified fibres, Int. J. Pavement Eng., 21 (2020) 1541–1549. https://doi.org/10.1080/10298436.2018.1554219

[19] B. Shirini , R. Imaninasab, Performance evaluation of rubberized and SBS modified porous asphalt mixtures, Constr. Build. Mater., 107 (2016) 165–171. https://doi.org/10.1016/j.conbuildmat.2016.01.006

[20] T. James, D. Watson, A. Taylor, N. Tran, C. Rodezno, Improving cohesiveness of porous friction course asphalt mixtures, Road Mater. Pavement Des., 18 (2017) 256–272. https://doi.org/10.1080/14680629.2017.1389073

[21] M. L. Afonso, M. Dinis-Almeida, and C. S. Fael, Study of the porous asphalt performance with cellulosic fibres, Constr. Build. Mater., 135 (2017) 104–111. https://doi.org/10.1016/j.conbuildmat.2016.12.222

[22] J. Cooley, E. R. Brown, and D. E. Watson, Evaluation of open-graded friction course mixtures containing cellulose fibers, Transp. Res. Rec. J. Transp. Res. Board, 1723 (2000) 19–25. https://doi.org/10.3141/1723-03

[23] N. F. A. A. Musa, M. Y. Aman, M. N. M. Taher, and Z. Noranai, Utilization of Synthetic Reinforced Fiber in Asphalt Concrete – a Review, Int. J. Civ. Eng. Technol., 10 (2019) 678–694.

[24] S. A. Tayh, R. A. Yousif, and Q. S. Banyhussan, A comparative study of physical properties using various grades asphalt binder with different type of fibers, J. Eng. Res., 17 (2020) 34–40. https://doi.org/10.24200/tjer.vol17iss1pp34-40

[25] M. L. Afonso, M. Dinis-Almeida, and C. S. Fael, Study of the porous asphalt performance with cellulosic fibres, Constr. Build. Mater. 135 (2017) 104–111. https://doi.org/10.1016/j.conbuildmat.2016.12.222

[26] A. Gupta, D. Castro-Fresno, P. Lastra-Gonzalez, and J. Rodriguez-Hernandez, Selection of fibers to improve porous asphalt mixtures using multi-criteria analysis, Constr. Build. Mater., 266 (2021) 121198. https://doi.org/10.1016/j.conbuildmat.2020.121198

[27] S. P. Wu, G. Liu, L. T. Mo, Z. Chen, and Q. S. Ye, Effect of fiber types on relevant properties of porous asphalt, Trans. Nonferrous Met. Soc. China, 16 (2006) 791–795. https://doi.org/10.1016/S1003-6326(06)60302-6

[28] S. N. Suresha, G. Varghese, and A. U. Ravi Shankar, Properties of cellulose fibres and waste plastic modified porous friction course mixes, Balt. J. Road Bridg. Eng., 5 (2010) 156–163. https://doi.org/10.3846/bjrbe.2010.22

[29] General Specification for Roads and Bridges SCRB, Section R/9, Hot-Mix Asphalt Concrete Pavement, Revised Edition. State Corporation of Roads and Bridges, Ministry of Housing and Construction, Republic of Iraq, 2003.

[30] ASTM D 7064-08, Standard practice for open-graded friction course (OGFC) mix design, ASTM Int., 08 (2013) 1–7. https://doi.org/10.1520/D7064

[31] ASTM D 6926, Standard Practice for Preparation of Bituminous Specimens Using Marshall, Annu. B. Am. Soc. Test. Mater. ASTM Stand., (2014) 1–6.

[32] C. Elements, U. Drilled, C. Cores, C. C. Specimens, H. Concrete, and B. Statements, Standard Test Method for, 08 (2012) 5–12.

[33] ASTM Standard D2041, Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures, ASTM Int., (2011)1–4. https://doi.org/10.1520/D2041

[34] A. Drews, Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), Man. Hydrocarb. Anal., 6th Ed. 1 (2008) 50-50–4. https://doi.org/10.1520/mnl10830m

[35] ASTM D 6390, Standard Method of Test For Determination of Draindown Characteristics In Un-compacted Asphalt Mixtures, Annu. B. Am. Soc. Test. Mater. ASTM Stand., (1997) 6–8.

[36] D. O. T. Florida, Florida method of test for measurement of water permeability of compacted asphalt paving mixtures, FM5-565, Dept Transp. Tallahassee, 2004.