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Effect of using Fibre on the Durability of Asphalt Pavement

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Abstract

Using the fibre additives with a uniform distribution in asphaltic concrete mixture is a well-known technique for improving the mechanical properties and durability of asphalt pavement. The purpose of this study is to investigate the effect of preparing fibre and production of the properties of bitumen and asphalt concrete mixture. In this study, a dense-graded aggregation, mineral fibres (asbestos) and synthetic fibres (polyester and nylon) were used. Laboratory studies were done by comparing different rheological properties, mechanical and moisture susceptibility of mixtures of fibres. Results of the penetration and softening point on mixtures of bitumen – fibre show that fibres improve the mixed rheological properties and stiffening effect of fibre properties. The results of Marshall Tests indicate that adding fibres reduces the strength in Marshall and results in the slight increase in the percentage of optimum bitumen content and asphalt percentage of air voids in comparison with typical fibre. The results of the indirect tensile tests showed that the addition of fibres, depending on the percentage of fibres significantly improves the durability of the mixture.

Keywords: Bitumen; Asphalt Pavement; Durability; Mineral Fibres; Synthetic Fibres.

1. Introduction

Durability of asphalt mixtures means the resistance against the effects of traffic and weather conditions. The effect of traffic depends on the wheel pressure, traffic speed and volume of traffic. Effects of environmental conditions, including changes in the properties of bitumen and the effect of temperature and water *Polymerization and Oxidation* and repeated freezing which causes stripping and segregation. Durability of asphalt mixtures can be increased by using the percentage of bitumen and et al.

1.1. Using Fibres in Asphalt Mixtures

Serfys and Samanos [1] used asbestos (Chrysotile), rock wool, fibreglass and cellulose in asphalt pavement. The experimental results on mixtures of bitumen - fibres showed that adding fibre to bitumen increases the Softening point of bitumen – fibre mixture in other words the bitumen – fibre mixture is harder than the original bitumen. The addition of fibres to the asphalt concrete mixture improves the bitumen characteristics and reduces bitumen drainage that reduces the bitumen content and increases the slippery resistance. The fibres increase the bitumen cover on aggregates is reducing and causes hardening of bitumen and improving the bitumen characteristics. The experimental results on the mixture of asphalt with fibre showed that fibre modified mixture have higher fibres resistant to cracking, fatigue, and moisture compared to unmodified mixtures. Also those showed that the mixtures of asphalt with asbestos fibres than control samples, have more bitumen content, but those have a good resistance.

Stuart and Malm Quest [2] used polymer additives, cellulose fibres and wool in aggregates asphalt mixtures (mastic asphalt) to reduce the drainage properties of bitumen. The results of drainage test showed that fibre has a very important effect in reducing the drainage of bitumen and polymer stabilization, but polymers does not have any effect on the drainage of bitumen. Results of wheel rutting on asphalt mixtures containing cellulosic fibres and polymer

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showed that Fibres have a significant impact on improving the permanent deformation of asphalt mixtures, but polymers are effective in improving the rutting content of asphalt mixtures. The results of the indirect tensile strength and reselling modulus at low temperature showed that addition of cellulosic fibres on aggregates asphalt mixtures to prevent cracking of asphalt mixtures at low temperatures is inconclusive.

Brown et al. [3] in order to prevent drainage of bitumen in asphalt mixtures Skeleton aggregates used polymer Styrene-Butadiene-Styrene (SBS), polyethylene, cellulose fibres and rock wool. The results showed that the fibres have no significant effect in reducing wheel rutting but are very effective in reducing the bitumen drainage and polymers have little impact on reducing drainage of bitumen but are effective in reducing wheel rutting.

Jiang and Mac Daniel [4] used polypropylene fibres in the manufacture of asphalt concrete mixtures. The results showed that Adding fibre improves the performance of the permanent deformation.

Freeman et al. [5] used polyester fibres. Marshall Test results showed that asphalt concrete mixtures containing polyester fibres, have optimum bitumen percentage more than the control sample and marshal stability more than the control sample and optimum bitumen percentage increases with increasing fibre. To study the properties of the mixture, the indirect tensile test was conducted in both dry and wet conditions. The experimental results showed that with increasing fibre percentage, the indirect tensile strength of dry asphalt mixtures, slightly reduced but the in a wet situation indirect tensile strength increases.

Hong and White [6], conducted flexural fatigue tests on asphalt concrete slab with polypropylene fibres Flexural fatigue test results showed that the fibres have a significant effect on the fatigue life of the mixture; So that the fatigue life of asphalt concrete beams with fibre (fibre percentages: 0.22 % of the total weight of asphalt mix) doubled the fatigue life of asphalt beams without fibres.

Shang Jing et al. [7] conducted indirect tensile tests on samples of asphalt concrete with polyester fibres and polypropylene. The results showed that the toughness of mixtures containing fibre, 50 to 100 percent increased. Tensile strength of asphalt mixtures containing fibres was slightly greater than the control sample.

1.2. Objectives of the Study

This study evaluates the performance of asphalt mixtures made with asbestos fibres, nylon and polyester and tries to improve properties of asphalt mixture and bitumen and provide pavement with better and more.

