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Effect of addition of short fibers of poly-acrylic and polyamide to asphalt mixtures

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In Egypt, the flexible pavement represents 100 % of the highway pavements. These roads are exposed to different conditions affecting the behavior of asphalt pavement. These conditions are the magnitude and frequency of loads density, duration of load cycle and other significant variables. The previous variables have serious effect on the asphalt pavements such as cracking, rutting and other distresses. Cracking is one type of failure of asphalt pavement. In order to prevent the cracking progress of asphalt layer, many additives such as polyester and waste materials are used to enhance the resistance of asphalt layers to reflective cracking or fatigue cracking. In this paper, laboratory tests were carried out to study the effect of the application of Poly-acrylic and polyamide produced from STIA Textile Fabric Company as waste materials to minimize the cracking progress of asphalt pavement layers. Marshall, static creep and indirect tensile strength tests are carried out on the mixes containing different percentages of short fibers of poly-acrylic and polyamide. The research results showed that, the application of poly-acrylic of asphalt mixtures could significantly enhance the resistance of asphalt layers to crack progress more than polyamide. In general, the incorporation of poly-acrylic and polyamide in the asphalt mixture can prolong the life of the asphalt pavement layers.

تمثل الطرق استثمارات كبيرة نظرا للتكاليفة الانشائية العالية لها. ويتطلب ذلك المحافظة عليها والإبقاء على نفس حالة الإنشاء الاولية التى كانت عليها خلال العمر الافتراضى لها. ويمثل الجانب الوظيفي للطريق مدى إمكانية التغلب على العوامل التى تؤثر على سلامتة. إلا أن هذه الطرق تتعرض لكثير من الظروف التى تؤثر على مستوى الخدمة بها مما ينعكس بدورة على كفاءتها. ومن العوامل التى تؤثر على سلوك طبقات الرصف أحمال وحدات النقل وتكرارها علاوة على مكونات هذه الطبقات التى تؤدى الى تكون الشروخ والتخدد بالطبقات السطحية بالاضافة الى العيوب الاخرى. وتعتبر الشروخ والتخدد من أهم العيوب التى تؤثر على العمر الافتراضي لشبكات الطرق. لذا اتجهت كثيرا من ألابحاث الى أيجاد افضل الأساليب لتلافى هذه العيوب . ويهدف هذا البحث الى دراسة إمكانية استخدام ألياف النايلون والاكليريك فى الحد من الشروخ المتراكمة بالطبقات السطحية من الرصف. ولتقييم هذه المواد تم استخدام مجموعة من التجارب هى مارشال والضغط المحورى واختبار الزحف باستخدام نسب مختلفة من هذه المواد. وأوضحت النتائج أن استخدام هذه المواد يساهم بشكل كبير فى مقاومة الشروخ التراكمية مما يعطى مردود بإطالة العمر الافتراضي لطبقات الرصف الاسفلتية. كذلك تم استنباط علاقة رياضية تربط بين الضغط الغير محاط وحمل الثبات للخلطات الإسفلتية.

Keywords: Flexible pavement, Poly-acrylic and polyamide, Marshall test, Creep test, Indirect tensile strength test

1. Introduction

The introduction of asphaltic concrete wearing course in Egypt over the past 30 years has brought the problem of the extensive quality control testing. This justified the need to produce mixes that meet the Marshall tolerance requirements. Even when these materials are produced according to specifications they are often inappropriate in areas of high traffic stresses, such as climbing lanes for the rapid rutting and shoving.

In Egypt, about 100% percent of highway pavements are asphalt pavements. The typical asphalt pavement construction of structural highway comprises asphalt surface of about 80 mm thickness with an under-laid strong base course of about 250 mm. Based on the design specifications for highway flexible pavement, the design life of this type of pavement ranges from 8 to 10 years. Unfortunately, pavements must be overlaid in three to four years at most after being opened to traffic. Normally, the overlayer is made with 40 mm asphalt concrete. For this type of

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overlayer, the cracks in the existing pavement will very soon reflect through it. Two or three years later, the pavement will need a new overlayer. For economic reasons, pavements cannot be overlaid often and so cannot be kept in a satisfactory surface condition and structure load bearing capacity. Therefore, the application of fibers and polymer to minimize reflective cracking progress has been investigated by many researchers [1-9]. In this research, Poly-acrylic and polyamide as waste fibers produced from STIA Textile Company in Alexandria were used as reinforcing materials of asphalt pavement over-layer. Five different percentages of fiber were used in experimental works. Traditional tests, Marshall, static creep and indirect tensile strength tests were carried out on the mixes.

