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Improvement the Properties of Porous Asphalt by Using Natural and Manufactured Fibers.

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الملخص العربى :

يعد استخدام الأسفلت المسامي (PA) أحد الحلول الأكثر شيوعًا في جميع أنحاء العالم لمعالجة تأثير التغيرات المناخية مثل هطول الأمطار الغزيرة. ان الهدف من هذه الدراسة هو تحديد خصائص هذه المخاليط مع ألياف البولي بروبلين وألياف الكتان الناتجة من مخلفات التصنيع والمعروفة بقدرتها على الالتصاق بين الركام والمادة الرابطة وسوف يساعد ذلك على منع فقدان المادة الرابطة عن طريق الصرف والتي تعد واحدة من المشاكل الرئيسية للإسفلت المسامي . يتميز الاسفلت المسامي بمحتوي منخفض من الركام الناعم بالمقارنة مع الأسفلت التقليدي. تم إضافة الألياف في هذا البحث إلى الاسفلت المسامي لتحسين خواصه.

ABSTRACT:

The porous asphalt (PA) used in road pavement surface layers is one of the most common solutions worldwide to address climate change impact like heavy rain. This study aims to determine the properties of these mixtures with polypropylene fibers and flax- shives fibers addition. Their ability to stick between the aggregate and the binder. This will help prevent the loss of binder through drainage which is one of the main problems of porous asphalt. The fine aggregate content is reduced compared to traditional asphalt. The fibers were added to the porous asphalt to improve properties of porous asphalt mixtures.

1. Introduction

The porous asphalt pavement differs from traditional asphalt pavement designs in that the structure allows fluids to pass freely through it, reducing or controlling the amount of runoff from the surrounding area by allowing precipitation and runoff to flow through the structure, This type of pavement acts as an additional rainwater management technique[1]. The total benefits of porous asphalt pavements may include both environmental and safety benefits including improved stormwater management, improved skid resistance, reduced spraying for drivers and pedestrians, as well as noise reduction. With increasing environmental awareness and atypical evolving shifts in rainwater management techniques[2]. One of its most important disadvantages is non-use in high traffic loads, high cost compared to traditional asphalt, and clogging of the pores. Thus we lose the main reason for the use of porous asphalt, which is its ability to drain surface water into the lower layers of the road. Therefore, all researchers tried to improve the properties and performance of porous asphalt using additives and reduce porous blockage to increase the porosity and thus increase the road life. The need to improve the durability of porous asphalt has led to the additives like fibers, not only in porous asphalt but also in stone matrix asphalt and asphalt concrete. A variety of fiber types were used in asphalt mixtures, including cellulose, minerals, synthetic polymer, glass fiber, newsprint, carpet fibers, and recycled tire fibers [3–4]. The current study uses polypropylene fibers as manufactured fibers and flax-shives as natural fiber to improve the performance of porous asphalt. These fibers offer an important advantage: wide availability at alow cost.

3. Objective of the Study

The main objective of this study is to study improving the properties of porous asphalt by adding polypropylene fiberand flax- shives fiber to the porous asphalt mixture by conducting porous asphalt tests on the control mixture without fiber and also with fiber and determining the extent of improving the properties such as permeability, stability, flow, indirect tensile strength and compressive strength.

4. Literature review

In previous studies (In 2017 Márcia Lopes Afonso and others studied the porous asphalt performance with cellulosic fibers)[5].In this study, the authors studied the effect of adding cellulosic fibers on porous asphalt. They divided samples with added cellulosic fibers into fine and coarse aggregate groups. They do permeability test and stiffens test. At permeability test calculated the coefficient of permeability by Darcy equation results showed time inversely proportional to drainage P.A with fine aggregate added with cellulosic fibers take less time to P.A with coarse aggregate added with cellulosic fibers. There for cellulosic fibers as an addition to P.A improves runoff of P.A. At stiffness test results showed a slight difference between samples with cellulosic fibers and without cellulosic fibers and showed a slight difference between samples with fine aggregate or coarse aggregate at a value of (ITS)indirect t tensile strength value. The study of resistance to permanent deformation and the results were similar to those with and without cellulosic fibers.

In 2016 Khairil Azman Masri and others do a study. (Abrasion Loss and binder drain down of porous asphalt with nano-silica- Modified Binder)[6]. This study explains the effect of using nano-silica as a modified binder with porous asphalt on the performance of porous asphalt in terms of binder drain down and abrasion loss.2-5% nano-silica is considered an effective percentage of nano-silica to be mixed with the binder to reduce the abrasion loss and binder drained of porous asphalt in addition 4% is the best proportion of nano-silica to enhance the performance of porous asphalt.

5. Methodology:

Porous asphalt mixture materials are prepared to confirm the control mixture of porous asphalt after determining the optimum bitumen content of the mixture by Marshall test. Laboratory tests are performed to determine the properties of porous asphalt such as permeability, stability, flow, indirect tensile strength, and compressive strength. Polypropylene fiber and Flax-Shives fiber are added separately to the control mixture in different proportions to determine the optimum fiber content by Marshall test and Indirect Tensile Test. After adding the optimum Percentage of polypropylene fiber and flax- shives fiber to the porous asphalt control mixture, perform porous asphalt tests to determine the effect of fibers on porous asphalt properties. Figure 1 shows the methodology steps and experimental work.