2. Material Properties Used in the Experiments

Materials used in this study consist of an aggregate type (limestone), pure bitumen of 60/70, asbestos fibres, nylon and polyester recycled from worn tires. Since the mixture of asphalt containing fibres used in the surface layer of asphalt pavement, aggregate with a nominal maximum aggregate size of 19 mm was used. Tables (1) and (2) respectively show the characteristics of aggregate and bitumen characteristics.

Table 1. Gradation, Density and Water Absorption of Aggregate [9]

No.200	No. 50	No. 8	No. 4	9.5 mm	19 mm	25 mm	Breathalyzer	
8	19	49	65	80	100	100	Top	Percent of pass
5	12	36	50	68	95	100	Mediocrity	
2	5	23	35	56	90	100	Lower	

Table 2. Characteristics of Bitumen in Laboratory

Standard value	Results	Standard number	Unit	Test type
60-70	66	49 AASHTO-T	I mm	Importance
-	2225	72 AASHTO-T	S	C. Bolt Furla viscosity at 98/9 ° C

According to several asbestos mines in the country (four fountains around Fariman mine, mine ligament in Zangycheh in Kashmar and Nehbandan), this material was selected as one of the additive (asbestos fibres were prepared from Mashhad Permit). Polyester fibres were extracted from worn tires. One of the major problems of worn tires is environmental pollution because Worn tires will be discarded every year especially in the industrialized countries. Nylon fibres provided from the factory of nylon in Isfahan. Tables (3) and (4) explain the properties of asbestos fibres, recycled polyester and nylon.

Important note about mixing the fibres with bitumen is that the mixture should be uniformly. However, according to the Journal of MS-22 [9] the minimum and maximum temperatures of 70-60 in mixing bitumen with aggregate in asphalt mixtures, respectively are 130 and 170 ° C. Therefore, in this study, for mixing the fibres with bitumen, the bitumen container was heated to 140 ° C. Then the fibres were added to the bitumen and were stirred with a mixer. Because asbestos fibres ranged in length resulting in a more uniform distribution than other fibres. Serfys and

Samanos [1] used asbestos fibre, rock wool, fibreglass and cellulose ratios of 2, 4, 5, 7, 10 and 13% by weight of bitumen. Freeman et al. [5] concluded that the amount of polyester fibre 0.5 % of the total weight of the mixture, its properties compared to other percentages of fibre (0.2 and 0.35 %), more improved. Hong and White [6] used polypropylene fibres of 0.25, 0.3 and 0.38 of the total weight of the asphalt mixture (bitumen fibre percentage than the percentage of bitumen, is about 5 to 7). The four fibre-bitumen weight ratio of 3, 6, 9 and 12%, was used for softening point and penetration degree experiments.

Table 3. Characteristics of Asbestos Fibres

Degradation temperature of the (° C)	Color	Tensile strength (N/mm2)	specific surface (m2/g)	Length (mm)	Diagonal (Microns)	Density
800	light White	3000	10	0.5-7	0.1-1.1	2.6

Table 4. Characteristics of Polyester and Nylon

Tensile strength (Kg/cm^2)	Melting point (° C)	Density	Length (mm)	Denier	Type of fibre
4000	241	1.4	12±1	7	Polyester
2700	195	1.14	12±1	3	Nylon

Denier: 9,000 m Weight of fibre's length in grams

3. Description of Experiments

When fibre is added to bitumen, rheological properties of bitumen such as penetration point and softening point change and these attributes have a direct effect on the properties of asphalt mixtures. The experiments of softening point and penetration point were done in order to compare the sensitivity of bitumen to changes in temperature and relative hardness of pure bitumen. Changes in softening point and penetration degree at a weight ratio of fibre are shown in figures (1) and (2).

To determine the percentage of optimum bitumen of mixtures, the marshal mix design in accordance with ASTM D 1559-82 method was used. Fibres are added to the bitumen and are mixed with aggregates or added directly to the mixture of bitumen and aggregate. Freeman et al. [5] added polyester fibres (organic) initially mixed with aggregate and bitumen. Hong and White [6] added polypropylene fibres (organic) was added to a mixture of bitumen and aggregate. Kelvin [8] added carbon fibre (mine) to the bitumen to obtain modified bitumen and then mixed with aggregate.

The experiments results on the mixture of bitumen-fibres showed that softening point and penetration degree of bitumen-asbestos mixture was higher than bitumen-nylon mixture and lower than the polyester – bitumen mixture. Asbestos fibres may improve the rheological properties of bitumen better than nylon and polyester. Therefore, a review of research concluded that: mineral fibres are added to bitumen to obtain modified bitumen and then are added to aggregates and the fibre length is too small; however, organic fibres are added to the mixture of bitumen and aggregate and the fibre length is relatively large. Therefore, in this study, the asbestos mineral fibre is added to bitumen to obtain modified bitumen but nylon and polyester fibres are organic fibres that are mixed with aggregate and then were combined to bitumen.