2. Materials data

Crushed dolomite and sand obtained from Alexandria-Cairo desert road were selected for the coarse and fine aggregates. Cement dust produced from Alexandria cement Portland Company was used as mineral filler. To describe the physical properties of the above materials, tests were carried out such sieve analysis, specific gravity, abrasion and water absorption. The percent wear after 100 and 500 revolutions are presented in table 1 together with the other results of materials. Asphalt cement produced by Alexandria Petroleum Company was used in this investigation. The average penetration, flash point and specific gravity were 65, 318°C and 1.03, respectively [10].

3. Poly-acrylic and polyamide

Poly-acrylic and polyamide are the waste materials produced from textile manufactures, such as STIA Company in Alexandria. These materials are short pieces of white colour about 10 to 15 cm length, 1 mm thickness. Five levels of Poly-acrylic and polyamide were used in the experimental works.

Table 1
Physical properties of aggregates

Characteristics	Crushed dolomite	Sand	Cement dust
Bulk specific gravity	2.60	2.63	2.75
Water absorption[%]	2.80	-	-
% of abrasion after 100 rev. after 500 rev,	5.60 10.20	-	-

4. Marshall test

4.1. Preparation of Marshall test specimens

One type of mixture containing asphalt cement grade 60/70 pen. and mixes grade (maximum size 9.5 mm for dense mixtures) according to ASTM D3515 for surface course were used in this investigation [10]. To conduct the program of this study, Marshall specimens were prepared at five levels of asphalt content, 4.%, 5%, 5.5%, 6%, 6,5% by the weight of mixtures. These specimens were prepared using the standard Marshall compactor (50 blows on each side).

After determining the optimum asphalt content, we have prepared another sites of Marshall specimens at five levels of poly-acrylic and polyamide addition 0.2%, 0.4%, 0.6%, 0.8%, and 1 % by weight of total mixtures. The way of adding of fiber is very important and must be performed with a great care, so that the poly-acrylic and polyamide added uniformity to the mixtures at the end stage of mix, (after adding the bitumen) and mixing with the mixtures until a homogenous consistency is reached. Marshall test results for different percent of poly-acrylic and polyamide at optimum asphalt content (6.0 percent) are discussed in the following sections.

4.2. Marshall test results and discussions

4.2.1. Stability and flow

Marshall stability and flow are used to measure the ability of a mix to resist a plastic flow. This test method is still an interbreed part of mix design criteria for section of asphalt contents for asphalt mixtures. From tables 2 and 3 as well as fig. 1 it can be noted that in general, Marshall stability were sensitive to fibers in various mixtures. Also, it can be noticed that mixtures of 0.4% Poly-acrylic or polyamide provided the highest Marshall stability values. However, at all fiber contents the stability values of mixtures are higher than those of traditional mixes instead of 1% of fibers. On the other hand, mixtures containing Poly-acrylic have highest stability values than those using polyamide at different percentages. These results may be attributed to the strong bond of poly-acrylic compared to polyamide. Also, this phenomenon may be attributed to the fact that, when the fibers are added, the coating of mix component is better and lead to a better compaction.

The relation between the flow values and percentages of poly-acrylic and polyamide in different mixtures is given in tables 2 and 3. From these tables, we can detect that flow values for mixtures, ranged between 2.5 mm to 3.3 mm. These flow values are within specification limits (2-5mm). On the other hand, it can be seen that, there is no trend between the percentages of additives and flow values.

4.2.2. Density

Tables 2 and 3 illustrate the density values at optimum asphalt content and different percentages of fibers. It can be noticed that there is no significant change in density values at different percentages of fibers. That is because the increase in the density values by increasing the fibers ranged between 3% to 1.7% for Poly-acrylic and polyamide respectively. Generally, it can be concluded that the densities for mixtures containing fibers and conventional mixes are almost equal.

