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Effect of HDPE Based Wastes on the Performance of Modified Asphalt Mixtures

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Abstract

Flexible asphalt pavement construction is an expensive investment. Nowadays, many methods are being investigated to improve the performance of asphalt mixtures. For this reason, bitumen is usually used with modified form in hot mix asphalt (HMA) in practice. The use of recycled waste materials as modifier additives on bitumen could have several economic and environmental benefits. The main aim of this research was to investigate the effect of HDPE (High density Polyethylene) based plastic waste materials on the performance of asphalt mixtures. For this purpose, HDPE based waste materials were added to the bitumen as modifier in to amount of 1%, 2%, 3%, 4%, then asphalt mixtures formed by the modified bitumen were tested for the determine their performances. The performance of specimens was firstly measured by stability, flow values. Then, susceptibility characteristics of the HMA to water damage were determined by using Indirect Tensile Test (ITT) method described in AASHTO T283 with classically compacted specimens. The results showed that, the best performance was obtained with a content 4% in terms of stability values. In addition, all specimens were showed resistance to water damage.

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Keywords: Hot mix asphalt; HDPE wastes, modified bitumen, water susceptibility.

1. Introduction

Flexible highway pavements are the most widely used pavement type in many countries [1]. The main approach used for preventing the deterioration of pavements is improving the properties of materials used for constructing

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highways [2]. Bitumen and aggregates are construction materials used in flexible pavements. Bitumen is generally modified with modifiers to gain strength against the negative effects of traffic loads and weather conditions [3-5].

Modification process improve the asphalt pavement performance such as stability, flexibility etc., [6]. The recycling of wastes not only allows the effective use of increasingly diminishing natural resources, but also reduces the amount of wastes that need to be buried underground, thus minimizing environmental damage. Waste materials can be used in asphalt pavement in order to improve their performance. There are numerous studies in the literature regarding the improves hot mix asphalt with waste materials such as bitumen modified with waste plastics [7-9] and use of waste aggregates in asphalt concrete [10-12]. Costa et al. [13] modified bitumen with different plastics wastes, namely polyethylene. They investigated the especially storage stability of modified bitumen. The experimental tests performed in the study were penetration, softening point, dynamic viscosity and storage stability. They found that, SBS, EVA, or alternatively HDPE have showed good performance according to storage stability. Amir et al [14] analyzed the effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes. They found that, bitumen modified with waste PET showed same behavior at 20 ^{0}C bitumen modified with SBS especially in terms of flexibility and fatigue behavior. Gomez-Meijide and Perez [15] used the construction and demolition waste aggregates in their study. They investigated the indirect tensile stiffness modulus (ITSM), the dynamic modulus at different temperatures and frequencies and the correlation between them. They found that, cold asphalt mixtures with 100% recycled waste aggregates achieved higher stiffness than control mixtures but that they required significantly higher bitumen. The aim of this study is to analyze effect of waste materials on the hot mix asphalt. For this purpose, HDPE wastes have been used as modifier because disposed HDPE wastes do not decay, corrode or dissolve like other waste plastics. This research includes an experimental study in order to determine the performance of HMA containing different ratio of waste HDPE as modifier.

2. Materials and experimental study

2.1. Materials

The bitumen used in the study with a 50/70 penetration grade was obtained from Batman Oil Terminal of the Turkish Petroleum Refinery Corporation. The tests were carried out according to Turkish Standards. Conventional bitumen tests such as penetration, softening point, ductility and flash point were performed in order to determine basic properties of the bitumen. Sensitivity of the bitumen was defined with penetration index (PI) value. PI values was calculated by using penetration and softening point values. The following equation [1] was used to calculate PI values:

$$\mathrm{PI} = \frac{1952 - 500\mathrm{x}\log(\mathrm{Pen}_{25}) - 20\mathrm{xSP}}{50\mathrm{x}\log(\mathrm{Pen}_{25}) - \mathrm{SP} - 120} \tag{1}$$

Table 1. The properties of the bitumen.