According to the granulating of aggregate, percentages of bitumen were selected 4, 4.5, 5, 5.5, and 6. Table (6) shows the optimum mixture control parameters Marshall asphalt, asbestos fibre, polyester and nylon. Changes in Marshall stability, density, and percentage of cavity of mixtures with 0.4 percentage of different fibres (asbestos, nylon and polyester), respectively, are plotted in figures of (3), (4) and (5). The percentage of optimum bitumen in the Marshall test was used to make the indirect tensile test samples.

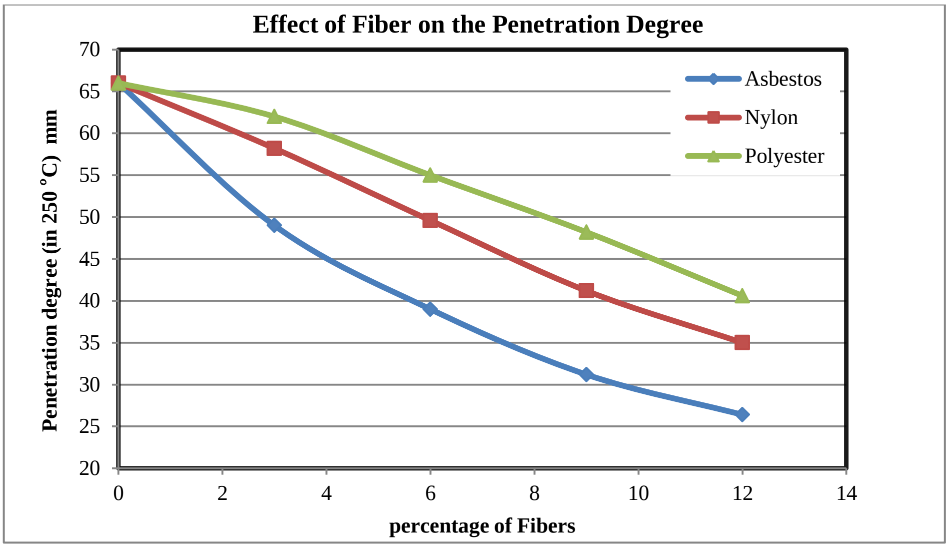

Figure 1. Effect of Fibre on the Penetration Degree of Bitumen- Fibre Mixture

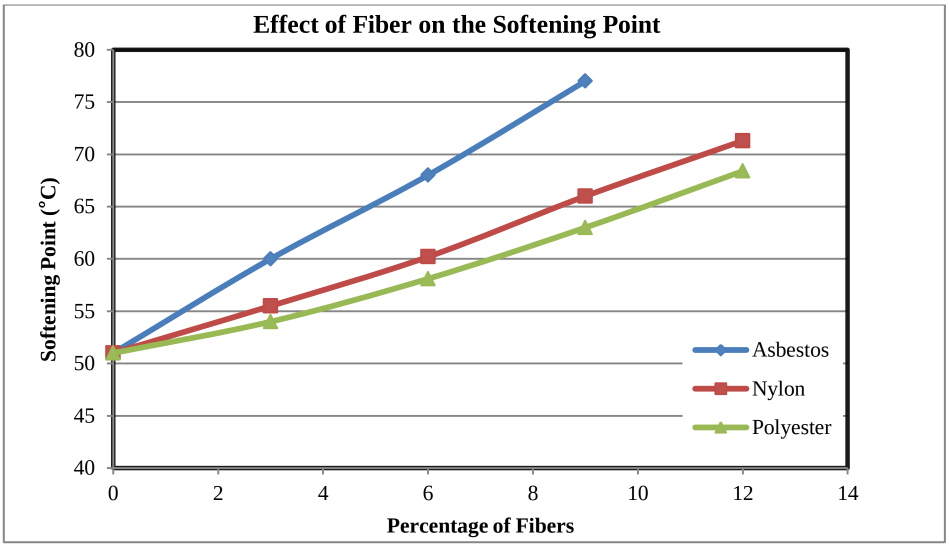

Figure 2. Effect of Fibre on the Softening Point of Bitumen-Fibre Mixture

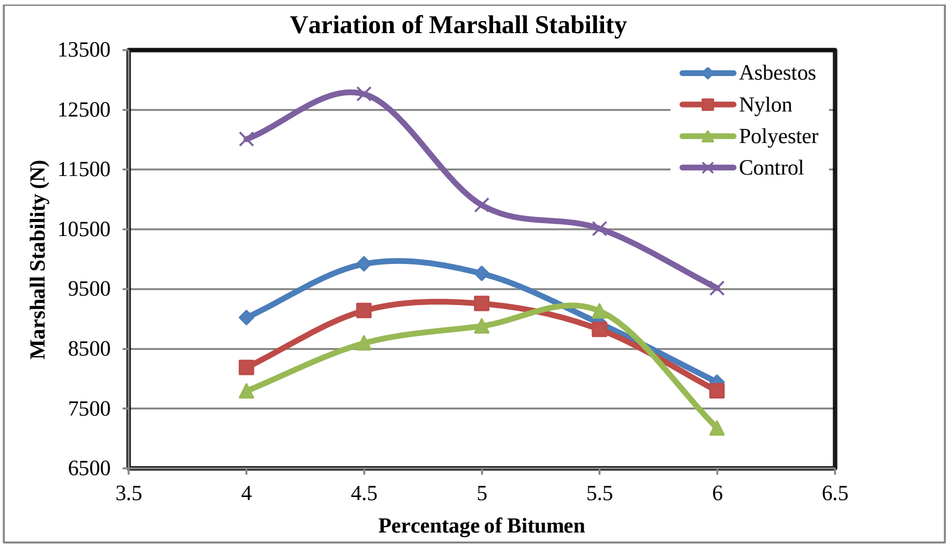

Figure 3. Variation of Marshall Stability in Samples Containing 0.4 % of Different Fibres against Percentage of Bitumen

