Petroleum and Coal

Article Open Access

Evaluating the Characteristics of Waste Modified Asphalt Mixture

Hossein Zanjirani Farahani[1], Massoud Palassi[1], Saeed Sadeghpour Galooyak[2]

[1] *School of Civil Engineering, College of Engineering, University of Tehran, Enghelab Ave., Tehran, Iran,*
[2] *Refining Technology Development Division, Research Institute of Petroleum Industry, West Blvd. of Azadi Sports Complex, Tehran, Iran*

Received July 13, 2017; Accepted October 4, 2017

Abstract

Human daily life activities in various industries and agriculture result in increasing a continuous production of waste materials, which cause major environmental problems, consequently. This study examines performance of an asphalt in which modified bitumen is used. Modified bitumen is prepared by adding 3% of waste plastic and 3% of crumb rubber to bitumen. These percentages of waste plastic and crumb rubber were identified as optimum percentages after performing various classic and functional tests. After preparation of asphalt samples using unmodified and modified bitumen, initial asphalt tests including Marshall stability and moisture sensitivity tests as well as functional tests including resilient modulus, dynamic creep, and indirect tensile strength (fatigue) tests were carried out on the samples. The results show improvements in the behavior of modified asphalt with regard to rutting and fatigue cracking.

Keywords: *Asphalt; Waste Material; Crumb Rubber; Moisture Sensitivity; Rutting, Fatigue*.

1. Introduction

The most commonly used polymer for bitumen modification can be subdivided into two main categories: thermoplastic elastomers and plastomers [1-2]. Thermoplastic elastomers copolymers constitute the most frequently used category of polymers for bitumen modification, among which styrene-butadiene-styrene (SBS) is the preferred one [3]. Poly (styrene-b-isoprene b-styrene) (SIS), which belongs to the same copolymer family, is also frequently used. As it is well known, block copolymers are produced by joining two or more chemically distinct polymer blocks in linear series of identical monomers. Examples of the plastomeric types of polymers studied for asphalt modification are polyethylene (PE), ethylene-vinyl acetate (EVA), and ethylene–butyl acrylate (EBA) random copolymers [4-7]. However, in the great majority of cases, the bitumen-polymer interactions are just of physical kind and depend on polymer architecture. Nowadays, plastics play very important role in every aspect of our life. The waste generated from plastic articles has to be disposed in an eco-friendly way to avoid any environmental pollution. The highest content of plastic is present in containers and packaging material i.e. bottles, packaging, cups etc. [8]. In this research we used waste material (LDPE and CR) to improve asphalt behavior. Plastics are also present in articles like tires, building materials, furniture and disposable medical devices. The use of plastic material is dependent on its specific properties such as low density, easy processing, excellent thermal and electrical insulating properties, good mechanical properties and chemical resistance, low cost in comparison to other materials [9].

Hadidy *et al.* [10] based on study on the utilization of LDPE in Stone Mastic Asphalt mixtures conclude that penetration at 25°C will generally decrease as LDPE content increases, which indicates an improved shear resistance in medium to high temperatures. Softening point tend to increase with the addition of LDPE, which indicates improvement in resistance to deformation.

Sinan *et al.* [11] reported that the specimens prepared with 165°C mixing temperature and 30-minute mixing time for 4% HDPE have the highest stability and the smallest flow, and thus the highest Marshall Quotient. Stability increase indicates that the HDPE-modified mixes are much stronger than the bitumen concrete mix with unmodified bitumen.

Ahmadinia *et al.* [12] concluded that with increase in polyethylene terephthalate (PET) content into the mixture, the Marshall Stability first started to increase significantly, but then decreased after 6%. However, the Marshall Flow started with an initial decrease, which was followed by an increase with the introduction of more PET into the mixture. Due to their high Marshall Quotient, the PET increased the stiffness level of the mixture improving its resistance against permanent deformation.

This paper investigates the effect of waste material on the asphalt mixture properties and discusses about the low cost eco-friendly asphalt mixture.

2. Materials and methods

To identify the effect of waste plastics (Fig. 1) and crumb rubber on the bitumen properties, 3% waste plastic and 3% crumb rubber were first mixed with the base bitumen.

Fig. 1 Waste Plastic (LDPE)

The bitumen was first heated to the temperature of 140°C and then, was combined with the modifying materials. To mix the bitumen and waste materials, the high shear mixer was used at 3750 rpm and the temperature of 150°C for 90 minutes. The resulting combination was divided into two parts: one part for conducting classic tests and another part for preparing asphalt samples. Aggregates used in the asphalt samples of this study was dolomitic limestone including almond gravel, pea gravel, sand and filler. The aggregates were provided by Akam sand industry, which were examined by different tests to check their quality. The gradation of aggregates used for preparation of asphalt samples is presented in Table 1.

