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Investigating the Properties of Nylon Fiber Reinforced Asphalt Concrete

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Abstract**-** The performance of asphalt pavements is highly dependent on the mechanical properties of asphaltic layers. Improving the mechanical properties of asphaltic mixtures by fiber reinforcement is a common method. Randomly distribution of fibers in the bituminous mixtures and placing between the particles develop reinforcing property in all directions in the mixture and improve their engineering properties. In this research, the effects of the nylon fiber length and content on some engineering properties of a typical binder course asphalt concrete have been investigated. The fibers at different contents of 0.3, 0.4 and 0.5% (by the weight of total mixture), each at three different lengths of 10, 25 and 40 mm have been used, and the properties of the mixtures, such as, volumetric properties, Marshall stability, flow, Marshall quotient, indirect tensile strength and moisture damage have been studied. It is found that the highest Marshall quotient is obtained by using 0.4% of 25mm long nylon fibers. The results also show that the indirect tensile strength and tensile strength ratio, which is an indication of moisture damage of asphalt concrete, decreases with increasing the length of fibers and fiber content.

Keywords**-** *asphalt concrete, moisture damage, nylon fiber, tensile strength*

I. INTRODUCTION

In Iran, almost all the urban and rural highways are paved with asphalt concrete. Today, an estimation of 100 million tons of hot mix asphalt is produced and placed in pavements in Iran annually, costing about 6 billion US dollar. In recent years, due to the cutting off the subsidiaries on the oil products by the Iranian government, the price of bitumen has raised dramatically. Therefore, preservation of the asphaltic layers for a longer time is environmentally and economically beneficial. It can be achieved by improving the mechanical properties of the asphaltic concrete.

Like any type of paving material, asphalt concrete is subjected to distress mechanisms which lead to deterioration and failure over time. However, asphalt concrete is more sensitive than the other materials [1]. Distresses are the result of one or more factors, including magnitude and type of load, environmental conditions, material characteristics and material interactions. Permanent deformation (rutting), fatigue cracking, thermal cracking and raveling are the major pavement distresses that challenge pavement engineers. With an attempt to minimize or slow the distresses, scientists and engineers are constantly trying to improve the performance of asphalt pavements, by which the service life of the pavement can be extended and the investment can be saved. Reinforcement of asphalt concrete using different materials is one approach for improving its performance. Reinforcement consists of incorporation of certain materials with some desired properties within other material which lack those properties [2]. One method of reinforcing a material is through use of fiber, as randomly distribution within the material or applying oriented fibrous materials, e.g. Geo-synthetics family. Inclusion of fibers in paving material interconnects the aggregate particles, through which the tensile strength is increased. This interconnection may allow the material to withstand additional strain energy before occurring crack or fracture. It is thought that the addition of fibers to asphalt enhances material strength and fatigue characteristics while adding ductility. In addition, fibers have the potential to increase the dynamic modulus [3], moisture damage resistance [4], creep compliance, permanent deformation resistance [5], freeze-thaw resistance [6], ageing resistance and resistance against reflective cracking [7] of asphalt concrete. It has been found that the fibers have the ability to prevent the formation and propagation of cracks in asphalt concrete [2]. Another application for fibers in asphalt mixtures is to prevent asphalt binder drain down in gap graded mixtures [8]. Another application of fibers in asphalt is for increasing the electrical conductivity of the asphalt mixtures, which is used for deicing, healing the cracks and as solar collector for heating adjacent buildings [9, 10, 11, 12].

Although a number of research can be found in literature on the subject of fiber reinforced asphalt concrete (FRAC) properties; however, they are limited to few fiber types and contents, and the effects of the length of fiber has not been well documented. This paper is prepared in the frame of a research work conducted to investigate and compare the effects of fiber content and length on the performance related properties of asphalt concrete for nylon fiber.