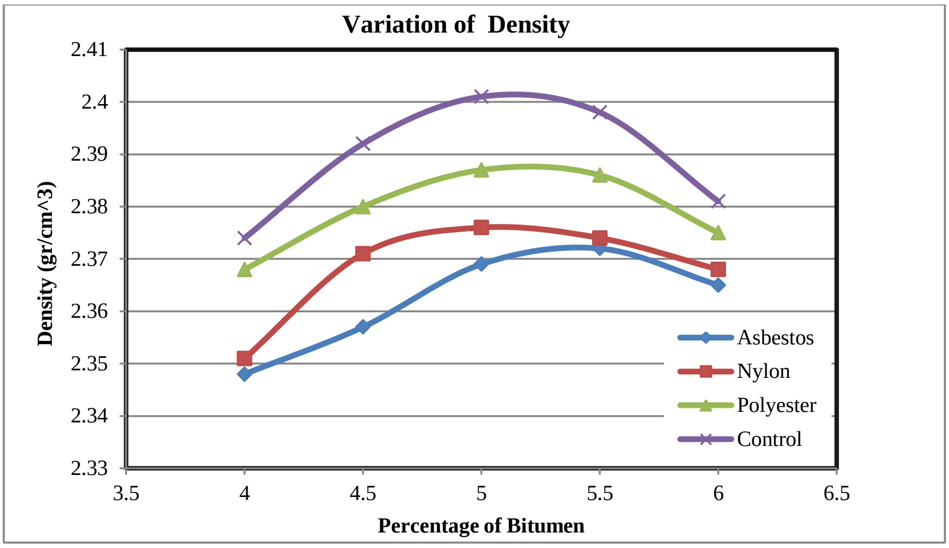

Figure 4. Variation of Density in Samples Containing 0.4 % of Different Fibres against Percentage of Bitumen

Evaluation of indirect tensile tests to determine the tensile strength and durability of asphalt mixtures in both dry and wet conditions was performed in accordance with AASHTO T 283-85. Dry and wet tensile strength, wet and dry toughness and toughness loss were calculated (Toughness is the area under the curve of tensile deformation, deformation when the deformation is twice as peak stress reducers). Indirect tensile samples (7 ± 1) % in the percentage of cavity (air volume expected in the area of asphalt pavement) and the optimum bitumen percentages were built. Indirect tensile tests were done using special loading frame by Marshall Upload speed was 2 inches per minute. To calculate the hard asphalt mixture, there is a need for plotting curve against changes in tensile deformation In addition to Marshall's gauge another gauge was installed to measure the axial deformation. Due to the high speed of loading, power and deformation gauges were used.

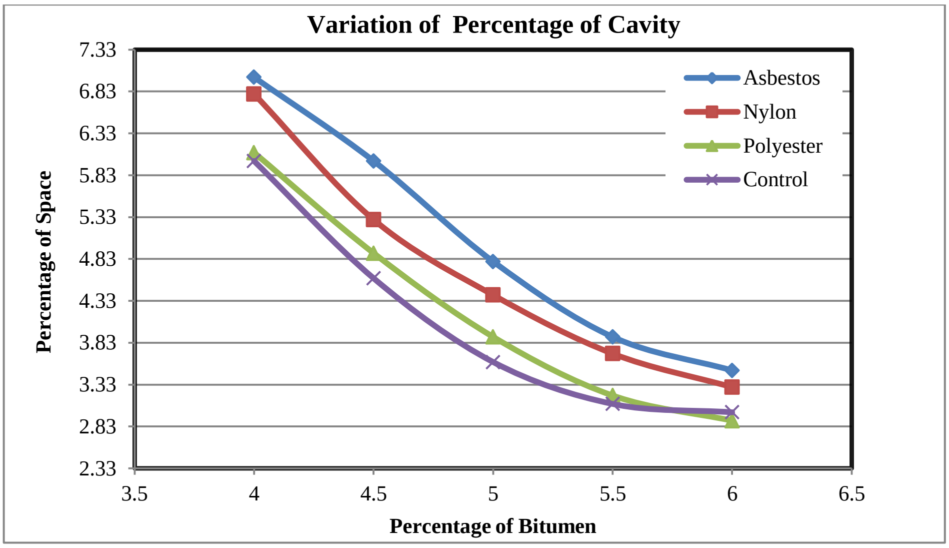

Figure 5. Variation of Percentage of Space in Samples Containing 0.4 % of Different Fibres against Percentage of Bitumen