Table 2
Marshall test results at optimum asphalt content [%], {Poly-acrylic}

Marshall properties	Percentages of Poly-acrylic [%]					
	0.0	0.2	0.4	0.6	0.8	1
Stability [kN]	4.0	4.2	4.5	4.5	4.3	3.8
Flow [mm]	3.3	3.0	3.2	2.8	3.0	3.7
Density [gm/cm3]	2.4	2.42	2.43	2.42	2.41	2.42
Air voids [%]	3.2	3.3	3.2	3.4	3.3	3.2

Table 3
Marshall test results at optimum asphalt content [%], {polyamide}

Marshall properties	Percentages of polyamide [%]					
	0.0	0.2	0.4	0.6	0.8	1
Stability [kN]	4.0	4.1	4.2	4.2	4.0	3.4
Flow [mm]	3.3	3.3	3.1	3.8	3.0	3.9
Density [gm/cm3]	2.4	2.40	2.41	2.41	2.42	2.44
Air voids [%]	3.2	3.0	2.8	3.0	3.1	2.9

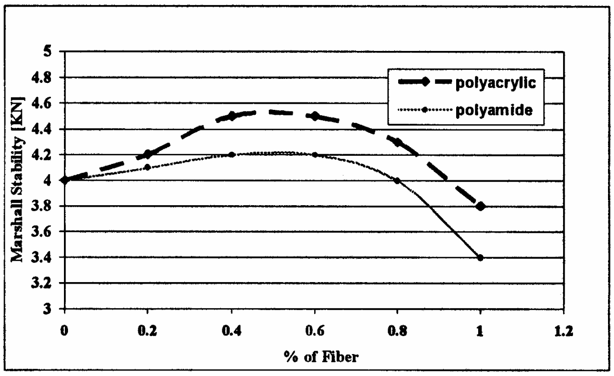

Fig.1. Percentage of fibers versus Marshall stability.

4.2.3. Air void percent

Air void percent at different concentration of fibers is shown in tables 2 and 3. From these tables it can be seen that the polyamide reduced the air voids compared to Poly-acrylic. However, in the mixtures containing Poly-acrylic, the percent of air void are almost equal. The air voids percent is reduced from 3.2% to 2.9% by increasing of polyamide in the mixtures from 0% to 1%. This reduction in the air voids represent 10%. These results may be attributed to the fact that the temperature of mixtures affects the characteristics of polyamide; this leads to the fact that the air voids are filled with polyamide, which leads to the reduction of air voids.

5. Indirect tensile strength test

The tensile strength of asphalt mixtures is a measure of pavement resistance to tensile stresses caused by traffic. For durable asphalt mixtures, high tensile strength values are required. Also, sufficient stiffness values at high temperatures are needed to avoid excessive permanent deformation or rutting. On the other hand, stiffness values should not be very high at low temperature to reduce or eliminate crack. The tensile strain at failure is directly related to cracking of the highway pavement. The occurrence of cracking increases as the failure strain decreases [11,12].

In this investigation, the indirect tensile strength for mixtures containing different percentages of poly-acrylic and polyamide at optimum asphalt contents will be studied. The compression test machine was used for this test as well as for Marshall test. The machine incorporates a test mould with two horizontal dial gauges for determining the amount of lateral deformation at the maximum load. Through the test results, the following eqs. (1) and (3) were obtained for an approximate samples diameter of 100 mm and height from 62 to 64 mm [3].

$$Ts = 2P / \pi d h, \qquad (1)$$

$$\varepsilon_p = (2U / \pi d) \times ((1+3\mu)/(0.273+\mu)), \qquad (2)$$

where μ = Poisson's ratio = 0.3.

$$\varepsilon_p = 6.63\, U / \pi d . \qquad (3)$$

Where:

P is the failure load [N],
Ts is the indirect tensile strength [MPa],
ε_p is the strain at failure [‰],
d is the diameter of specimen [mm],
h is the height of specimen [mm], and
U is the transverse deformation [mm].

The tensile strength of different mixtures at optimum asphalt contents are shown in table 4. Also, fig. 2 illustrates the relationship between indirect tensile strength and percentage of fibers in the mixtures. From this table as well as the figure, it can be noticed that significant change in tensile strength of mixtures containing poly-acrylic compared to polyamide. Moreover, it is clear that the increase of poly-acrylic content leads to increase the tensile strength of mixtures until the highest values then it decreased again. These results may be due to the increase the poly-acrylic more than 0.4% leading to a reduction of bond between the mixtures component and un-homogeneity of mixes. On the other hand, test results show that increases of polyamide in the mixtures do not significantly affect the tensile strength. By adding 0.6% of polyamide, a higher tensile strength value is obtained than other percentages.