II. MATERIALS

TABLE I. SPECIFICATIONS OF THE BITUMEN

Test	Standard	Results
Density in 15˚C	ASTM-D70	1.016
Penetration in 25˚C (0.1mm)	ASTM-D5	66
Softening Point (˚C)	ASTM-D36	49.1
Ductility in 25˚C (cm)	ASTM-D113	150
Solubility in Trichloroethylene %	ASTM-D2042	99.8
Flash Point (˚C)	ASTM-D92	298
Loss in weight after thin film oven test %	ASTM-D1754	0.03
Retained penetration after thin film oven test %	-	98
Ductility after thin film oven test (cm)	-	94

TABLE II. PROPERTIES OF THE NYLON FIBERS

Properties	Original Length (mm)	density (gr/cm^3)	Tensile Strength (MPa)	Melting point (˚C)	Elastic Modulus (MPa)	Moisture Absorption %
Value	50	2.8	480	172	3670	0

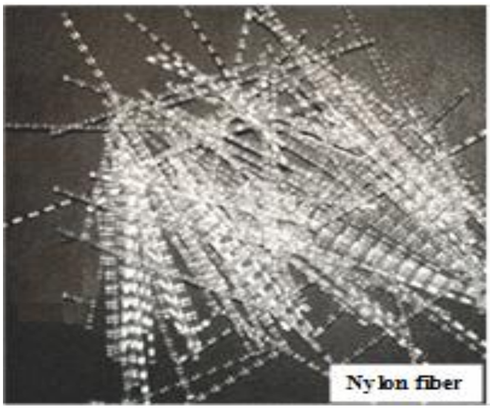

Figure 1. Nylon fibers

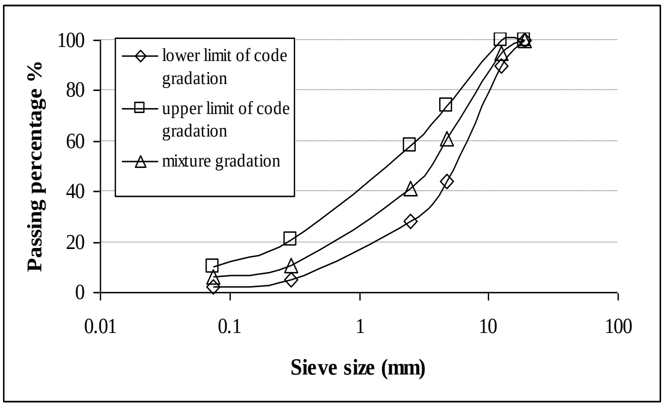

Figure 2. gradation of the mixture aggregates

TABLE III. AGGREGATES PROPERTIES

Properties (tests) / Materials	Sand Equivalent% ASTM-D2419	Los Angeles Abrasion Test ASTM-C131	Plasticity Index AASTM-D4318	Angularity in two sides % ASTM-D5821	Moisture Absorption %	Density ASTM-C127,128 ,D854	Flakiness BS 812	Loss in Magnesium Sulfate Solution % ASTM-C88
Coarse aggregate	-	21	-	85	1.6	2.607	12	1
Fine aggregate	53	-	N.P	-	2	2.593	-	1
Filler	-	-	N.P	-	-	2.72	-	-

III. RESEARCH METHODOLGY

Review of literature shows that the effects of fiber length and content on the mechanical properties of asphalt concrete have not been well documented. Therefore, in this research, nylon fibers, which have not been sufficiently investigated in previous studies, have been used in different lengths and contents for reinforcing a typical asphalt concrete of binder course with a maximum aggregate size of 25mm. Using the same aggregates, gradation and bitumen, the effects of fiber length and content on some engineering properties of asphalt concrete, including Marshall stability, flow, volumetric properties, indirect tensile strength and moisture damage have been investigated. The fibers were included in the mixture at three different lengths of 10, 25 and 40mm, each at three percentages of 0.3, 0.4 and 0.5, by the weight of total mixture. In total 10 compositions were investigated, including the mixture without fibers as the control mixture.. According to the Marshall mix design method, the optimum binder content of the control mixture was determined to be 5.2%. By evaluating the volumetric properties of the fiber reinforced mixtures, the optimum binder content of the mixtures containing 0.3, 0.4 and 0.5%, determined to be 5.5, 5.6 and 5.7%.