4. Analysis of Results

4.1. Tests on Bitumen

The following results were obtained from the tests on asphalt – fibres mixture (softening point and penetration point):

It can be seen that the mixture of bitumen – Asbestos has the lowest amount of penetration point and the highest amount of softening point and polyester - bitumen mixture has the highest penetration degree and the lowest softening point. Factors that cause these differences include: size, shape, number of fibres (silk), the lateral area of absorption, the physical state of the surface(rough, smooth) and fibres([1,5]). Polyester fibres have smooth and homogeneous surface and the asbestos have rough surface. Surface roughness of asbestos fibres caused that the lateral surface is greater. In addition, the length of asbestos fibres are variable, but the length of nylon fibres are constant. Variable lengths of asbestos fibres cause a more uniform distribution than other mixes. It can be concluded that fibre causes hardening of bitumen–fibre mixtures.

4.2. Marshall Test

The following results have been obtained from the Marshall tests:

With respect to the figure(6) it can be seen that the percentage of bitumen mixed with fibres 1 to 12.4 % higher than the control samples and the optimum bitumen increases with increasing fibre percent, because when the fibre asphalt mix bitumen is needed to be added to the fibre surface and coating materials. Additional bitumen amount is based on the following parameters: size, shape, number of fibres, the lateral surface, the physical state of the surface (rough, smooth), chemical and physical bonding between bitumen and fibres, fibres kinds and… [1,5]. Asphalt concrete mixtures containing asbestos fibres due to the more lateral surface, high absorption (the hollow fibres) and rough surface, have highest level of optimum bitumen than other mixtures. Asphalt concrete mixtures containing polyester fibres due to the smooth surface, have less absorption level than other mixtures. Maximum and minimum percentage of optimum bitumen in asphalt concrete containing fibres, respectively, are related with 0.6% asbestos and 0.2% polyester(fibre amount is a percentage of the total weight of the mixture). The thickness of bituminous coatings on grains increases resistance against the separation of the mixture. This results correspond with the results of Freeman et al and Serfys and Samanos [1].

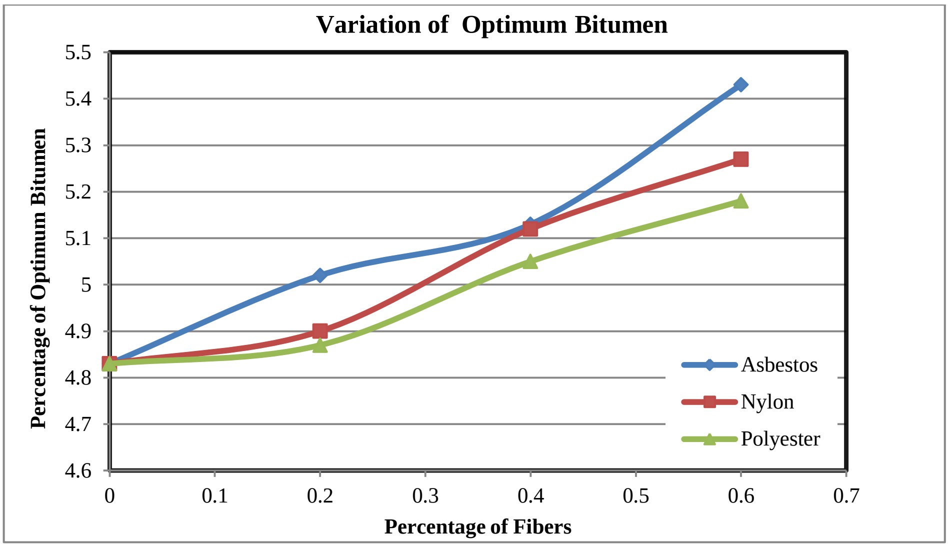

Figure 6. Variation of Optimum Bitumen Samples Containing Different Percentages of Asbestos Fibres, Polyester and Nylon

- According to Table 6 and Figure 7 can be seen that Marshall stability of asphalt concrete samples containing fibres, is less than control samples, 12.3 to 26 %. With increasing percentage of fibres, due to the high percentage of optimum bitumen, Marshall stability decreases. The maximum and minimum values of Marshall stability were related to the specimens containing 0.2 % asbestos and 0.6 % nylon repectively. According to the Asphalt Institute publication MS-22([9]), the minimum value of Marshall stability of asphalt concrete samples for roads with heavy traffic, is 6672 N. Therefor all asphalt mixtures are accepted in terms of Marshall stability.
- According to table (6) it can be seen that the Marshall fluidity of asphalt concrete containing fibres, is greater than control samples (7.3% to 48.8%) and when fibres amount is increased, Marshall fluidity is increased too. The maximum and minimum values of Marshall fluidity were related to the specimens containing 0.6 % polyester and 0.2 % asbestos repectively. According to the Asphalt Institute publication MS-22([9]), the minimum and maximum value of Marshall fluidity of asphalt concrete mixtures for roads with heavy traffic, respectively, is 8 and 16. Therefore all asphalt concrete mixtures, except mixture containing 0.6 % of polyester, are accepted.