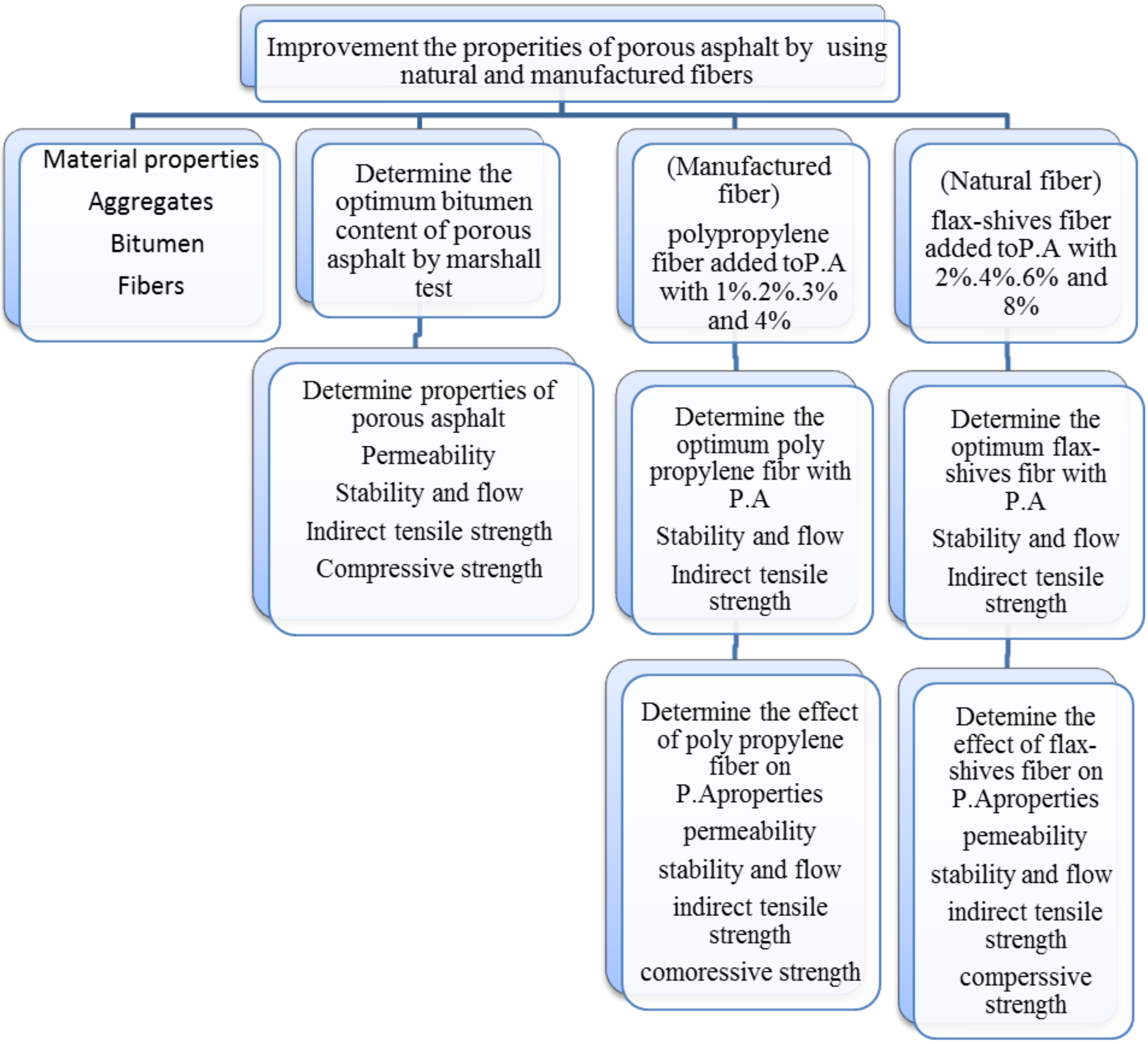

Figure 1: Methodology steps and experimental work.

4. Materials:

This study presents porous asphalt mixtures consisting of coarse aggregate(dolomite), fine aggregate (crushed natural sand), bitumen, and polypropylene or flax shives fibers as additives.

4.1. Aggregate blend.

Porous asphalt components are assembled to give the largest percentage of air voids. There fore the large nominal size of aggregates and design gradient specific to porous asphalt are used in this study. Coarse aggregate by 85 % and crashed sand by 15% as fine aggregate. Porous asphalt has its aggregate gradation to ensure the most important characteristic that distinguishes it from traditional asphalt is the size of the large air voids. This was therefore confirmed when conducting a sieve analysis of the aggregate used for the porous asphalt mixture, according to the specification of the porous asphalt aggregate gradation [7].

Table 1: Proportions of the mixture and the design gradation.

Sieve size (mm)	coarse aggregate		Fine aggregate crushed sand		desi gn gradient	Blend aggregate gradation for P.A
	Pass	85%	Pass	15%		
25	100	85	100	15	100	100
19	92	78.20	100	15	93.20	85-100
12.5	37	31.50	100	15	46.5	45-60
9.5	7	6	100	15	21	15-45
No.4	0	0	99	14.9	14.9	12-35
No.8	0	0	87	13.1	13.1	10-25
No.16	0	0	48	7.2	7.2	5-20
No.30	0	0	32	4.8	4.8	3-15
No.50	0	0	19	2.9	2.9	3-12
No.100	0	0	11.2	1.7	1.7	2-8
No.200	0	0	7.3	1.1	1.1	0-4

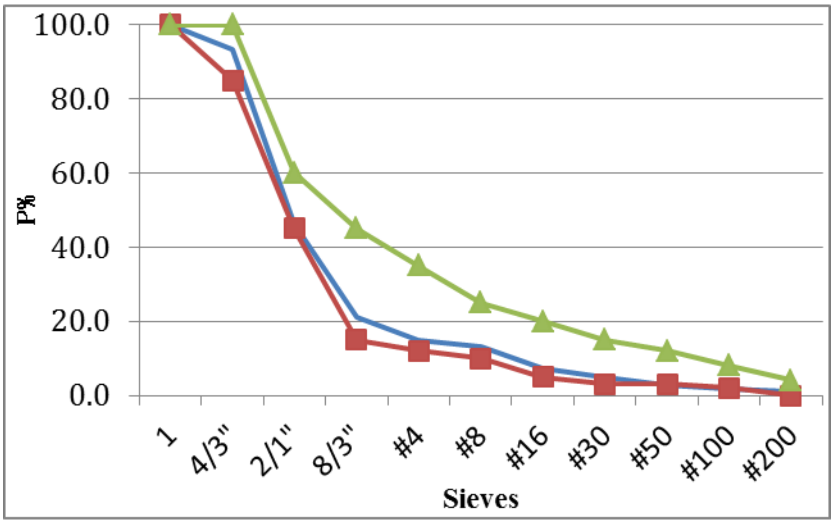

Figure 2: Aggregate blend chart.

