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The effect of adding carbon nanotubes on rutting resistance of the asphalt containing modified bitumen by SBS polymer

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Abstract: One of the important and major defects seen in asphalt pavement is rutting or permanent deformation. Given the recent reports, millions of dollars are paid for repairing rutted pavements.The only solution for this problem is to evaluate the mixture quality in design stage. In present work, the prediction of asphalt mixtures behavior was studied using additives and such a behavior was related to one of rapid pavement test tools (wheel track). Uniaxial dynamic creep test was employed to evaluate mixtures behavior versus iterated load as well as to find creep parameters and to specify flow number in asphalt samples. In recent decades, the polymer and nanoparticles are widely used to modify the bitumen used in road pavements so that using modified bitumen in the asphalt, road construction executives have significantly increased service life of roads and thereby improved the operational life of them. The bitumen used in asphalt mixtures composes a very low weight value of this mixture (4-6%) but has a considerable effect on the asphalt efficiency. In this study, SBS polymer (as a modifier of thermoplastic elastomer with diverse weights (4-6%)) was mixed with MWNT carbon nanotubes having 1-3% weights and 60-70 bitumen of Tehran refinery and the corresponding effect was studied on diverse properties of asphalt mixtures. Conducting dynamic creep and wheel track tests, adding nanotube was found to have a significant impact on rut depth reduction and rutting strength increase.
Keywords: Rutting, dynamic creep test, wheel track test, SBS Polymer, MWNT carbon nanotubes

Introduction

Rutting is one of the conventional defects in asphalt pavement. Preventing rut formation in asphalt pavement is one of the major causes of the roads safety which is always paid into attention. Millions of dollars are annually paid for repairing rutted pavements. If traffic load is increased considerably and the weather is also hot then rutting risk will be increased in pavements. Modification of the materials inside the asphalt concrete, improvement of asphalt mixtures design, evaluation methods and pavement plan can result in increased pavement life as well as considerable saving of maintenance cost for pavement.

Generally, there exist three factors which lead to form rut in asphalt pavement, including accumulation of permanent deformation on the surface of the asphalt layer, permanent deformation of subgrade, and erosion or wear of asphalt due to passing vehicles in the wheels site.Traditionally, subgrade deformation was believed to be the main cause of rutting on pavement and thereby lots of design methods were based on limiting vertical strain on the subgrade. The recent studies,however, show that rutting is arisen mainly due to the upper part of asphalt surface layer or the upper layer. For the mentioned reasons, the asphalt samples fabricated by polymer and nanotube will be studied in present work to evaluate rutting resistance and reach optimal value of additives with maximum rutting strength.

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1. Rutting mechanisms

Rutting mechanism in diverse pavement lifetimes can be divided into two major categories:

A. Primary rutting which is made at the beginning of pavement lifetime and is often associated with the layer density due to heavy traffic. Such parameters as selecting a very thin thickness for pavement section as well as inaccurate pavement implementation are effective in formation of such rutting. The most important factor for rutting under the above mechanism is the weakness of lower layers including subgrade/bed soil. In this kind of rutting, thickness of asphalt layer is almost fixed and the lower layers are deformed. Figure (1) shows primary rutting (Transportation research center, 2007).
B. Upon the primary stage, decreased pavement materials volume under the tires is almost equal to increased raised side areas volume. It means that the primary density is completed and since then rutting occurs due to replacement of layer with a fixed volume. Such rutting is fundamentally resulted from resistance and strength of asphalt layer. Poor strength can be caused by improper distribution of aggregates, damages arising from moisture or weakness in mixed aggregates interlock. Figure (2) shows the mechanism of this rutting type (Transportation research center, 2007).