Table 5. Parameters of Asphalt Marshall Specimens at the Optimum Asphalt Percent

Density (gr/cm^3)	Percentage of aggregate space (VMA)	Flow (0.25 mm)	Percentage of asphalt concrete gap	Marshall stability (N)	Percent of optimum bitumen	Type of asphalt mix
Design criteria based on publication MS-22[3]						
-	At least 14	8-16	3-5	At least 6672 N		
2.398	14.30	12	3.93	11536.4	4.83	Control
2.380	15.02	12.88	4.38	10118.9	5.02	Asbestos -0.2
2.370	14.98	13.62	4.51	9542.8	5.13	Asbestos -0.4
2.364	15.92	14.48	4.29	8976.1	5.43	Asbestos -0.6
2.392	14.42	13.34	3.97	10054.3	4.9	Nylon -0.2
2.376	15.09	14.36	4.19	9152.7	5.12	Nylon -0.4
2.367	15.35	15.57	4.29	8547.1	5.27	Nylon -0.6
2.392	14.33	14.35	3.90	9908.2	4.87	Polyester -0.2
2.387	14.54	15.49	4.06	8807.1	5.05	Polyester -0.4
2.376	14.89	17.86	4.13	8552.7	5.18	Polyester -0.6

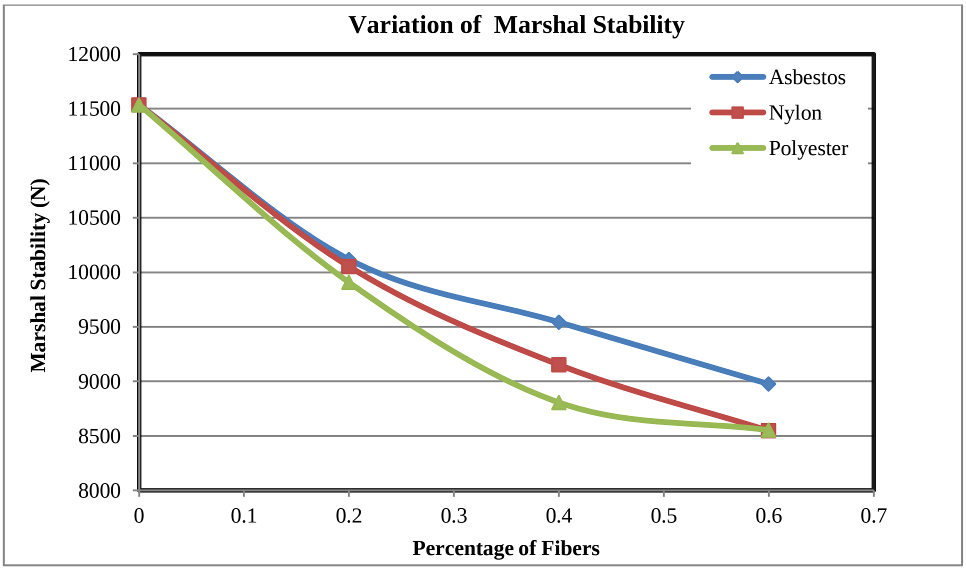

Figure 7. Variation of Marshal Stability Samples with Different Percentages of Asbestos Fibres, Polyester and Nylon, the Optimum Bitumen Content

- According to table (6) it can be seen that cavity percentage of asphalt concrete samples containing fibres is greater than control sample (1% to 14.8%) and when fibres amount is increased, cavity percentage is increased too. The minimum and maximum values of cavity percentage were related to the specimens containing 0.4% asbestos and 0.2% polyester respectively. According to the Asphalt Institute publication MS-22 [9], the minimum and maximum value of cavity percentage of asphalt concrete mixtures for roads with heavy traffic, respectively, is 3 and 5. Therefore all asphalt concrete mixtures are accepted.
- According to Table (6) it can be seen that density of asphalt concrete samples containing fibres is greater than control sample (0.25% to 1.4%) and when fibres amount is increased, density is decreased. The maximum and minimum values of density were related to the specimens containing 0.6% asbestos and 0.2% polyester respectively. The condensation energy of mixtures containing fibres is greater than control sample.
- According to Table (6) it can be seen that cavity percentage of aggregate is greater than control sample (0.25% to 1.4%) and when fibres amount is increased, cavity percentage of aggregate is increased too. The maximum and minimum values of cavity percentage of aggregate were related to the specimens containing 0.6% asbestos and 0.2% polyester respectively According to the Asphalt Institute publication MS-22 [9], the minimum value of

cavity percentage of aggregate is 14. Therefore all asphalt concrete mixtures are accepted.

According to the noted items, we can conclude that the properties of asphalt mixtures with different fibres, except mixture containing 0.6 % of polyester, are according with Asphalt Institute publication MS-22([9]).