4.2. Asphalt binder (bitumen).

The asphalt binder properties were determined and the results have been recorded as shown in table 2.

Table 2: Properties of bitumen.

Binder grade	Penetration ASTMD5	Softening point ASTMD36	Flash point ASTMD93	kinematic viscosity ASTMD2170	Specific gravity
60/70	64 mm	51 °C	270°C	449 CS	1.020 g/cm3

4.3. fibers.

Fibers are widely used in different industries and were used as an addition to the asphalt mixture. The Fibers, including natural and synthetic.

Natural fibers are expensive, but flax- shives have been used in this research because it is considered one of the wastes of the flax industry in Egypt, and it cheap and easy to get. Synthetic fibers are the most widely used and widespread because they are available, cheap, and easy to form. Polypropylene fibers were used in this research. As when mixed with the components of the porous asphalt mixture, it is observed that it welds and creates a layer as viscous coating envelops the aggregate granules. This increases the adhesion strength between the aggregate granules and improves the mechanical properties of the mixture[8-9].

4.3.1. Flax-shives fiber.

Flax-shives is natural fiber and remnants of the flax industry, differing from the flax length of the filaments only. Flax length is from 60 cm to 100 cm. While the Flax-shives is small in length from 0.30 cm to 2.5 cm and the remnant of the flax industry (the leftover wood of the flax pulping plant) is used in the manufacture of particleboard.

Figure 3: Flax-shives fiber

4.3.2. Polypropylene Fiber.

Polypropylene Fiber is a monofilament polypropylene additive fiber to reduce the occurrence of plastic shrinkage and plastic settlement cracking while enhancing the surface properties and durability of hardened cementitious products. The fibers are extremely fine, by taking pictures using a microscope capable of zooming 1000 times, then processing that image to measure the average diameter and average length In addition to coming with a photo analyzer, the zoom (64x) was used using a standard digital micrometer, and polypropylene fibers have a uniform shape and size. The length range ranged from (3~18) mm. Where the average diameter = 18 microns.

Figure 4: Polypropylene fiber.

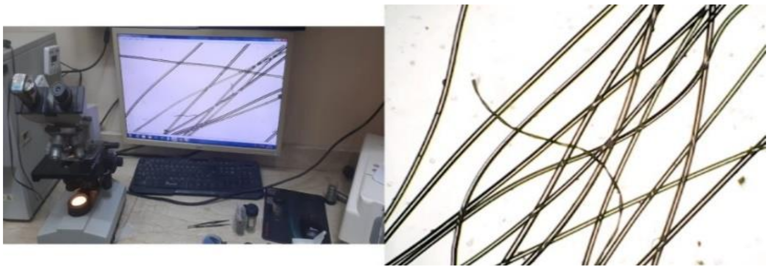

Figure 5: Microscope and using 64x magnification.

5. Experimental work and Analysis.

5.1. Determination of the optimum bitumen content and design of porous asphalt control mixture.

The optimum bitumen content of porous asphalt was determined by Marshall test according to ASTM D1559. The mixture consists of 85% coarse aggregate, 15% fine aggregate, and the content of bitumen in different proportions is 3%, 3.5%, 4.0%, and 4.5%. The samples for each bitumen ratio were prepared by working 5 molds and testing Marshall on them. The optimum bitumen content values, which will achieve AV%=16.00% in the mixture, the highest stability value of 950 kg, and the highest γb 2.34 kg/m3. B.C% were x1=3.3%, x2=4.0% and x3=3.35% determine by investigation between bitumen content and air voids ratio,stability and unit weight. The average of these values considered the optimum bitumen content of the mixture equals 3.55%. For optimum bitumen content check the relation between bitumen content and voids mineral aggregate (VMA%) and flow. The results showed in table:3 and figure: 6.

- Flow=13.31/10 inch =3.325mm. According to ASTM 1559.
- VMA%=22.00% According to ASTM 6995.

5.2. Job mix formula of porous asphalt control mixture.

From Marshall test results, the control porous asphalt mixture consists of 3.55% optimum bitumen content, 16.00 % air voids, and the remaining is aggregate 85% coarse aggregate and 15% fine aggregate.

5.3.Determination the optimum percentage of polypropylene fiber with (P.A).

Polypropylene fiber was added to the control porous asphalt mixture in different proportions of 1%, 2%, 3%, and 4% of the weight of the bitumen. Optimum bitumen content represents 3.55% of the total sample weight equal41gm. The average total sample weight is 1150 gm. Five molds were made for each percentage of polypropylene fibers added to the control porous asphalt mixture, Marshall test was done to calculate air voids ratio and stability according to ASTM D1559 and AASHTO T245, indirect tensile test according to ASTM D6931 and compressive strength test according to ASTM D1074. The results showed in table:3 and figure:7,8,and9.