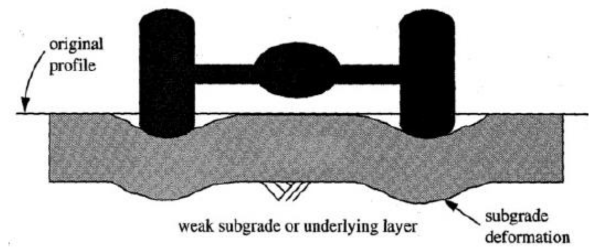

Figure 1. Caused by poor layers under asphalt

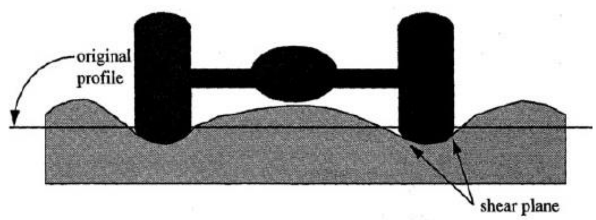

Figure 2. Caused by low shear strength of asphalt

2. Dynamic creep test

Due to relative readiness of the test and its logical relation with permanent deformation, uniaxial dynamic creep test has been used to determine rutting potential of asphalt mixtures for several years. This test mainly aims to classify materials and compare them in terms of rutting potential. In other words, the rut depth cannot be predicted by dynamic creep test. The device UTM5 is one of the means invented based on dynamic creep test. This device can be known as the first generation of UTM devices in such a way that the new series called UTM14 and UTM25 are presented to the market, as well. This device which is able to determine important mechanical parameters of asphalt mixtures under the same field conditions (in terms of loading and temperature) has the loading system with compressed air and can apply every load including sinusoidal, rectangular, etc. The software of this test is developed based on Australian regulation and complies with European, British and American regulations, as well. The most important output of the software is cumulative strain diagram against the number of loading cycles that is somehow dependent on a rutting resistance of the mixture. As it can be seen from Figure (3), the diagram is composed of three individual parts: the primary area where permanent deformations are quickly accumulated on each other, the secondary area in which increased cumulative strains are made in gentle and almost constant slopes and the third area where cumulative strains increase trend is again rapidly increased. Based on Mr. Witsak's opinion, the number of cycles in which the third area of the diagram is started is named flow number.

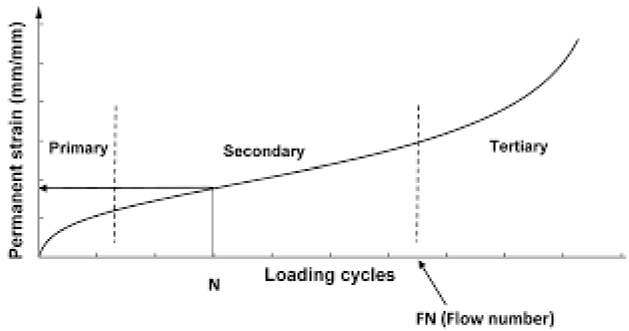

Figure 3. Cumulative strain diagram against the number of loading cycles, resulted from dynamic creep test

3. Methodology

The present study tried to select cases so as to include a wide range of materials used in Iranian asphalt manufacturing industry. For this purpose, aggregates and one kind of bitumen (bitumen with a penetration degree of 60-70) were used. After specifying diverse compositions for desired asphalt mixture, the optimal bitumen of each composition was determined by Marshal Method. This method is currently the most conventional asphalt mixing procedure in Iran. Then, the main required laboratorial samples for modeling were made using Marshal Method and according to the standard ASTM-D1559. Ultimately, the asphalt samples will be tested by dynamic creep and wheel track methods.

The materials used in present work include:

A kind of aggregate, a kind of bitumen and a kind of filler. The aggregates used in asphalt samples were provided from coarse and fine aggregates in diverse sizes of sand (0-6 mm), fine gravel (6-12 mm) and medium gravel (12-19 mm). The filler was stone powder passing through the sieve 200. Also, a bitumen sample with penetration degree of 60-70 was used which is manufactured by Tehran Pasargad Refinery. This bitumen type is the most conventional one in Iran for asphalt. Hence, given the results of field studies, the Gradation number 4 of Iranian asphalt pavement regulations that is common for upper layer of pavement was used here. In this paper, the SBS polymer made by Korean LG Chem Company was used and the carbon nanotube here was multi-walled nano-particles with dimensions of 5-15 nm made in the US.

4. The tests conducted on the samples

Bitumen tests: upon specifying physical and resistance parameters of the manufactured samples, few curves were drawn using physical and resistance properties table of asphalt mixtures and all obtained values. These curves helped to determine proper bitumen percentage due to have bitumen percentage as the horizontal axis.

Table 1. The final results of Marshal test for optimal bitumen percentage

The final results of Marshal test for optimal bitumen percentage (70-60 bitumen , Gradation number 4 of Iranian asphalt pavement regulations)						
6.5	**6.0**	**5.5**	**5.0**	**4.5**	**4.0**	**bitumen percentage**
11.644	**13.871**	**14.626**	**14.224**	**13.400**	**11.163**	**Average resistance marshal (kN)**
4.3	**4**	**3.4**	**3.3**	**3**	**2.8**	**Average psychological Marshal(mm)**
2.28	**2.32**	**2.37**	**2.31**	**2.26**	**2.22**	**Average density**

2.56	2.99	4.05	5.58	6.12	8.45	The percentage of empty space mix asphaltic
15.19	13.66	13.03	13.44	13.89	14.44	The percentage of empty space stone materials
83.15	78.11	68.92	58.45	55.94	41.48	The percentage of empty space filled with bitumen
optimal bitumen percentage = 5.5%						

Following the bitumen tests and finding optimal bitumen percentage, the corresponding tests were started to be conducted on asphalt mixtures by Marshal Method. Initially, dynamic creep test was carried out to reach flow number and finally, wheel track test was conducted too calculate depth of the rut made on the sample.