	Specification	Results	Specification limits
Penetration (25 ^{o}C; 0.1mm)	TS EN 1426	61	50-70
Softening point (^{o}C)	TS EN 1427	48 ^{0}C	46-54
Penetration index(PI)	-	-1.26	-
Ductility (25 C^{0};5 cm/min)	TS 119	>100	-
Flash point	TS ISO 2592	304 ^{0}C	230 (min)
Thin Film Oven Test (TFOT) (163 ^{0}C; 5h)	TS EN 12607-2		
Change of mass		0.23	0.5 (max)
Change of softening point	TS EN 1427	6.2	9 (max)
Retained penetration	TS EN 1426	55	50 (min)
Specific gravity	TS 1087	1.030	-

The bitumen was aged in the TFOT device for 5 hours at 163 ^{0}C. This aging process was performed in order to identify certain short time aging properties that might be observed during storage, transfer to the plant, mixing in the plant, transportation, spreading and compression. Table 1 shows the results of the conventional tests performed on the bitumen. All test results showed that, the bitumen was used in the experimental study provides the specification limits. The mixtures were produced with limestone aggregates obtained from quarries around Antalya, Turkey. In order to find out the properties of the coarse aggregate (25-4,75 mm) used in the study specific gravity, Los Angeles abrasion test, magnesium sulphate soundness test, flakeness tests were conducted.

In order to find out the properties of the fine aggregate (4.75-0.075 mm), specific gravity, plasticity index and methylene blue tests were conducted. Finally, only specific gravity test was conducted to the filler. Table 2 shows the basic properties of limestone aggregates.

Table 2. Basic properties of the limestone aggregates.

Sieve diameters	Test	Results	Specification limits	Specification
25 - 4.75 mm	Volume specific gravity (g/cm^3)	2.6935		ASTM C127
	Apparent specific gravity	2.7105		ASTM C127
	Water absorption (%)	0.23	max. 2.5	TS EN 1097-6
	Soundess of aggregate by use of Magnesiun Sulphate (%)	11.50	max. 18	TSE EN 1367-2
	Los Angeles abrasion (%)	22.50	max. 30	TS EN 1097-2
	Flakeness index (%)	18.50	max. 35	BS 812
4.75-0.075 mm	Volume specific gravity (g/cm^3)	2.706		ASTM C128
	Apparent specific gravity	2.720		ASTM C128
	Water absorption (%)	0.59	max. 2.5	TS EN 1097-6
	Plasticity index	NP		TS 1900-1
	Methylene blue, g/kg	1.25	max. 1.5	TS EN 933-9
Filler	Apparent specific gravity	2.6869		BS 812

In order to create aggregate distrubition in asphalt mixtures, aggregate grading curves were prepared according to Turkish Highway Construction Specifications 2013 [17]. Fig 1 shows the gradation curves of limestone aggregates and gradation limits used in this study. Gradation limit values are belonging to the binder course in this figure.

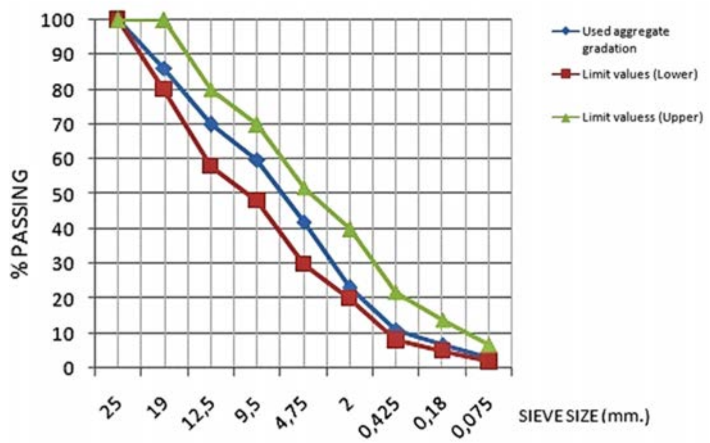

Fig. 1. Grading curves of limestone aggregations and specification limits.