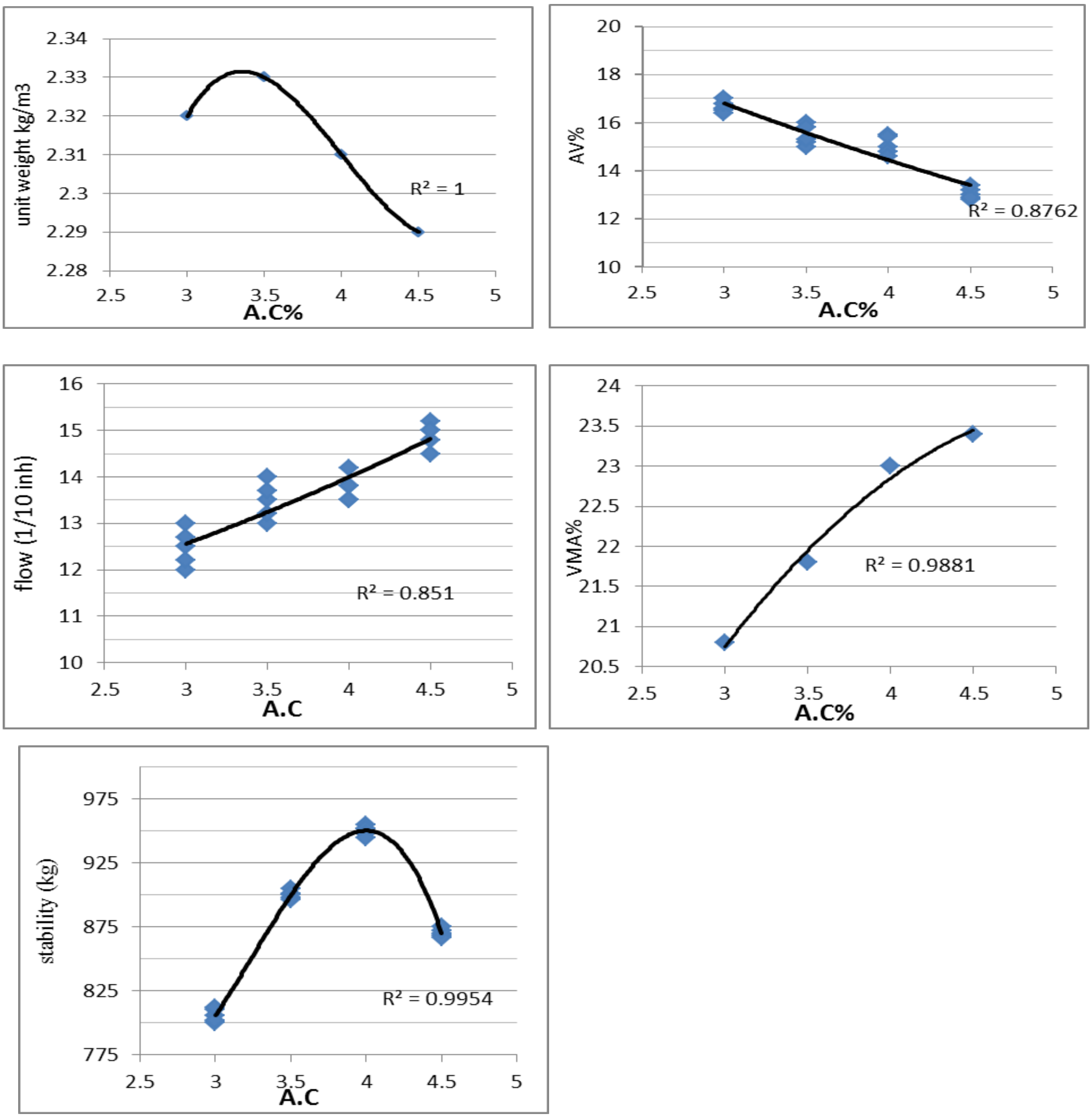

Figure 6: Marshall test charts.

Table 3: Marshall test ,ITS test and CS test results for modified P.A via polypropylene fiber.

Poly propylene fibers %	1.0%					2.0%					3.0%					4.0%				
	0.41gm					0.82gm					1.23gm					1.64gm				
molds	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
AV%	16.2	16.1	15.8	15.8	16	16.0	15.9	16	15.8	16.2	15.2	14.8	15	15.2	15.0	14.3	13.9	13.8	14	13.9
AV% Average	16.00					16.00					15.00					14.00				
Stability (kg)	1005	1010	1012	1008	1010	1038	1039	1042	1040	1038	1015	1018	1016	1017	1018	1010	1012	1011	1013	1013
Average Stability (kg)	1009					1039					1017					1012				
ITS (MPa)	1.1	1.08	1.05	1.04	1.07	1.5	1.6	1.45	1.51	1.48	1.4	1.42	1.38	1.39	1.41	1.38	1.39	1.38	1.38	1.37
Average ITS(MPa)	1.07					1.50					1.40					1.38				

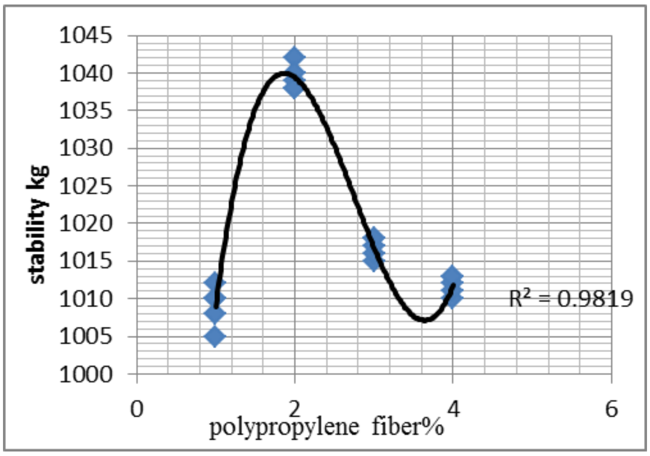

Figure 7: Polypropylene fiber% and stability.

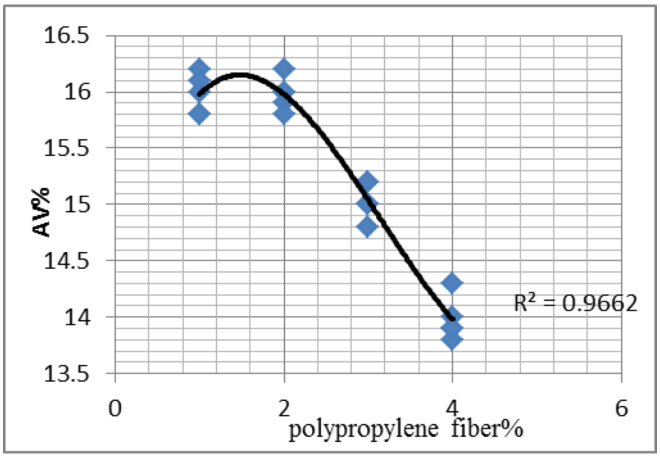

Figure 8: Polypropylen fiber% and AV%.