IV. SPECIMEN FABRICATION

The specimens for the experiments of this research were made using Marshall compactor, according to ASTM D1559 standard method. Cylindrical specimens, 100mm in diameter and, approximately, 65mm in height were fabricated. The required aggregates were weighed and heated in oven at 172˚C for 4 hours, and the bitumen was heated at 150˚C. To make sure that the fibers are properly dispersed in the mixture, various methods of addition were evaluated. It was found that the addition of the fibers at the final stage of mixing minimizes the flocculation of the fibers in the mixture. Therefore, the fibers were added to the mixture after addition of the bitumen to the aggregates and completing the coating of the aggregates by bitumen. Then, the hot mixture was placed in the Marshall compactor mold and compacted by the automatic compacter by 75 blows at each side. After 24 hours, the specimens were removed from the mold and used for the desire testing program.

V. EXPERIMENTS

A. Marshall tests

The Marshall tests were conducted according to ASTM D1559. The specimens were placed in water tank set at 60˚C for 30 minutes, after which were loaded using the Marshall test set up, at a constant rate of 50.8mm/min, and the force required for breaking the specimen was measured at the Marshall stability, and the diametrical deformation of the specimen at failure was measured as flow. The Marshall quotient was calculated by dividing the Marshall stability to the flow, which is usually used as an indicator for the strength against permanent deformation.

Before doing the Marshall tests, the bulk density of the compacted mixtures was measured according to ASTM D2726 standard method. The maximum theoretical density of the loose mixtures was also measured according to ASTM D2041 standard method. Using the bulk and the maximum theoretical density of the mixtures, and other required data, the air voids content of total mixtures (VTM), the voids in mineral aggregates (VMA), and the voids filled with asphalt (VFA), were determined using the equations presented in Asphalt Institute Manual [13Asphalt Institute, 1997].

B. Indirect tensile strength tests

The indirect tensile strength tests were conducted at 25˚C according to the ASTM D6931 standard method. The specimens were immersed in water tank set at 25˚C for 30 minutes, after which placed in ITS frame and loaded by Marshall test set up at a rate of 50.8mm/min until failure (Figure 3). The required force for breaking the specimen was measured and the indirect tensile strength was calculated using Equation (1).

$$S_t = \frac{2000P}{\pi t D} \tag{1}$$

In which, S_t is the indirect tensile strength in kPa, P is the maximum applied load for breaking the specimen in N, D is the specimen diameter in mm, and t is the thickness of specimen in mm.

ASTM D4867 standard test method has been used for evaluating the moisture damage property of the fiber reinforced mixtures. The specimens of each composition were divided into two groups. The specimens in one group, known as conditioned specimens, were saturated at 55 to 80% of their air voids, by placing them in water and using vacuum pump. Then, they were placed in a water bath set at 60˚C for 24 hours, and, then, in a water bath set at 25˚C for one hour, before conducting the indirect tensile test. For the specimens in the other group, known as unconditioned specimens, the indirect tensile test was conducted after placing them in the water bath set at 25˚C for 30 minutes. The ratio of the indirect tensile strength of the conditioned specimen to that of unconditioned specimen was calculated as tensile strength ratio (TSR), which is used as a criterion for evaluating the moisture damage potential of asphaltic mixtures.