Table1. The used grading in asphalt samples preparation

Average passing	Percent passing	Sieve size, (mm)
100	100	19
95	90-100	12.5
59	44-74	4.75 (No. 4)
43	28-58	2.36 (No. 8)
13	2-21	0.30 (No. 50)
6	62-10	0.075 (No. 200)

3. Results and discussion

3.1. Bitumen conventional experiments

As it can be seen in Table 2, the results of classic tests show that adding waste materials to the bitumen improves its classic characteristics including penetration and softening point and does not have any negative effect on the rotational viscosity of the bitumen.

Table 2. Effect of waste material on the physical properties of bitumen

Sample	Softening point	Penetration (dmm)	Ductility(cm)	Viscosity at 135°C (Pa.s)
Base bitumen	47.2	93	100+	0.41
Modified bitumen (3%PE +3% CR)	64	63.6	75.5	1.15

3.2. Asphalt basic experiments

3.2.1. Marshall Stability test

Marshall Stability test is performed according to AASHTO-T245, which measures two parameters of stability and flow for determining the resistance of asphalt mixtures. It should be noted that the results of Marshal test do not give a response related to output of tests such as fatigue, indirect tensile, and so on. That is because this test is one of the empirical tests and is used infrequently due to the lack of direct relation of test output with mixture performance. As it can be seen in Fig. 2, Marshall Stability for all tested samples is more than the minimum base (800 kg) specified by Iran Asphalt Pavement Publication. In addition, Marshall resistance is increased by adding waste plastics and crumb rubber. However, the flow level of all samples is in the standard range, which shows better performance of asphalt under traffic loading.

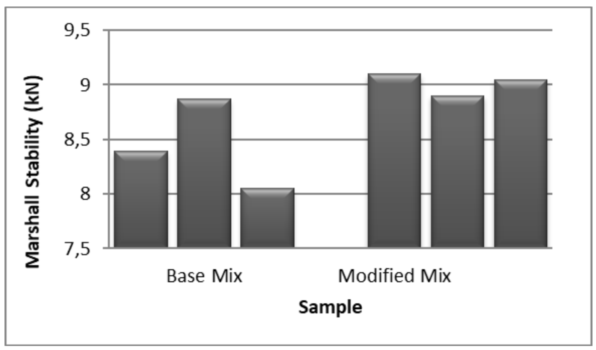

Fig. 2 Marshall Stability results

3.2.2. Moisture sensitivity (ITS)

Due to specific loading conditions, indirect tensile strength test causes tensile stress in the asphalt sample. Since tensile force in the asphalt is basically tolerated by the bitumen as a binder, adhesion between bitumen and aggregates can be deduced based on results of this test. This test is carried out according to AASHTO T283 standard and by Indirect Tensile Strength machine. Six Marshall samples were prepared for each mixture. While three samples are used for testing under the dry conditions, other samples are tested in the saturated conditions. The ratio of saturated samples resistance to dry samples resistance is used as a parameter to evaluate the sensitivity of the mixture to moisture. In the standard, ratio of 0.75% is known as a limiting value for the sensitivity of mixtures. As it can be seen in the Fig. 3, the moisture sensitivity is more than 0.75% for all samples. In addition, this ratio is increased by adding waste materials to the bitumen. It shows that adding waste materials to the bitumen increases the bitumen adhesion to the aggregates, which is important to prevent aggregates stripping.

3.3. Asphalt performance tests

3.3.1. Resilient performance

Resilient modulus test of UTM machine was used to determine resilient performance of asphalt mixture. The resilient modulus is considered as an important parameter to identify pavement performance which is needed for analyzing pavement response to loading traffic. The asphalt samples were prepared for the resilient modulus test by using Super Pave mix design method and gyratory compactor machine. According to the resilient modulus test of ASTM D4123 standard, the asphalt samples were prepared with 100 mm diameter, 63 mm height, and 4% void space. Two series of the asphalt samples are needed; one as base and another for modified bitumen and results of three samples are averaged for each test. As such, there are six samples which are in the unsaturated conditions. For conducting the resilient modulus test, the samples were first exposed to the temperature of 25°C for 8 hours. After applying load as half-sin, the resilient modulus of the asphalt samples was measured with frequency of 1 Hz and loading period of 0.1 second (0.9 second rest). Fig. 4 shows resilient modulus changes for different samples in 25°C. According to the results shown in this Figure, it can be observed that adding waste plastics and crumb rubber to the base bitumen increases the resilient modulus of the asphalt mixture. In addition, the resilient modulus of the modified samples is higher than the base samples. It can be due to creation of three-dimensional networks within the bitumen after formation of long and dispersed chains of LDPE polymer. So, the polyethylene polymer and poly butadiene chains of crumb rubber increase resistance and flexibility of modified bitumen, respectively, which resulted in increase in elasticity and consequently increase in the resilient modulus.