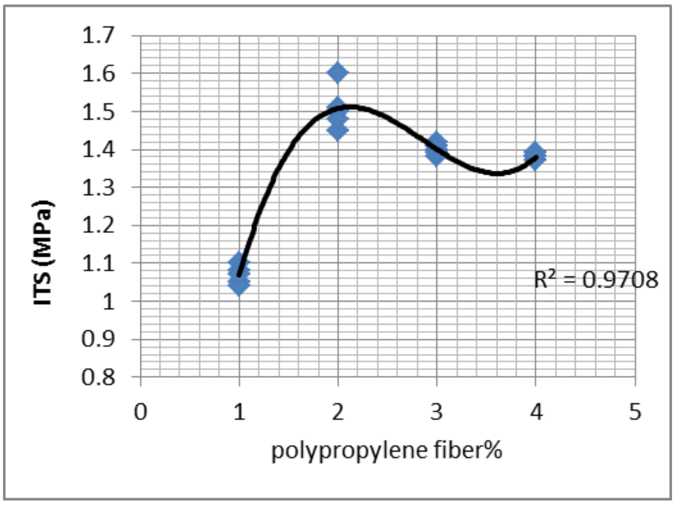

Figure 9: Polypropylene fiber% and ITS(MPa) .

Figure 10: Polypropylene fibers with aggregate.

The results of the tests were carried out on the porous asphalt mixture with different percentages of polypropylene fibers. The polypropylene fiber keeps the air voids ratio when added to the mixture by 1% and 2% and the values of 3% and 4% decreased the air voids ratio that is because the fibers It has interfered with bitumen, then covered the aggregate. When the amount of polypropylene fiber increases it takes part of the air voids ratio in the mixture. which reduces the permeability of the mixture. The proportion of 2% of the polypropylene fibers achieved good value for the stability and indirect tensile strength of the porous asphalt mixture, so the proportion of the optimum polypropylene fibers was 2%.

5.4 Determination of optimum percentage of flax-shives fiber with (P.A).

Flax- shives fiber add to control porous asphalt mixture in different proportions of 2%, 4%, 6%, and 8% of the weight of the bitumen. Optimum bitumen content represents 3.55% of the total sample weight equal41gm. The average total sample weight is 1150 gm. Five molds were made for each percentage of flax-shives fiber added to the control porous asphalt mixture, Marshall test was done to calculate air voids ratio and stability according to ASTM D1559 and AASHTO T245, indirect tensile test according to ASTM D6931 and compressive strength test according to ASTM D1074. The results showed in table:4 and figure:11,12,and13.

Table 4: Marshall test ,ITS test and CS test results for modified P.A via flax-shives fiber.

Flax- shives fibers %	2.0%					4.0%					6.0%					8.0%				
	0.7gm					1.4gm					2.1gm					2.9gm				
molds	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
AV%	14.4	14.5	14.7	14.7	14.4	14.5	14.6	14.4	14.4	14.6	13.5	13.6	13.2	13.3	13.3	13.0	12.9	12.8	12.8	12.9
AV% Average	14.50					14.50					13.40					12.90				
Stability (kg)	924	926	926	927	927	936	934	937	936	935	896	892	890	893	890	852	850	850	848	847
Average Stability (kg)	926					935					893					850				
ITS (MPa)	1.05	1.06	1.05	1.04	1.06	1.12	1.1	1.09	1.11	1.13	1.09	1.08	1.08	1.09	1.07	1.07	1.06	1.08	1.08	1.07
Average ITS(MPa)	1.05					1.11					1.08					1.07				

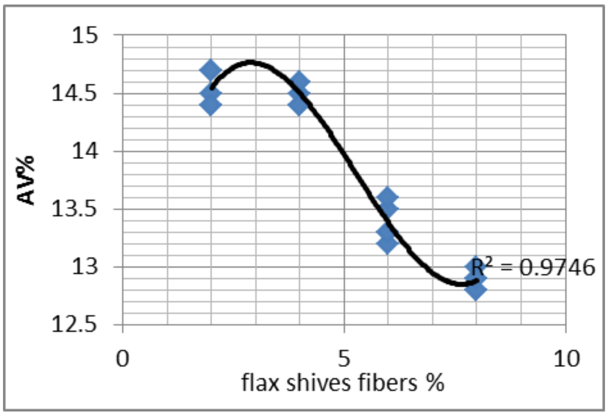

Figure 11: Flax-shives fiber% and AV%.

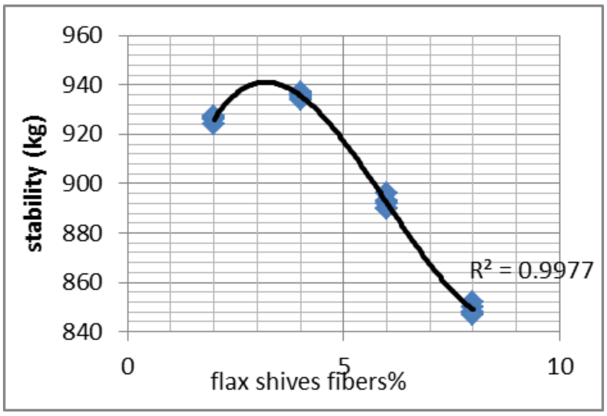

Figure 12: Flax-shives fiber% and stability .

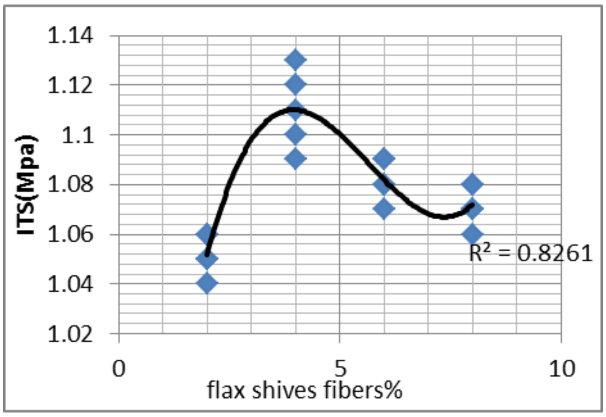

Figure 13: Flax- shives fiber% and ITS (MPa) .