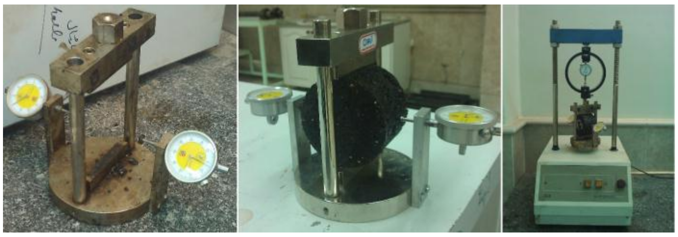

Figure 3. Indirect tensile strength test set up

VI. TEST RESULTS AND DISCUSSIONS

A. Volumetric properties

Air voids content of compacted mixture (VTM), voids in mineral aggregates (VMA), and the voids filled with asphalt (VFA) are the three important volumetric properties of asphalt concrete which can largely affect the performance of the mixture, and are considered in the mix design process to satisfy the limitations specified by the specifications. Figures 4, 5 and 6 show, respectively, the VTM, VMA and VFA of the mixtures. As can be seen, the air voids content of the mixtures increases with increasing the length of fiber and fiber content of the mixture, which confirm the findings of previous researchers [14, 15]. The increase of air voids content with increasing the fiber length and content is attributed to the increase of resistance against densification and the displacement of aggregate particles. Iranian specification requires the minimum and maximum of air voids content of asphalt concrete for binder coarse to be 3 and 6%, respectively. Therefore, all of the mixtures meet the specification requirement. The results also show that the voids in mineral aggregate (VMA) increases with increasing the fiber length and content. The VMA include the volume of air voids and the effective bitumen in the mixture. The minimum VMA required by the specification, for the asphalt concrete with the maximum aggregate size of 25 mm is 13%, which is satisfied by all the mixtures. The results of voids filled with asphalt (VFA) in Figure 6 show that, in an opposite trend of the VTM, VFA decreases with increasing the fiber content and length. The minimum and maximum values of the VFA of asphalt concrete for heavy traffic are defined by specification to 60 and 75%, respectively. As can be seen in Figure 6, all the mixtures meet the requirement of specification.