Table 4 shows the obtained results of strain at failure for different concentrations of poly-acrylic and polyamide in the mixtures. It can be seen that, mixtures without fibers (traditional mixtures) give a lower strain at failure compared to other mixtures. On the other hand mixtures containing 0.4 % poly-acrylic give a higher strain value at failure (0.041). Also mixtures composed of 0.6 polyamide gave a higher strain at failure compared to the other mixtures

From the above results it can be concluded that, tensile strength can be increased by 1.8 times and 1.4 times by using 0.4% and 0.6% of poly-acrylic and polyamide in asphalt mixtures respectively. On the other hand, the strain at failure is increased by 1.89 times and 1.64 times by using 0.4% and 0.6% of poly-acrylic and polyamide in asphalt mixtures.

6. Relation between Marshall stability and indirect tensile strength

The relationship between Marshall stability values and indirect tensile strength is illustrated in fig. 3. Using the regression analysis

Table 4
Indirect tensile strength [MPa] for different percentages of fiber

% of P.C. or P.A.	Poly-acrylic (P.C.)		Polyamide (P.A.)	
	I.T.S. [MPa]	S. at failure [‰]	I. T. S. [MPa]	S. at failure [‰]
0	1.44	21	1.44	21
0.2	1.54	32	1.50	25
0.4	1.72	41	1.58	28
0.6	1.62	37	1.64	32
0.8	1.54	27	1.50	26
1	1.40	20	1.48	23

Note. (Poly-Acrylic) P.C. and (polyamide) PA
Indirect Tensile Strength I.T.S., Strain S.

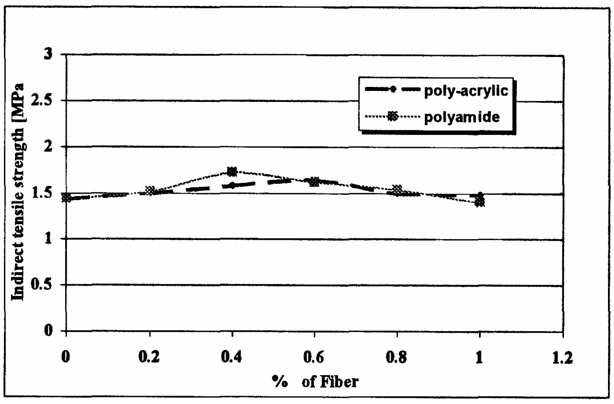

Fig. 2. Percentage of fibers versus indirect tensile strength.

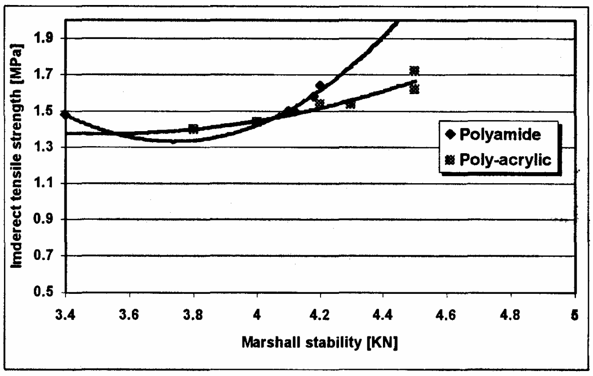

Fig. 3. Relationship between indirect tensile strength versus Marshall stability.

we can find that the relation between Marshall stability and indirect tensile strength values is a polynomial equation with reasonable correlation. The relation is given in the following formula:

Using Poly-acrylic in the mixture,
$Y = 0.2989\,X^2 - 2.0996\,X + 5.0508,$
$R^2 = 0.9117.$

When using polyamide in the mixtures,
$Y = 1.3159\,X^2 - 9.8335\,X + 19.703,$
$R^2 = 0.9356.$

Where:

Y = Indirect tensile strength [MPa], and
X = Marshall stability [MPa].

7. Static creep test

The creep test (unconfined or confined) has been used to measure mixtures characteristics for a variety of predictive methods. Among its users, there have been researchers at SHELL laboratory in Amsterdam. They have conducted extensive studies using the unconfined creep test as a basis for predicting rut depth in asphalt pavements [13]. In the present investigation, unconfined static creep test is conducted by using the consolidation equipment (odometer equipment, Geo. Egypt lab.)