Figure 14: Flax- shives fibers with aggregate

The results of the tests were carried out on the porous asphalt mixture with different percentages of flax-shives fiber. The flax-shives fiber reduced air voids ratio when added to the mixture with all the added proportions. Because flax-Shives retain their texture, which can be observed with the naked eye. Flax- shives fiber when mixed with bitumen and heated, they retain their shape, which causes a decrease in the proportion of air voids in the mixture. The percentage of flax- shives fiber is inversely proportional to the percentage of air voids ratio .from results, 2%, and 4% had the same effect on the volume of the air voids and when the ratio was higher than that, the air voids decreased significantly. The proportion of 4% of the flax-shives fiber achieved good value for the stability and indirect tensile strength of the porous asphalt mixture, so the proportion of the optimum flax-shives fibers was 4%.

5.5. Effect of polypropylene and Flax-Shives fibers on properties of porous asphalt.

Porous asphalt has the same mechanical properties as traditional asphalt. The most important characteristic that distinguishes porous asphalt from traditional asphalt is the permeability due to the high percentage of inter-connected air voids in the mixture ranging from 16% to 22%, while traditional asphalt does not exceed 8%. To study the effect of fibers on these properties, tests were conducted for porous asphalt mixture on the control mixture without additives and also with the addition of 2% polypropylene fiber and 4% flax- shives fiber, each separately, which is the optimum percentage of additives fibers.

5.5.1. Effect of polypropylene and Flax-Shives fibers on stability, flow, and air voids of porous asphalt.

The stability of the asphalt mixture gives indicators of the performance of the asphalt mixture and its resistance to deformation, rutting, and shear stresses. The stability of the asphalt mixture is attributed to two factors: the value of internal friction and cohesion, such as the latter represents the binding force of the bitumen while the first represents the internal friction and interference of the aggregate, while the flow gives a clear idea of the amount of deformation that occurs when the mixture is subjected to large loads, and since the asphalt mixture is subjected to large traffic loads, it is necessary to use asphalt mixture with good and appropriate stability and flow properties. According to ASTM D6927 standards. The results showed in table:5 and figure:15.

Table 5: Marshall test results for P.A without fibers and P.A with 2% polypropylene fibers and4% flax- shives fibers.

	Control P.A			P.A with 2% polypropylene fibers			P.A with 4% Flax- Shives fibers		
S.N	1	2	3	1	2	3	1	2	3
Stability kg	838	790	806	1037	1041	1032	903	937	920
Average stability	811			1036			920		
Flow(mm)	3.30	3.35	3.45	3.40	3.35	3.4	3.4	3.20	3.10
Average flow (mm)	3.35			3.38			3.23		
A.V%	16.200	16.00	15.80	16.00	15.90	16.10	14.60	14.20	14.80
Average AV%	16.00			16.00			14.50		

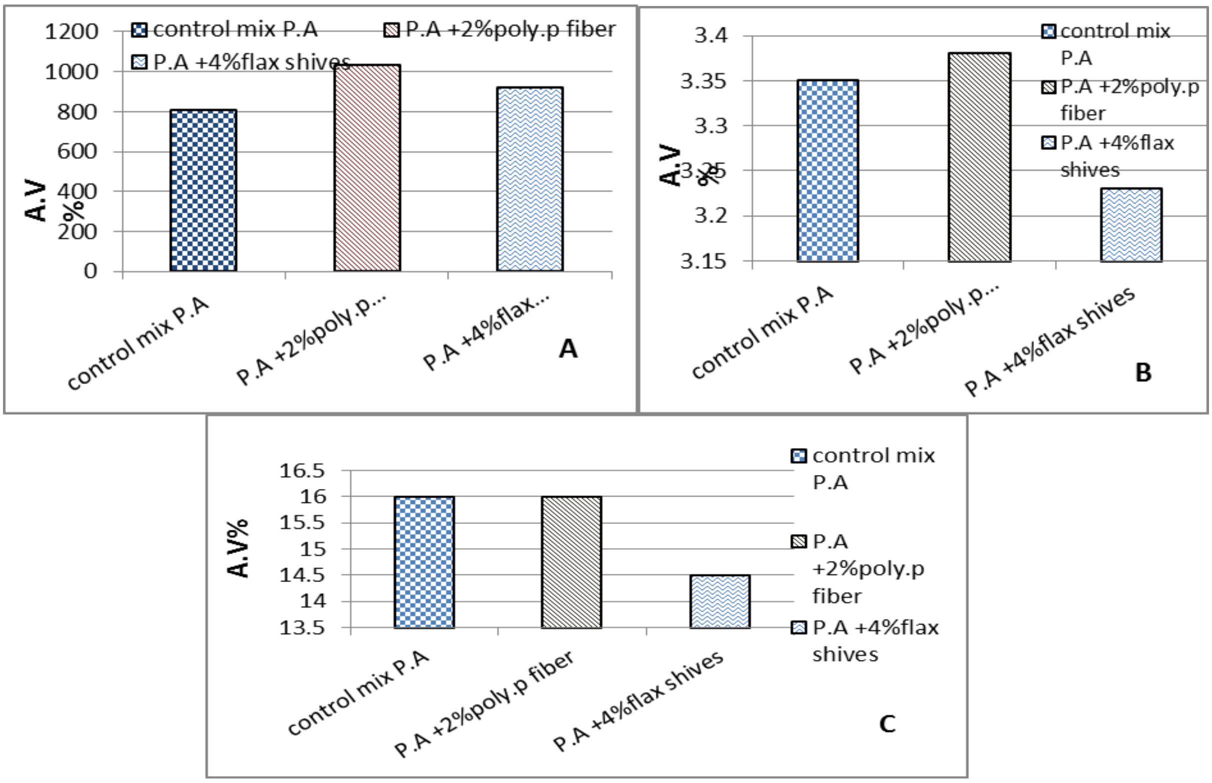

Figure 15.A: stability with P.A, P.A+2%polyprpylene fiber, and P.A+4%flax- shives fiber.
B: Flow with P.A, P.A+2%polyprpylene fiber, and P.A+4%flax- shives fiber.
C: A.V% with P.A,P.A+2%polyprpylene fiber and P.A+4%flax- shives fiber.