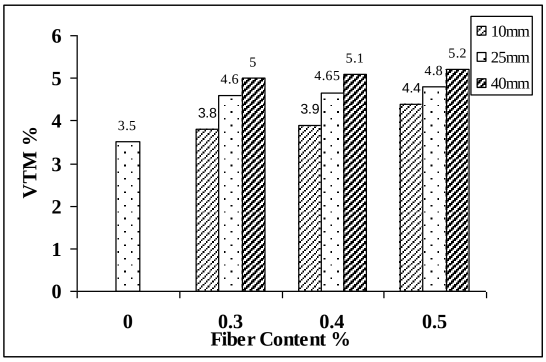

Figure 4. VTM of mixtures

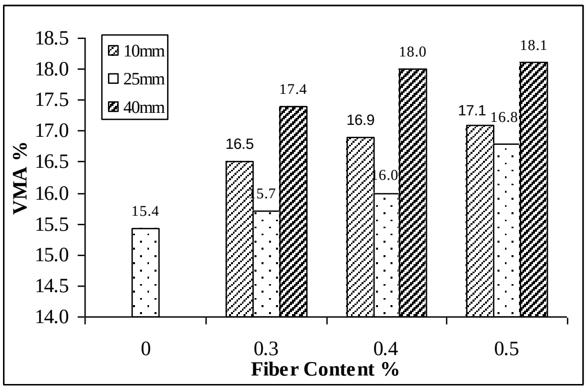

Figure 5. VMA of mixtures

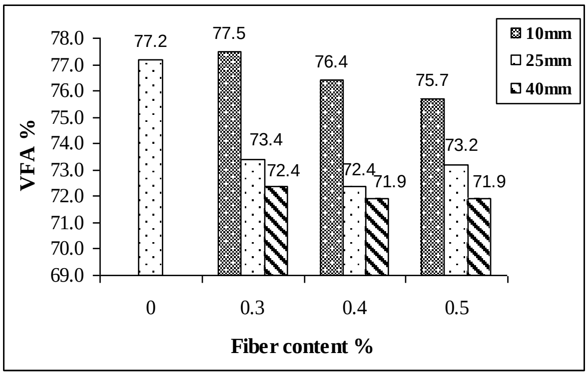

Figure 6. VFA of mixtures

B. Marshall tests results

Figure 7 shows the variation of Marshall stability with nylon fiber content and fiber length. As can be seen, except the mixture containing 0.5% of 40mm fibers, the Marshall stability of all the mixtures containing fiber is higher than the control mixture. The results also show that, at each fiber length, the peak Marshall stability is associated with 0.4% of fiber content, beyond which the Marshall stability decreases with increasing fiber content. In addition, at each fiber content,, the highest Marshall stability is associated with the mixtures containing 25mm long fibers. The higher Marshall stability of the fiber containing mixtures can be explained by the reinforcing effects of the fibers in the composite. However, excessive fiber content and length of fiber results in increasing air voids content and reduction of voids filled with asphalt, which adversely affect the stability of the mixture.

The fundamental equations of composite materials are used for explaining the results. According to the "law of mixtures" [16] the modulus of fiber reinforced mixture can be expressed as:

$$\sigma_c = \sigma_f V_f + \sigma_m V_m \tag{2}$$

Where, σ and V are the strength and volumetric fraction, respectively, and the indices of f, c and m represents the fiber, composite and matrix. Equation (3) states that the strength of the composite increases with increasing the fiber content, which is consistent with the experimental results for the mixtures containing up to 0.4% of fiber content. However, beyond this level, the results do not obey the law. This may be described by the concept of "slippage ratio", developed by Shao et al. [17]. Based on this theory, when a pressure load is applied on a fiber reinforced matrix, as in Marshall test, it can make an interfacial shear stress, τ, between fiber and matrix, and consequently causes a tensile stress in the fiber. It is also assumed that, during the extension of the fiber by the generated tensile strength, a certain length of the fiber from both ends can slip, while a central region at the middle, called non slippage region, is gripped by the matrix. The slippage ratio, λ, is defined as the ratio of the length of slipping portion to the whole fiber length, L_f. Therefore, the length of fiber from each end, which can slip is $\lambda L_f/2$. The slippage ratio λ represents the value of fiber cooperation in the bearing of tensile stresses resulted by the compressive force in Marshall Test. The higher the slippage ratio, the lower the assistance of the fibers in bearing of the tensile stresses by the composite and vice versa. The slippage ratio has been defined by the following equation [18]:

$$\lambda = (d_f . E_f . \varepsilon_f \big/ (2.\mu.G.L_f) \tag{3}$$

Where, μ is the coefficient of friction between fiber and matrix, G is the normal pressure, d_f, E_f and ε_f are, respectively, the diameter, elastic modulus and strain of the fiber. Equation (3) show that, the slippage ratio, decreases with increasing the length of fiber, meaning that the fiber-matrix cooperation in bearing the tensile stresses increases, which is consistent with the experimental results, for the length up to 25mm. However, beyond that level, for the fiber length of 40mm, the decrease of the stability is attributed to the increase in voids content. As seen earlier in this section, based on the law of mixture, the elastic modulus of a composite should increase with increasing the fiber content, which was seen to be not true for the experimental results of this research. It was seen that, the Marshall stability of the Nylon fiber reinforced mixtures, decreases with increasing the fiber content beyond 0.4%. This can be described by the adverse effects of increasing of air voids content and the slippage ratio by increasing the fiber content. The coefficient of friction between the fiber and matrix decreases by increasing the fiber content, which results in increasing the slippage ratio and reduction of cooperation of fiber-matrix.

Figure 8 shows the variation of flow with fiber content of the mixtures. As can be seen, independent of fiber length, the minimum flow is achieved at 0.3% of fiber content, beyond which the mixtures show a softening behavior and the flow increases with increasing the fiber content. It is also observed that the lowest and highest flow is associated with the mixture containing 25 and 40mm fibers, respectively. This can be described by the effects of fiber content on the air voids content.