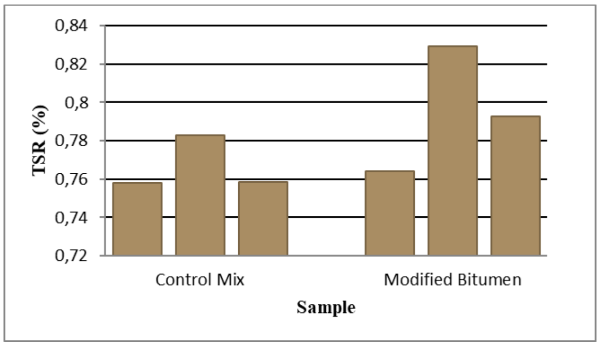

Fig. 3. Tensile Strength Ratio parameter for control and modified samples

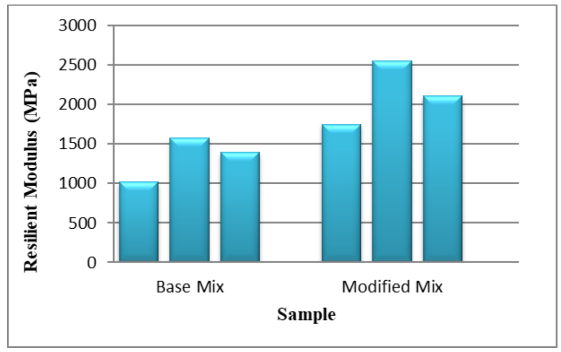

Fig. 4. Resilient modulus of base and modified asphalt mixtures at 25 ^{0}C

3.3.2. Rutting behavior of mixtures

The dynamic creep test of UTM machine was used to determine high temperature performance. As mentioned before, six samples, all in the unsaturated conditions were needed for this stage. Then, the chart of the permanent accumulated deformation against loading cycle number was drawn and flow number was calculated. The flow number is defined as the number of loading cycles in which irreversible strain of the third area is started. This test is carried out according to AS 2891.12.1-1995 standard. Based on this standard, the loading was applied as half-sin. The values of stress level, loading time, rest period, and loading cycle were considered 450 kPa, 0.1 second, 0.9 second and 1 second, respectively. Test temperature was 50°C due to sensitivity of asphalt samples to irreversible displacement in high-service temperatures. During the test, the accumulated deformation and changes of strain rate against the number of loading cycles were measured. By using sensors on the sample, irreversible displacement and strain were determined in every loading cycle and the three-step graph of the dynamic creep were obtained by summing strains in each loading cycle as accumulated. Flow number is equal to loading cycle with minimum strain rate, which is reported for control and modified samples in Fig. 5.

Based on the results in Fig. 5, it can be noted that adding waste plastics and crumb rubber to base bitumen increases the flow number of the asphalt mixture, which implies on performance improvement of modified asphalt mixtures at the high temperature (Rutting).

3.3.3. Fatigue performance of samples

To determine the bitumen performance at mid temperature, fatigue life in indirect tensile strength test was evaluated by UTM machine according to BS EN 12697-24 standard. For conducting this test, asphalt samples were prepared according to Super Pave mix design and by gyratory compactor. Then, samples with 4% void space, 100 mm diameter and about 63 mm height were obtained. In this test, if loading is applied repeatedly (loading- unloading), it can be used to assess the fatigue life of the asphalt samples. Loading type of this test is stress control and load is always applied on the sample as half-sin for 0.1 second (0.9 second as rest time). Of course, the rest time of 0.1 and 0.4 second has also been recommended. According to Khattab and Baladi [13], the fatigue life of the asphalt samples obtained by this method is less than the fatigue life obtained by other methods, which is because of biaxial stress in the test. In Fig. 6, fatigue life of asphalt mixtures is shown for stress level of 250 kPa and temperature of 20°C. As noted, fatigue life of modified samples is better than control samples, which shows better performance of asphalt mixture at mid temperatures.