2.2. Experimental Study

2.2.1. Preparation of Samples

At the beginning of the study, optimum bitumen weight was determined for the aggregates and bitumen used in the study with the Marshall test. For this purpose, mixtures with limestone aggregates and 50/70 penetration bitumen were prepared for six different bitumen content (3.0%, 3.50%, 4.0%, 4.50%, 5.0% and 5.50%). The sum total of the samples prepared for determination of optimum bitumen content 18 (3 x 6). In the experiments, aggregates were heated at about 160 ^{0}C and mixed in the asphalt mixer with bitumen binder which was heated at about 155 ^{0}C Subsequently, they mixed into the mixture for 120 seconds. Prepared hot mixtures were placed in the steel moulds (101,6 mm x 63,5 mm) and compacted at about the 145 ^{0}C to obtain Marshall samples [3]. In the next step 18 samples tested with Marshall Stability Test machine and Marshall stability, Marshall flow values were obtained and eight curves were plotted. These values were obtained from the curves; Bulk specific gravity (D_p) versus bitumen content, Marshall stability versus bitumen content; Marshall flow versus bitumen contents; percentage of air void (V_h)versus bitumen content; percentage of void filled with bitumen (V.F.A.) versus bitumen content; percentage of void in mineral aggregates versus bitumen content. Optimum bitumen rate was calculated by using this curves as follows:

$$\frac{5.3 + 4.7 + 4.6 + 5.1}{4} = 4.93 \tag{2}$$

At the next step, modified bitumen was prapered. HDPE wastes used in the study as the modifier were obtained from recycling facility in Antalya in the powder form. After sieved process with No 40 sieve, the modifier was obtained with the necessary fineness from the HDPE wastes. The HDPE wastes used in the study were prepared at 1%, 2%, 3%, 4%,of bitumen weight. After bitumen was heated up to 155-160 ^{0}C in the oven, it was poured into the chamber of the mixer. Following this, the modifier was slowly added to the bitumen, which was then mixed in the mixer at 500 rpm speed for approximately 15 minutes, until the mixture temperature reached 180^{o}C. After reaching this temperature, the mixer speed was raised to 1300 rpm, and the mixing process was continued for another 60 minutes. After this process; the samples were poured into small containers, which were covered by using aluminum foil, and then stored for use in the study experiments.

Different hot mixture specimens obtained from the bitumen prepared with the modifier used different raito and limestone agrgregates were coded as follows:

- Control mixture- "HMA-0";
- Mixture with modified bitumen by 1% HDPE – "HMA1"
- Mixture with modified bitumen by 2% HDPE – "HMA2"
- Mixture with modified bitumen by 3% HDPE – "HMA3"
- Mixture with modified bitumen by 4% HDPE – "HMA4"

2.2.2. Determination performance of modified with HDPA wastes HMA

Performance evaluation of modified HMA were determined with Marshall stability test. All specimens were tested with Marshall stability test machine and stability as well as flow values were determined. Stability values showed us the resistance performance of designed specimens. Flow values showed us the flexibility performance of specimens.

The other used performance evaluation method were susceptibility characteristics of the HMA to water damage. The specimens were classically compacted by the automatic Marshall impact compactor until the %7±1 air void obtained for each specimen. This test was conducted in accordance with the procedures described in AASHTO T283. Only Super pave gyratory compaction machine was not used. The specimens are grouped as control and conditioned. Conditioned specimens were saturated with water by use of vacuum desiccators. The aim of this process was to obtain %70-%80 saturated conditioned specimens. Then all saturated specimens were wrapped with stretch film and they were placed in the plastic bags with 10 ml. water. After the specimens were kept at -18 ^{0}C for 16 hours, they were taken in a water bath at 60 ^{0}C for 24 hours. After all these process, all control and conditioned specimens were taken in a water bath at 25 ^{0}C for 2 hours. Then they were broken with indirect tensile splitting device as vertically. The indirect tensile strength ratio (TSR) of conditioned specimens were compared to the control specimens by use of following equation [18]:

$$\mathrm{TSR} = \frac{S_2}{S_1} \tag{3}$$

where S1 is the average indirect tensile strength values of control specimens and S_2 is the average indirect tensile strength values of conditioned specimens. The TSR value should be minimum %80 according to AASHTO T283.

3. Results and Discussion

3.1. Marshall Test Results

Figure 2 and Figure 3 show the average stability values of the specimens. As can be seen from Figure 2, Marshall stability values of all specimens were measured higher than 750 kg which is lower limit value according to Turkish Highway Construction Specifications 2013. The stability values of HMA1 and HMA2 were measured very close to the control specimens (HMA0), it can be said that HDPA modifier did not affect the specimen at the low rates. Adding these materials equal to or more than 3%, effects began to be observed. Highest stability was obtained by HMA4.