Marshall quotient is used as an indicator of the resistance of asphaltic mixtures against permanent deformation [18]. Figure 9 show the variation of the Marshall quotient of the mixtures with fiber content and length. As can be seen, up to a certain level of fiber content and fiber length, the Marshall quotient increases with increasing the fiber content and length, beyond which a reduction in the value is observed. However, all of the fiber reinforced mixtures have a higher Marshall quotient than the control mixture without fiber, with the highest quotient for the mixture containing 0.4% of 25mm fibers.

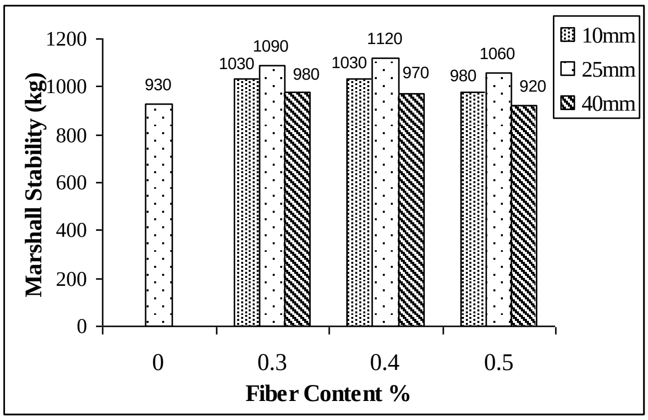

Figure 7. Marshall stability of mixtures

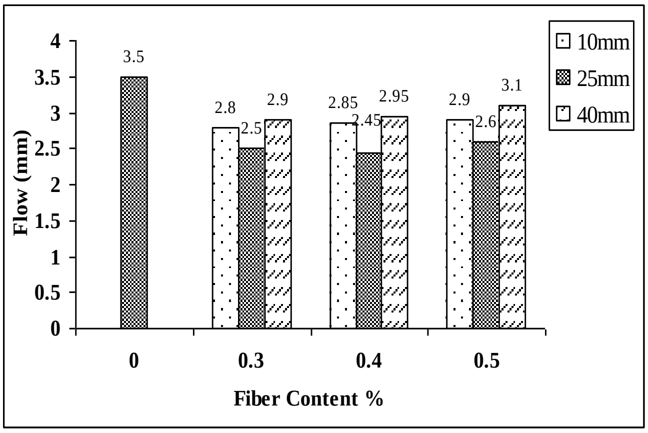

Figure 8. Flow of the mixtures

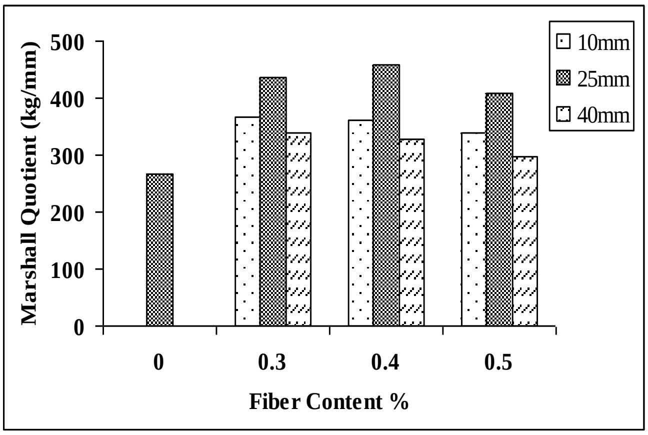

Figure 9. Marshall quotient of mixtures

C. *Indirect tensile tests results*

Figure 10 shows the variation of indirect tensile strength of the mixtures with fiber content and length. As can be seen, except a slight increase of the tensile strength for the mixture containing 0.3% of 10mm fibers, the indirect tensile strength of the fiber reinforced mixtures is lower than the control mixture, which confirms the findings of previous research studies [17]. It can be stated that, in general, the indirect tensile strength decreases with increasing fiber length and content. Although choosing an appropriate amount of fiber content and length can result in a higher tensile strength; however, the reduction of the indirect tensile strength of fiber reinforced mixtures is not an important issue, as many research have resulted that the fibers increase the ductility and energy absorption of the mixture and increase the fatigue life by preventing the crack development in the mixture. In this research, this was observed by evaluating the specimens after failure in indirect tensile strength test, which was revealed that the mixtures maintain their integrity after failure. As the potholes develop after crack occurrence on the surface, it can be said that the fiber reinforced mixtures postpone the pothole development.