The specimens used in the experimental work, are Marshall specimens, which were evaluated at five different concentrations of fibers (poly-acrylic and polyamide) at optimum asphalt contents (6%). The specimens under test procedure are shown in fig. 4. To conduct the experimental program, the testing load to be taken is 165 kg corresponding to vertical stress 0.2 N/mm2. This stress was applied to specimens for one hour. At this period the vertical deformation is recorded by reading the dial gage and calculated the creep strain ε as well as the stiffness (s) from the following equations number (4) and (5) [4]. The applied load was lifted gradually and the permanent vertical deformation was measured after 30 minutes. The static creep test was performed at room temperature, ranged between 20-23 C°.

$$\text{Creep strain } (\varepsilon) = (\Delta h / h) \times 1000\ [‰], \qquad (4)$$

$$\text{Stiffness } (s) = (\sigma / \varepsilon) \times 10000\ [\text{MPa}]. \qquad (5)$$

Where:
Δh is the total vertical deformation [mm],
h is the height of Marshall specimens [mm], and
σ is the vertical stress [N/mm^2].

Moreover, using the results of creep tests, the following analysis can be made:

- Plastic deformation, and
- Elastic deformation

Figs. 5 and 6 show the relationship between time versus deformation at different concentration of poly-acrylic and polyamide respectively. From figs. 5 and 6 it can be noticed that, asphalt samples experience some amount of instantaneous elastic strain when they are under load. When the applied

Fig. 4. Specimen under static creep test procedure.

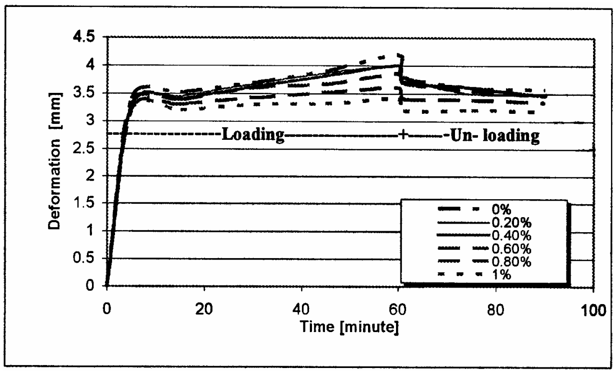

Fig. 5. Time versus deformation for various poly-acrylic concentrations.

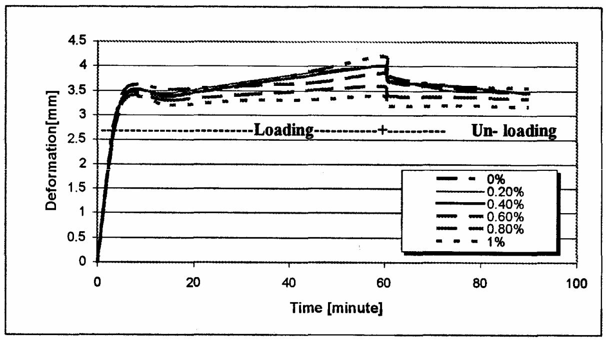

Fig. 6. Time versus deformation for various polyamide concentrations.

Table 5
Creep test results for different poly-acrylic concentrations

% of Poly-acrylic in mix.	Creep test results				
	(ε) [‰]	(s) [mm]	Total vertical deformation [mm]	Plastic (permanent) strain [mm]	Elastic strain [mm]
0	4.2	39.29	0.28	0.23	0.05
0.2	4.0	41.25	0.27	0.23	0.04
0.4	4.0	41.25	0.25	0.22	0.03
0.6	3.9	42.75	0.25	0.22	0.03
0.8	3.6	45.83	0.23	0.22	0.01
1	3.4	48.53	0.22	0.20	0.02

Table 6
Creep test results for different polyamide concentrations

% of polyamide in mix.	Creep test results				
	(ε) [‰]	(s) [mm]	Total vertical deformation [mm]	Plastic (permanent) strain [mm]	Elastic strain [mm]
0	4.2	39.29	0.270	0.226	0.044
0.2	4.14	39.86	0.260	0.224	0.036
0.4	4.0	41.25	0.267	0.226	0.041
0.6	3.92	42.09	0.262	0.228	0.034
0.8	3.88	42.53	0.260	0.195	0.065
1	3.8	43.42	0.247	0.182	0.065

stress is more than the elastic limit, an additional plastic strain is developed. When the load is removed after a short period, only the elastic strain will be recovered, while the plastic strain will remain [14]