According to the results; fiber improved Marshall stability, add 2% of polypropylene fiber to the control porous asphalt mixture led to an increase in the stability by 28%. Also, 4% of Flax- shives fibers led to an increase in stability by 13.50%. The fibers did not affect the flow and had a slight effect on the proportion of air voids ratio in the mixture.

5.5.2.Effect of polypropylene and Flax-Shives fibers on Permeability of porous asphalt.

Permeability is the most important characteristic of porous asphalt. New ways of determining drainage capacity had to be created. Objective measurement of this property is critical to the analysis of these mixtures. According to ASTM (D 7064-04), The permeability coefficient was calculated from Darcy's equation: 1. The results showed in table:6 and figure:16.

$$K = 2.3\,\frac{al}{At}\,[\log(\frac{h_1}{h_2})] \qquad \text{E q(1)}$$

Where: **k** is the permeability coefficient measured in (cm/s), **a** is the area of the tube (cm2), **L** is the thickness of the specimen (cm), **A** is the area of the specimen cross-section (cm2), **t** is time for water to flow water from **h1**to **h2** (sec), and **h1** and **h2** are the starts and end level respectively.

- a is the area of the tube $=\pi\frac{d^2}{4} = \pi\,\frac{2.5^2}{4} = 4.90\ cm^2$
- A is the area of the specimen cross-section$=\pi\frac{d^2}{4} = \pi\,\frac{10.4^2}{4} = 85.00\ cm^2$
- H1=56cm and H2=18cm
- T = is time for water to flow water from h1to h2 It is calculated for each sample separately.

Table6: Permeability test results .

	Control P.A			P.Awith 2% Polypropylene fibers			P.A with 4% Flax- Shives fibers		
S.N	1	2	3	1	2	3	1	2	3
K(cm3\sec)	0.039	0.041	0.041	0.040	0.038	0.042	0.032	0.035	0.034
Average K(cm\sec)	0.040			0.040			0.033		

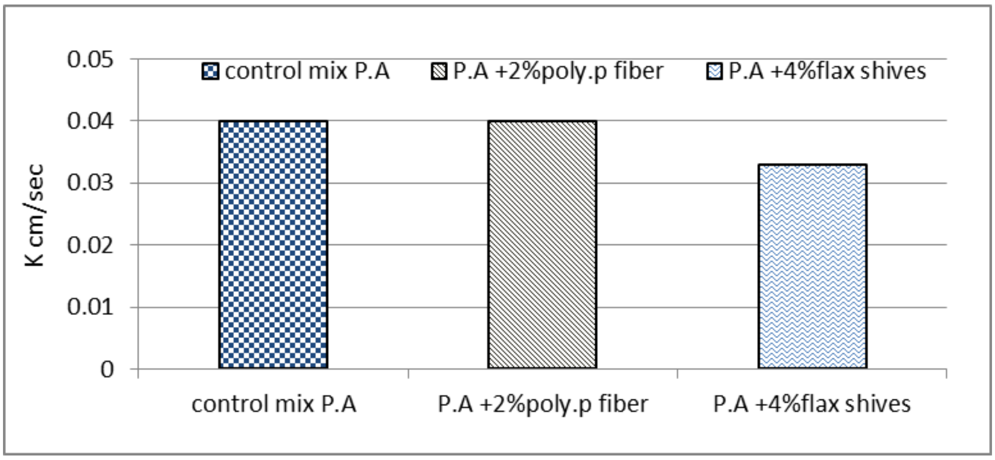

Figure 16: Permeability coefficient of porous asphalt ,porous asphalt with2% polypropylene fiber and porous asphalt with4% flax- shives fiber.

Addition 2% polypropylene fiber to the porous asphalt mixture maintains the same air voids ratio and thus maintains the same permeability coefficient of 0.04 cm/sec. The addition of 4% flax- shives fiber reduced the proportion of air voids, and the permeability coefficient decreased by17.5%.

5.5.3.Effect of polypropylene and Flax-Shives fibers on indirect tensile strength (ITS) of porous asphalt.

The indirect tensile strength test (ITS) reflects the bond cohesion strength between the mortar and the aggregates. In this investigation, the indirect tensile test was conducted to characterize the effect of polypropylene and flax shives fibers on porous asphalt according to ASTM D6931. The indirect tensile strength of the samples could be calculated using equation :2.The results showed in table:7 and figure:17.

$$(\text{ITS}) = \frac{2F}{\pi DH} \qquad (\text{eq :2})$$

Where : ITS = the indirect tensile strength (MPa), H = specimen height (mm), F = the total applied vertical load at failure (N), and D = the diameter of specimen (mm).

Table 7: Indirect Tensile Strength test results.

	Control mix P.A			P.A with 2% polypropylene fibers			P.A with 4% Flax-Shives fibers		
Sample number	1	2	3	1	2	3	1	2	3
F(KN)	10	11	12	15	16	16	11	12	12
ITS (MPa)	0.97	1.063	1.16	1.44	1.54	1.54	1.06	1.16	1.16
Average ITS(MPa)	1.065			1.50			1.12		

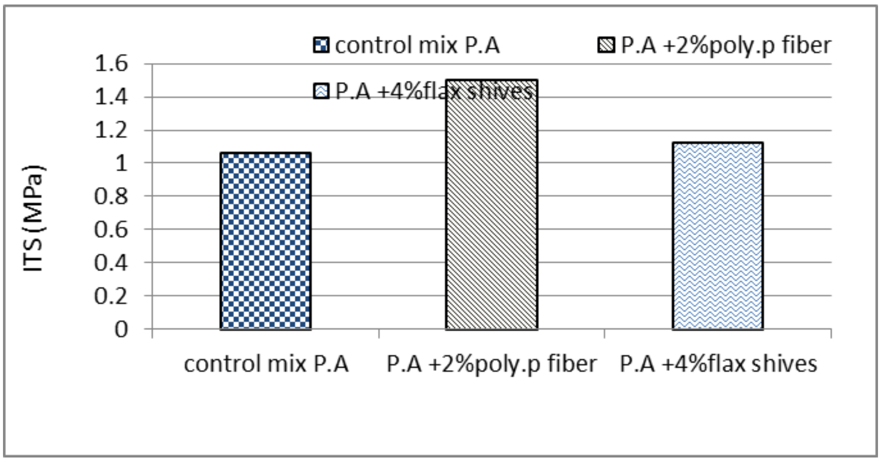

Figure 17: Indirect tensile strength of porous asphalt with2% polypropylene and porous asphalt with4% flax- shives.