5. Analysis results

Table 2. Final results of dynamic creep test (Polymeric samples)

Flow number				The specification of samples
Average	The third sample	The second sample	The first sample	
716	840	856	453	Control sample
976	1105	1083	742	SBS 4%
1090	1185	1350	736	SBS 5%
933	982	1230	588	SBS 6%

Table 3. Final results of dynamic creep test (Carbon nanotube samples)

(Multi walled carbon nanotubes)

Flow number				The specification of samples
Average	The third sample	The second sample	The first sample	
716	840	856	453	Control sample
1170	1065	1218	1229	MWCNT 1%
1230	1130	1255	1305	MWCNT 2%
1312	1376	1095	1465	MWCNT 3%

Table 4. Final results of dynamic creep test (Hybrid samples)

Flow number				The specification of samples
Average	The third sample	The second sample	The first sample	
716	840	856	453	Control sample
1730	1760	1580	1850	MWCNT 1%& SBS 4%
1758	1685	1550	2040	MWCNT 2%& SBS 4%
1849	1640	2120	1788	MWCNT 3%& SBS 4%
2257	1875	2325	2572	MWCNT 1%& SBS 5%
2309	2480	2615	1832	MWCNT 2%& SBS 5%
2520	2483	2740	2337	MWCNT 3%& SBS 5%
2507	2690	2280	2552	MWCNT 1%& SBS 6%

2460	2670	2250	2460	MWCNT 2%& SBS 6%
2423	2335	2850	2086	MWCNT 3%& SBS 6%

Wheel track machine:

This machine is designed to assess changes of asphalt mixtures specifications in high temperatures including resistance to rutting, stripping, etc. due to traffic load and humidity and it can be used in both dry and wet conditions. The amount of wheel track rutting on the asphalt mixture sample due to applying load in a specific temperature is measured after passing a certain number of wheel sweep. The mentioned machine contains steel wheels with solid rubber coating with diameter and height of 20 and 5 cm, respectively and a fixed load is passed through a sample surface with a fixed ambient temperature. Rutting of asphalt mixture samples was done and measured in a temperature of 50˚C under a wheel contact pressure of 6.4 kg/cm^{2}and 25 sweeps/min.

The results of wheel track test:

Table 5. Final results of wheel track test (Polymeric samples)

عمق شیار (میلیمتر)				The specification of samples
Average	The third sample	The second sample	The first sample	
6.98	6.96	6.61	7.37	Control sample
2.59	2.63	2.94	2.22	SBS 4%
2.24	2.07	2.56	2.11	SBS 5%
2.64	2.65	2.5	2.77	SBS 6%

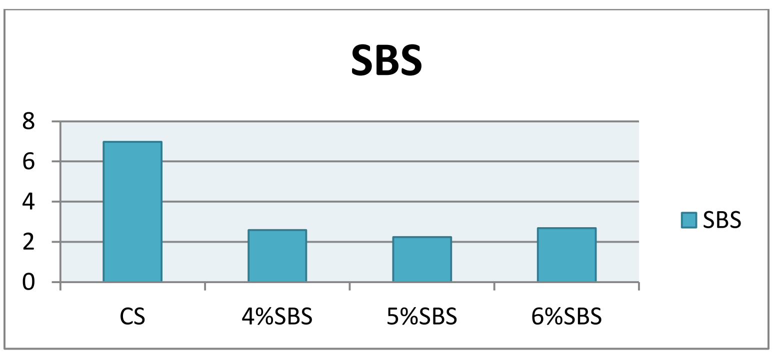

Figure 4. The comparison diagram for controls and polymeric samples

Table 6. Final results of wheel track test (Carbon nanotube samples)

عمق شیار (میلیمتر)				The specification of samples
Average	The third sample	The second sample	The first sample	
6.98	6.69	6.61	7.37	Control sample
2.30	1.93	2.21	2.76	MWCNT 1%
2.25	2.08	2.12	2.56	MWCNT 2%
2.18	1.89	2.03	2.63	MWCNT 3%