4.3. Indirect Tensile Test

The results of the indirect tensile tests on both dry and wet conditions, respectively:

- The maximum tensile strength of asphalt mixtures containing fibres in the dry state is less than control sample(1% to 26.3%) and when fibres amount is increased, tensile strength is decreased; Because asphalt mixtures have more flexibility than the mixtures without fibres and when fibres amount is increased, flexibility is increased. In the same amounts of fibre, asphalt mixtures containing asbestos in the dry state have more tensile strength than mixtures containing nylon and polyester. The reason can be explained thus: mixtures containing asbestos fibres due to the variability of fibre length distribution are more uniform than that of asphalt mixtures containing polyester and nylon. The rough surface of asbestos fibres improved the tensile strength of the asphalt mixture. There isn't significant difference between the tensile strength of asphalt concrete mixtures containing polyester and nylon fibres. For example, changes in the tensile deformation mixed with 0.4 % of fibres in the figure(8) are plotted.

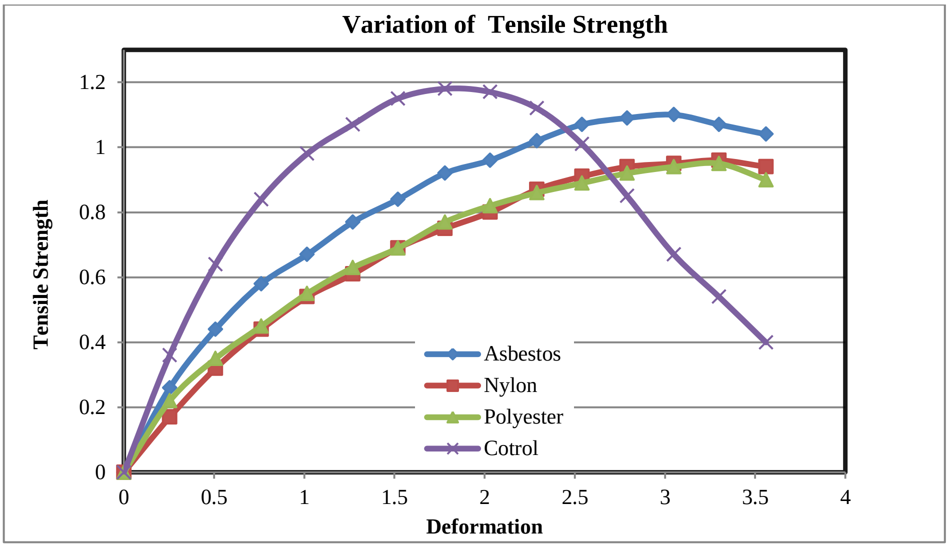

Figure 8- Variation of tensile strength of asphalt concrete mixtures 0.4 percent of the fibre deformation

The maximum tensile strength of asphalt mixtures containing fibres in the wet state is greater than control sample (except for mixtures with 0.6 nylon and polyester fibre percentage). Because the mixtures containing fibres have greater percentage of optimum bitumen than the control sample. Increasing the percentage of optimum bitumen causes increasing the thickness bitumen coating. As the figure above you can see with increasing of asbestos fibres, tensile strength mixtures containing asbestos increase too, but in mixtures containing nylon and polyester, tensile strength in wet state increases and then decreases; Because with increasing fibres, cavity percentage of asphalt concrete increases. In other words, mixtures containing fibres have more the pores than the control sample. As a result, the mixture of air and water easily penetrates and tensile strength is reduced. It should be noted that however, increasing fibre, increasing the thickness of the material to be coated bituminous mixtures to increase durability but also increases durability and reduces pores are. Thus increasing the fibre is somewhat acceptable.

Figure 9 shows the variation of tensile strength ratio of asphalt concrete mixtures with different amounts of asbestos, nylon, and polyester fibres and control sample. If the tensile strength ratio is close to one, it is indicative of the high durability of asphalt concrete mixtures in environmental conditions. The minimum tensile strength ratio is 0.7 [11] that in the case of all asphalt concrete samples have been fulfilled. Tensile strength ratio of a mixture containing fibre is greater than the control sample. The maximum and minimum, respectively, is related with the sample fibres mixed with 0.6% of asbestos fibres and polyester.

In order to investigate the performance of asphalt concrete mixtures containing fibres due to moisture-induced damage, in addition to tensile strength and its ratio, toughness and it's loss was used. The area under the stress - strain curve is more; toughness of asphalt mixture (ability of energy absorption) is higher. According to Figure 10 and Table 7, it can be seen that dry and wet toughness of asphalt mixtures containing fibres is higher than that of the control sample. Also with increasing fibre, toughness is increased, because with increasing fibre, asphalt mixtures are more flexible and thus its deformation increases. With increasing deformation, the area under tensile strength-deformation curve is high, so toughness increases. With increasing fibre percentage, the percentage of toughness loss of asphalt mixtures decreases, that it's indicating resistance against damage caused by moisture; with increasing thickness of the fibre coating of bituminous aggregate increases. According to the results of the indirect tensile test (indirect proportion to the percentage drop torturous stretch) it is observed that the best percentage of fibres were 0.6, 0.4 and 0.4 percent among the mixtures containing asbestos fibres, nylon and polyester.