The experimental static creep test results for poly-acrylic and polyamide are shown in table 5 and 6, respectively. From figs. 5 and 6, it can be noted that the total creep deformation of two types of mixture were reached at the initial time of loading (after 15 minutes). Thereafter, the deformation remained almost constant. At the same trend, after releasing the load, the permanent (plastic) reached the minimum value after 5 minutes and remained constant. On the other hand, fig. 7 illustrated the relation between creep strain and percentages of fibers in mixtures, from this figure as well as tables 5 and 6 it can be noted that, the specimens with 1% of poly-acrylic or polyamide gave the lowest creep strain, highest stiffness and lowest vertical deformation. At the same trend, mixtures with 1% of fibers have lowest values of elastic deformation. On the other hand, plastic deformation for different mixtures is almost equal. At the same percentage of fiber, the creep strain of poly-acrylic is lower than

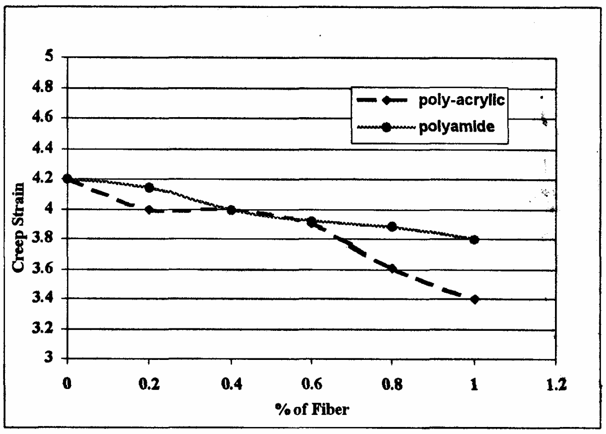

Fig. 7. Percentage of fibers versus creep strain.

those values in polyamide. By using regression analysis, we can find the relation between creep strain values and percentage of fiber in the mixtures in a polynomial form as follows:

For poly-acrylic,
$Y = -0.324\,X^2 - 0.42\,X + 4.1629$,
$R^2 = 0.9729$.
For polyamide,
$Y = +0.1339\,X^2 - 0.5425\,X + 4.2121$,
$R^2 = 0.9843$.
Where:
Y = creep strain [‰], and
X = percentage of fiber in mixtures.

8. Conclusions

Based on the obtained results of the present investigation, the following conclusions can be given:

- Poly-acrylic or polyamide fibers can be added to asphalt mixtures without any problems or any increase in the compactive effort.
- Adding the two types of fibers do not increase the cost of asphalt layer that is because these materials are provided from the waste textile manufacturing.
- Test results show that, at all fiber contents the stability values of mixtures are higher than those of conventional mixes. On the other hand, mixtures containing poly-acrylic have higher stability values than those using polyamide at different percentages.
- It can be concluded that, tensile strength can be increased by 1.8 times and 1.4 times by using 0.4% and 0.6% of poly-acrylic and polyamide in asphalt mixtures. Also, at the same percentages, the strain at failure increases by 1.89 times and 1.64 times, respectively.
- Using the regression analysis, the relation between Marshall stability and indirect tensile strength values can be explained as a polynomial equation with reasonable correlation. The relationship is given in the following formula:
Using poly-acrylic in the mixture,
$Y = 0.2989\,X^2 - 2.0996\,X + 5.0508$,
$R^2 = 0.9117$.
When using polyamide in the mixtures,
$Y = 1.3159\,X^2 - 9.8335\,X + 19.703$,
$R^2 = 0.9356$.
- The optimum suggested percentages that gave the best results for different properties is 0.4% and 0.6 for poly-acrylic and polyamide, respectively.
- Finally, the application of poly-acrylic of asphalt mixtures can significantly enhance the resistance of asphalt layers to tensile stress than polyamide. In general, the application of Poly-acrylic and polyamide to the asphalt mixture can significantly prolong the life of the asphalt pavement layers.

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