Figure 11 shows the variation of ratio of the indirect tensile strength of the conditioned specimen to that of the unconditioned specimen, TSR, with fiber length and content. TSR is used as an indication of the moisture damage potential of asphaltic mixtures. As can be seen, the mixtures containing nylon fibers have a lower TSR than the control mixture, indicating that the fiber reinforcement of asphalt concrete increases their vulnerability to moisture damage. It can also be seen that, TSR decreases with increasing the fiber content and length. The increase of moisture damage is attributed to the increase of air voids content with increasing the fiber content and length. Higher air voids content allows more moisture penetration in the mixture and inducing more damage. However, most of the mixtures meet the requirement of specification which limit a minimum TSR of 80 for the mixtures to be used in asphalt pavement.

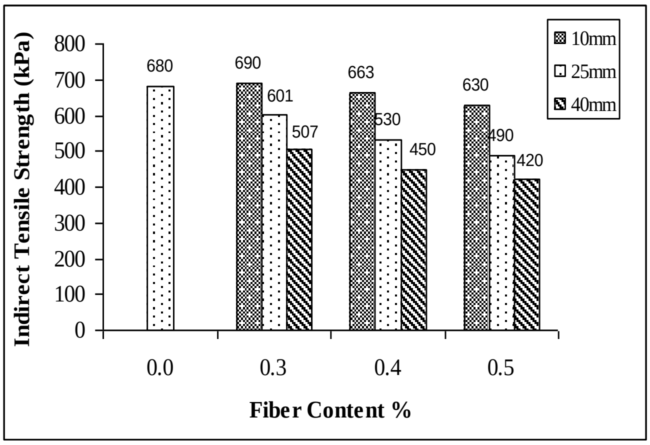

Figure 10. Indirect tensile strength of the mixtures

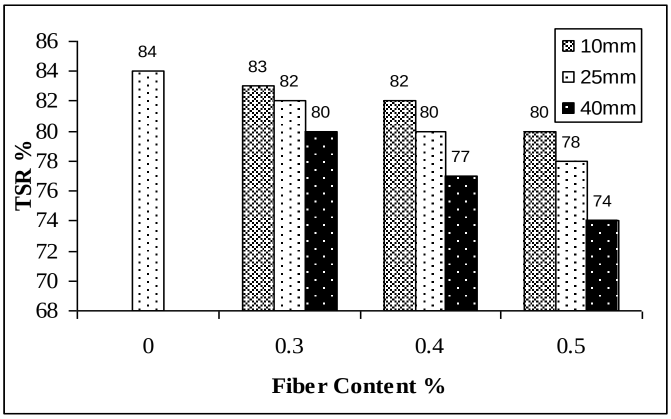

Figure 11. TSR of the mixtures

VII. CONCLUSIONS

Nylon fibers at different contents and lengths were added to binder course asphalt concrete and some engineering properties were evaluated. The following results can be drawn from this research.

- The air voids content of asphalt concrete increases with increasing fiber length and content.
- The Marshal stability of the mixtures increases with increasing the fiber content and length up to a certain amount after which decreases with increasing the fiber length or content.
- The flow of the mixtures decreases with increasing the fiber length and content, up to a certain amount, after which increases with increasing the fiber length or content.
- The highest Marshall quotient is achieved at 0.4% fiber content of 25mm fibers.
- Tensile strength of asphalt concrete decreases with increasing the fibers content and length. However, the mixtures containing fibers have more toughness and are energy absorbent.
- The moisture damage of the mixtures increases with increasing fiber content and length, with some mixtures not satisfying the specification requirement. However, the mixture with the optimum fiber length of 25mm and content of 0.4% satisfy the minimum TSR of 80%.
- Nylon fibers can be used for reinforcing the asphalt concrete and improving its mechanical properties.