According to the results, 2% of polypropylene fiber led to an increase in the value of the indirect tensile strength by 40%. Also, 4% of flax-shives fiber increased indirect tensile strength value by 5.16%.

5.5.4. Effect of polypropylene and Flax-Shives fibers on compressive strength (Cs) of porous asphalt.

The compressive strength test was conducted according to ASTM D1074 and can be calculated using equation: 3.

$$(CS) = \frac{F}{A} \qquad \text{eq(3)}$$

Where: *CS* = the Compressive strength (MPa),

F = the total applied vertical load at failure (N), and A = Area of the specimen (mm^2).

Three samples were prepared from the control mixture of porous asphalt, that contains the optimum bitumen content (3.55%). Three other samples from the mixture with 2% of polypropylene fiber, and the other three samples with 4% of Flax- shives fiber. The area of the specimen surface is 8500mm2. The results showed in table:8 and figure:18.

Table 8: Compressive strength test results.

	Control mix P.A			P.A with 2% polypropylene fibers			P.A with 4% Flax Shives fibers		
Sample number	1	2	3	1	2	3	1	2	3
F(N)	18570	18640	18750	20900	21050	21100	18650	18710	18790
CS (MPa)	2.18	2.19	2.2	2.46	2.47	2.48	2.19	2.20	2.21
Average CS(MPa)	2.19			2.47			2.20		

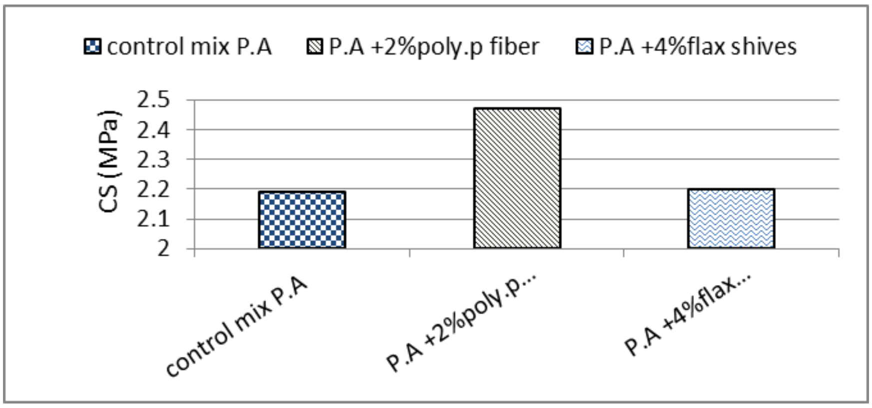

Figure 18: Compressive strength with control porous asphalt, porous asphalt with2% poly propylene fiber and porous asphalt with4% flax- shives fiber.

From the results when 2% of polypropylene fiber was added to the control mix of porous asphalt, the value of the Compressive strength increased by 12.80%, with the value of compressive strength for the control mix without additives reaching 2.19 MPa and increasing to 2.47 MPa. When 4% Flax- shives fiber was added to the control mix of porous asphalt, a slight improvement was observed in compressive strength values, The average compressive strength value increased from 2.19 MPa to 2.20 MPa.

6. Conclusions.

- porous asphalt properties can be improved via both polypropylene and flax-Shives fibers as additives.
- The optimum percentage of polypropylene fiber is 2%, and flax-Shives fiber is 4%. percentage by weight of the optimum bitumen content.
- By adding the optimum percentage of polypropylene fibers, the stability increased
- by 28 % and there is no effect on the voids ratio, flow and permeability in the mixture. Also, The indirect tensile strength increased by 40% and compressive strength increased by 12.80%.
- By adding the optimum percentage of flax- shives fiber, the stability increased by 13.50 % and there is no effect on the value of flow. The percentage of air voids decreases by 1.50%, which affects the permeability of the mixture which decreasesed by 17.50%. The indirect tensile strength increased by 5.0% and there is a slightly improvement in the Compressive strength values

7. References:

1.J.E. Ball, K. Rankin, “The Hydrological Performance of A Permeable Pavement, Urban Water” J. 7 (2010). P.79–90

2.Thomas H. Cahill, P.E. Michele Adams, P.E., and Courtney Marm,”The Right Choice for Porous Pavements”. SEPTEMBER/OCTOBER 2003 P. 3-5.

3.A.Chowdhury, J.W. Button, A. Bhasin, "Fibers From Recycled Tire as Reinforcement in Hot Mix Asphalt", Texas Transp. Inst. (2006)P. 58.

4.W. Shao-peng, L. Gang, M. Lian-tong, C. Zheng, Y. Qun-shan, "Effect of Fiber Types on Relevant Properties of Porous Asphalt", Trans. Nonferrous Met. Soc. China 16 (2006) P 791–795.

5.Márcia Lopes Afonso, Marisa Dinis-Almeida, Cristina Sena Fael, "Study of The Porous Asphalt Performance With Cellulosic Fibres", January 2017.

6.Khairil Azman Masri, Ahmad Kamil Arshad, Juraidah Ahmad and Mohamad Saifullah Samsudin, "Abrasion Loss And Binder Draindown of Porous Asphalt With Nanosilica-Modified Binder" , 2016.

7.Yao Zhao , Lei Tong, and Yating Zhu1, "Investigation on The Properties and Distribution of Air Voids in Porous Asphalt With Relevance to The Pb(II) Removal Performance" July 2019.

8.Anik Gupta Daniel Castro-Fresno Pedro Lastra-Gonzalez Jorge Rodriguez-Hernandez, "Selection of Fibers to Improve Porous Asphalt Mixtures Usingmulti-Criteria Analysis" January 2021.

9.Serkan Tapkın. "The Effect of Polypropylene Fibers on Asphalt Performance", February 2007 .