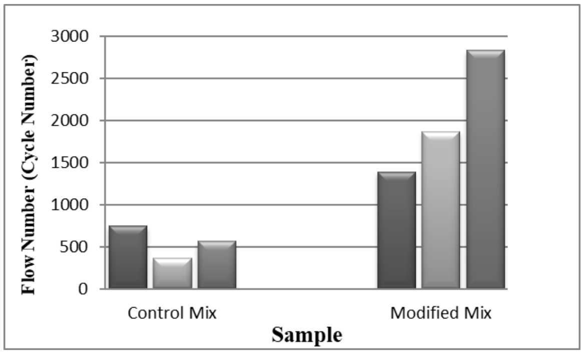

Fig. 5. Flow number for control and modified mixture

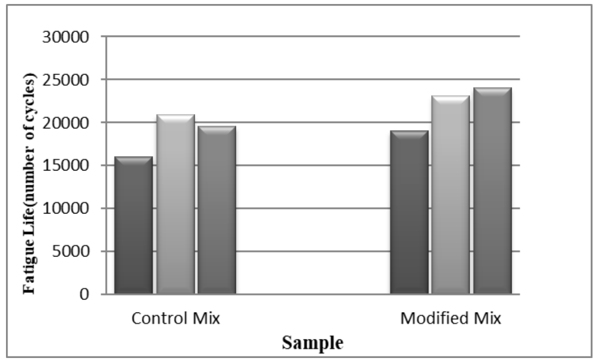

Fig. 6. Fatigue parameter of base and modified bitumen samples

4. Conclusions

Modifying bitumen by using polymer is one of the recommended solutions for increasing pavement life and reducing asphalt failure. This study evaluates the performance of an asphalt in which modified bitumen is used. Modified bitumen was prepared by adding 3% of waste plastic and 3% of crumb rubber to bitumen. After preparation of asphalt samples using unmodified and modified bitumen, various tests were carried out on the samples. It was observed that the modified asphalt mixture has better performance in terms of Marshall Stability and moisture sensitivity. It was also shown that waste materials used in the tests, had a considerable role in increasing the resilient modulus of asphalt which can be effective in decreasing the thickness of asphalt layers. Based on the results of the dynamic creep test, which are related to rutting performance of asphalt, it was concluded that use of waste material improves asphalt performance in the places with hot climate or with very heavy traffic (effective factors of asphalt deformation). Finally, it was shown that fatigue life of modified asphalt mixtures was enhanced which is important in prevention of fatigue cracks.

References

[1] Diehl CF. Ethylene-styrene inter polymers for bitumen modification. In: Proc Second Eurasphalt Eurobitume Congress vol. 2, Barcelona, 2000. p. 93-102.

[2] Bardesi A. Use of modified bituminous binders, special bitumens and bitumens with additives in pavement applications. Technical committee flexible roads (C8) World Road Association (PIARC); 1999.

[3] Kok BV, Yilmaz M, Sengoz B, Sengur A, Avci E. Investigation of complex modulus of base and SBS modified bitumen with artificial neural networks. Expert Syst Appl., 2010; 37:7775-80.

[4] Garcia-Morales M, Partal P, Navarro FJ, Martinez-Boza F, Gallegos C, González N, González O, Muoz ME. Viscous properties and microstructure of recycled EVA modified bitumen. Fuel, 2004; 83: 31-8.

[5] Fawcett AH, McNally T, McNally GM, Andrews F, Clarke J. Blends of bitumen with polyethylenes. Polymer, 1999; 40:6337-49.

[6] Fawcett AH, McNally T. Blends of bitumen with various polyolefins. Polymer, 2000; 41:5315-26.

[7] Perez-Lepe A, Martinez FJ, Gallegos C, Gonzalez O, Munoz ME, Santamaria A. Influence of the processing conditions on the rheological behaviour of polymer-modified bitumen. Fuel, 2003; 82: 1339-48.

[8] R Soudani K, Cerezo V, Haddadi S. Rheological characterization of bitumen modified with waste nitrile rubber (NBR), Construction and Building Materials, 2016; 104:126–133.

[9] Siddique R, Khatib J, Kaur I. Use of recycled plastic in concrete: A review, Waste Manage-ment, 2008; 28: 1835–1852.

[10] Al-Hadidy AI, Yi-qiu T. Effect of Polyethylene on Life of Flexible Pavement. Construction and Building Materials, 2009; 23: 1456–1464.
[11] Ahmadinia E, Zargar M, Karim MR, Abdelaziz M, Shafigh P. Using Waste Plastic Bottles as Additive for Stone Mastic Asphalt. Materials and Design, 2011; 32: 4844–4849.
[12] Hinislioglu S, Agar E. Use of Waste High Density Polyethylene as Bitumen Modifier in Asphalt Concrete Mix. Materials Letters, 2004; 58: 267– 271. 2004.
[13] Khattab MJ, Baladi GY. Fatigue and Permanent Deformation Models for Polymer-Modified Asphalt Mixtures. Transportation Research Record, 2001: 1767.

To whom correspondence should be addressed: Prof. Massoud Palassi, School of Civil Engineering, College of Engineering, University of Tehran, Enghelab Ave., Tehran, Iran. P.O. Box: 11155-4563, Tel: +98-21-61112226, Fax: +98-21-66403808, E-mail: mpalas@ut.ac.ir