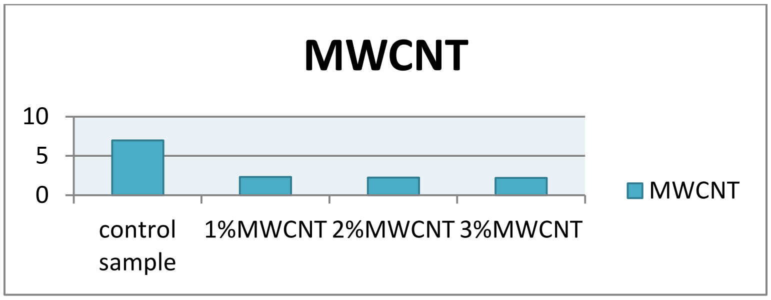

Figure 5. The comparison diagram for controls and carbon nanotube samples

Table 7. Final results of wheel track test (Hybrid samples)

عمق شیار (میلیمتر)				The specification of samples
Average	The third sample	The second sample	The first sample	
6.98	6.96	6.61	7.37	Control sample
1.88	1.43	1.86	2.35	MWCNT 1%& SBS 4%
1.11	1.25	0.91	1.17	MWCNT 2%& SBS 4%
1.07	0.71	1.15	1.36	MWCNT 3%& SBS 4%
1.3	0.96	1.58	1.36	MWCNT 1%& SBS 5%
1.14	0.65	1.55	1.22	MWCNT 2%& SBS 5%
1.04	1.01	1.21	0.91	MWCNT 3%& SBS 5%
1.73	2.05	1.75	1.4	MWCNT 1%& SBS 6%
0.81	0.69	1.19	0.55	MWCNT 2%& SBS 6%
0.78	0.59	0.71	1.04	MWCNT 3%& SBS 6%

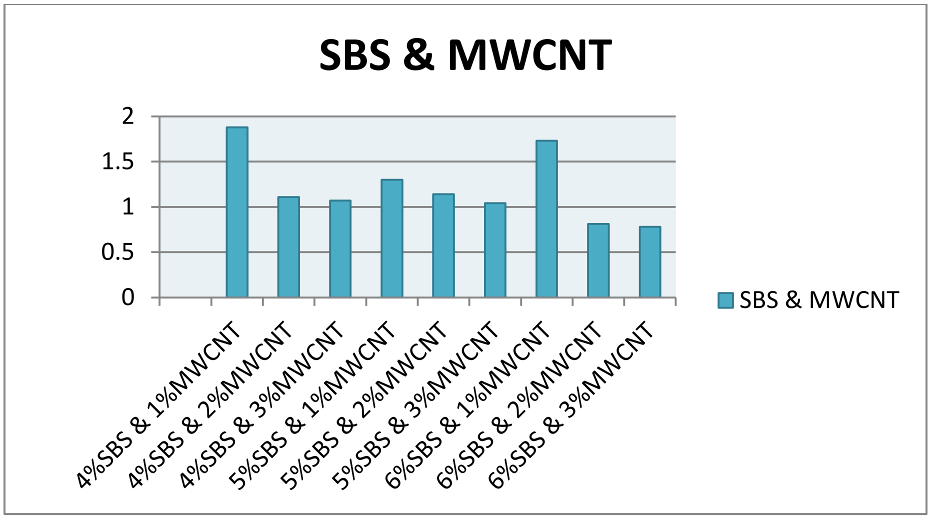

Figure 6: Hybrid samples

6. Conclusion

Regarding the addressed issues here, the results can be mentioned as follows:

- ✓ Given the results of dynamic creep test (Perverted stress load of 450 kPa in UTM test), the optimal polymer value is 5% (the best percentage for use) and with increased nanotube sample percentage, flow number is increased on average.
- ✓ Adding polymer and carbon nanotube leads to increase shear strength and thereby to decrease rut depth.
- ✓ Regarding wheel track test results, the higher percentage of carbon nanotube, the lower rut depth in samples. In other words, increased polymer of 4-6% results in decreased rut depth. However, using a 6% polymer causes a decreasing trend in rutting resistance of the samples.
- ✓ Also, since flow number of asphalt mixtures can be estimated accurately by UTM with no time-wasting, complicated and wrecker actions, thereby rutting potential can be effectively assessed by UTM.
- ✓ Advanced asphalt tests (e.g. wheel track rutting and dynamic creep) showed that the asphalt prepared using the bitumen modified by carbon nanotube will bring better results compared to conventional asphalt.

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