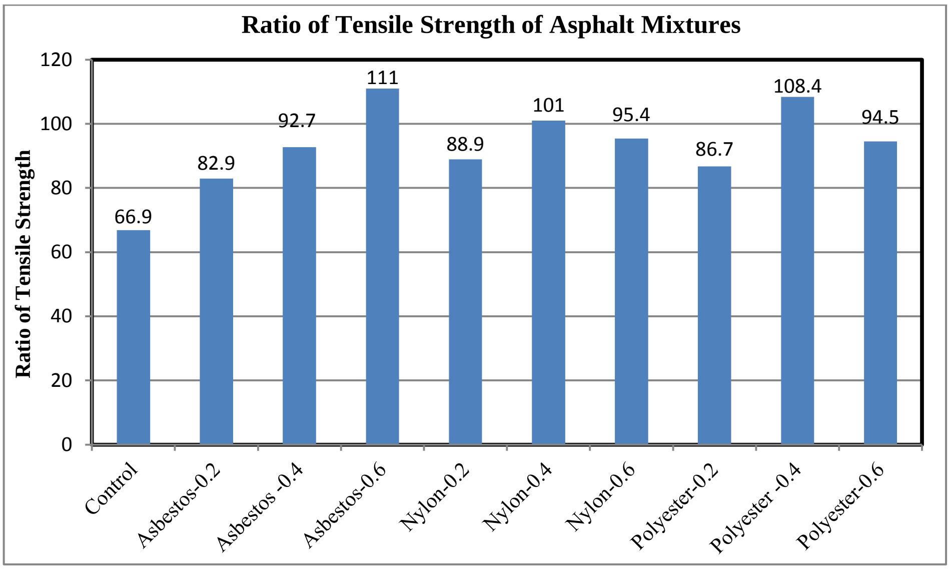

Figure 9. Ratio of Tensile Strength of Asphalt Mixtures Containing Different Percentages of Asbestos Fibres, Polyester and Nylon

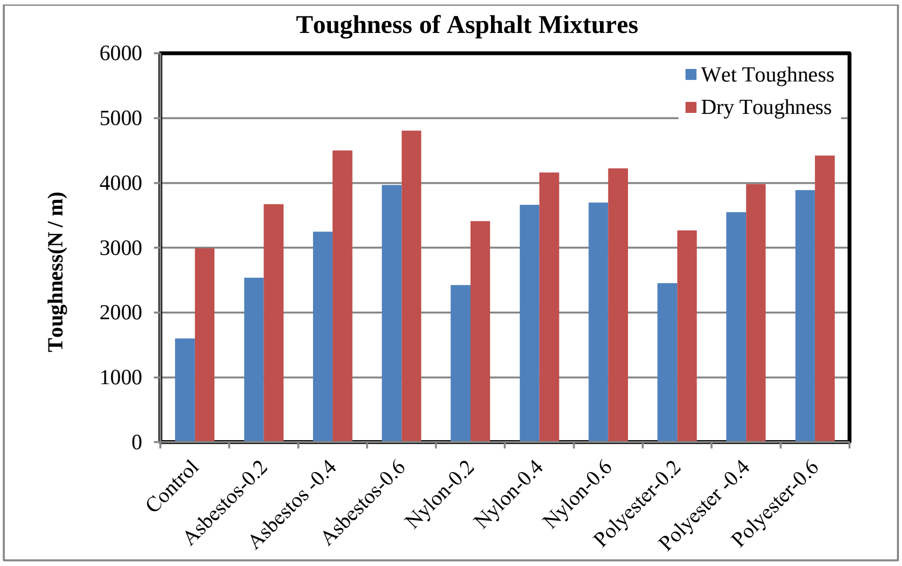

Figure 10. Variation in Dry and Wet Toughness of Asphalt Concrete Mixtures Containing Different Percentages of Asbestos Fibres, Polyester and Nylon

Table 6. Values of Drop Torturous and Demanding Asphalt Concrete Specimens with Different Fibre

Percent of tolerance drop	Wet tolerance (N/m)	Dry Tolerance (N/m)	Type of mixture		
46.5	1601.5	2992.1	control		without fibres
30.8	2538.7	3670.3	0.2	Asbestos	With Fibre
27.9	3248.7	4503.4	0.4		
17.5	3966.2	4805.7	0.6		
28.9	2423.2	3408.7	0.2	Nylon	
12	3662.7	4163.1	0.4		
12.5	3695.7	4225.3	0.6		
24.9	2453.6	3269	0.2	Polyester	
10.9	3550.9	3985	0.4		
12	3891.3	4421.3	0.6		

5. Conclusion

According to the previous contents, what can be concluded that adding fibre to bitumen causing it to be establized and increasing slippery resistance. Stabilization power depends on some factors such as shape, size, lateral surface, absorption percentage and fibres percentage. Also adding fibre to the asphalt mixtures causes increasing tensile strength ratio and toughness that is indicated increasing durability and decreasing cracking of asphalt mixtures. Asphalt mixtures with 0.4% fibre is better than other fibres (0.2% and 0.6%), in order to improve properties of asphalt concrete mixtures. According to the lower percentage of bitumen in mixtures containing polyester fibres and it's lower cost, funding costs for polyester samples are lower than other samples. Therefore, it's recommended to use polyester fibres in further research.

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