REFERENCES

[1] Abtahi, S. M., Sheikhzadeh, M., Alipour, R., Hejazi, S. M., "Physical and mechanical properties of fibers-reinforced bitumen mixtures".*7th National Conference on Textile Engineering Rasht, Iran*, 2009.

[2] Maurer Dean A, Gerald M. (1989) "Field performance of fabrics and fibers to retard reflective cracking." Trans Res Recycle,1248:pp. 13–23.

[3] Wu S, Ye Q, Li N, Yue H. (2007), "Effects of fibers on the dynamic properties of asphalt mixtures. " J Wuhan Univ Technol – Mater Sci Ed 2007;22:pp. 733–736.

[4] Putman, B. J., Amirkhanian, S. N. (2004) "Utilization of waste fibers in stone matrix asphalt mixtures" Resources, conservation and recycling, 42:pp-265-274.

[5] Chen H, Li N, Hu C, Zhang Z. (2004) "Mechanical performance of fibers-reinforced asphalt mixture." J Chan Univ – Nat Sci Ed 2004;24(2): pp. 1–5.

[6] Echols J. (1989) "New mix method for fiber-reinforced asphalt." Public Works 1989;119(8): pp. 72–73.

[7] Goel A, Das A. (2004) "Emerging road materials and innovative. In: National conference on materials and their application in civil engineering." Hamipur, India; August 2004.

[8] Hansen R, McGennis B, Prowell B, Stonex A. (2000) "Current and future uses of nonbituminous components of bituminous paving mixtures." Transportation in the new millennium. Washington (USA): TRB A2D02; 2000.

[9] Garcia, A., Novambuena-Contras, J., Partl, M. N., Schuetz, P. (2013) "Uniformity and mechanical properties of dense asphalt concrete with steel wool fibers" Construction and building materials, 43(9), pp:107-117.

[10] Wu SP, Mo LT, Shui ZH., (2002)" An improvement on electrical properties of asphalt". Journal of Wuhan Univ Tech –Mater Sci Ed 2002;17(4): pp. 63–65.

[11] Wu SP, Mo LT, Shui ZH, Chen Z., (2005) "Investigation of the conductivity of asphalt concrete with conductive fillers. Carbon , 43(7): pp. 1358–1363.

[12] Wu S, Liu X, Ye Q, Li N. (2006) "Self-monitoring electrically conductive asphalt-based composite with carbon fillers.' Trans Nonferrous Met Soc China, 16:pp. 512–516.

[13] Asphalt Institute (1997): Mix design methods for asphalt, 6th ed., MS-02, Asphalt Institute, Lexington, KY.

[14] Huang H., White T.D. (1994) "Dynamic Properties of Fiber-Modified Overlay Mixture", Transportation Research Record No.1455, TRB, National Research Council, Washington D.C, pp 98-104.

[15] Jahromi S, Khodaii A.(2008) " Carbon fiber reinforced asphalt concrete" Arabian Journal of Science and Engineering, Vol. 33: pp.355–64.

[16] Vasiliev, V., Mozorov, V., (2007) "Advanced mechanics of composite materials" Elsevier, UK, pp. 57-100.

[17] Shao, X.; Qiu, Y.; Wang, Y., (1996) "Theoretical modeling of the tensile behavior of low twist staple yarns, Part I – theoretical model", Journal of Textile Institute, vol. 2, pp. 25-32.

[18] Abtahi, S. M., Esfandiarpour, S., Kunt, M., Hejazi, S. M. and Ebrahimi, M. G., (2013) "Hybrid reinforcement of asphalt concrete mixtures using glass and polypropylene fibers" Journal of Engineering Fibers and Fabrics, Vol. 8, Issue 2, pp. 25-35.