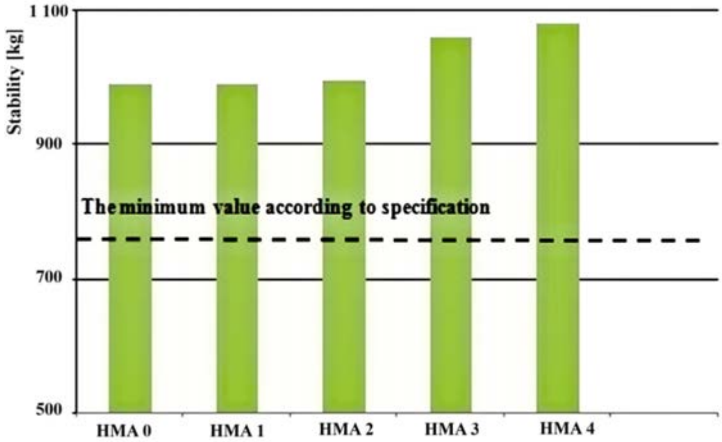

Fig. 2. Average stability values of the Marshall specimens modified HDPA.

Flow values were measured Marshall stability machine as well as stability values. Figure 4 shows the average flow values of the specimens. It is found that, flow values of HMA1 were not measured between 2-4 cm which are limit values of specification. The slight flow value increase was observed by HMA2 and HMA3 coded specimens. The highest value was obtained by HMA4. The flow value shows the flexibility and plasticity performance of the hot mixture asphalts under repetitive loading.

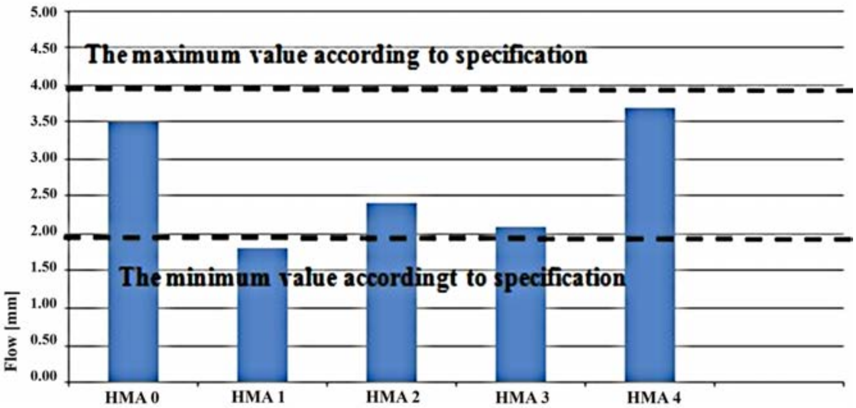

Fig. 3. Average flow values of the Marshall specimens modified HDPA.

3.2. Determination of Water Susceptibility

Table 3 shows the Tensile Strength (TSR) values of specimens. According to Turkish Highway Construction Specifications 2013, TSR values should be min. 80%. As can been from the table, TSR values of all specimens were calculated higher than 80%. It is found that, only TSR value of HMA3 was determined very close to lower limit. The best values were obtained by HMA2 and HMA4. This indicates that, the best resistance of hot mixtures asphalts to the detrimental effect of water was obtained with modifier rate 2% and 4%.

Table 3. TSR values corresponding to the modifier rate.

Specimens	TSR
HMA0	0.83
HMA1	0.85
HMA2	0.86
HMA3	0.81
HMA4	0.86

4. Conclusions

In this study, the HDPE based waste materials were added to the bitumen as modifier.

The following conclusions can be drawn based on the results obtained in the study:

- The addition of HDPA modifier in control specimens didn't effect to up to 3%. The positive effect of the HDPA can be seen 3 and 4 percent especially.
- Flexibility of mixture was decreased with 2% additive.
- The best resistance of hot mixtures asphalts to the detrimental effect of water was obtained with modifier rate 2% and 4%.
- Based on the results of investigation of HDPE modified hot mixtures, it can be noted that, additive by 4% increase stability and resistance of water damage. Additionally, flow values were found at this rate between specification limits. So, hot mixtures modified with 4% were not affected adversely in terms of flexibility and plasticity.

When all results are considered together, it can be concluding that, in the modification of bitumen with waste HDPE materials, the best results were obtained with the 4% in terms of hot mixtures performance. Further research is needed to determine the effect more than 4% modifier on hot mix asphalt.

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