International Journal of Engineering
Journal Homepage: www.ije.ir

TECHNICAL NOTE

Modification of the Properties of Warm Mix Asphalt Using Recycled Plastic Bottles

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PAPER INFO

Paper history:
Received 13 March 2018
Received in revised form 21 April 2018
Accepted 26 April 2018

Keywords:
Polyethylene Terephthalate Waste
Marshall Properties
Rutting Susceptibility
Warm Mix Asphalt

ABSTRACT

The construction of flexible pavements with hot mix asphalt (HMA) consumes considerable energy, which impacts global resources and environment. Warm mix asphalt (WMA) is an effective alternative because it is produced with mixing and compaction temperatures lower than those used in HMA production. This technology decreases energy consumption, saves money and reduces the environmental pollution. Moreover, this technology can generate a revolution in sustainable construction if combined with the use of waste materials to improve the properties of WMA. Polyethylene terephthalate (PET) wastes are increasingly accumulated over the world. However, to the best of knowledge of authors, no research has adopted using PET wastes in combination with improving WMA properties. Therefore, the present study covers the usage of PET waste bottles to modify the properties of WMA. Ground PET waste bottles with a maximum particle size of 2.36 mm with different contents (0.1, 0.3, 0.5, 0.7, 0.9 and 1.1% by the weight of aggregate) were used to replace an equivalent portion of fine aggregate. Laboratory tests were conducted to investigate the effects of different PET contents on the properties of WMA. The testing programme included Marshall, rutting susceptibility and indirect tensile strength (ITS) tests. Results exhibited significant improvements in the engineering properties of the mixtures modified with the optimum PET content (which was found to be 0.5%) in terms of increase in stability, stiffness, ITS and moisture damage resistance and decrease in rutting susceptibility, without adverse effects on the other desirable properties of the mixtures.

***doi**: 10.5829/ije.2018.31.09c.06*

1. INTRODUCTION

Highways can be considered main facilities of transportation [1-7]. Most highways are paved with hot mix asphalt (HMA) [8]. However, the production of HMA consumes considerable energy and causes emissions, which increase pollution. Warm mix asphalt (WMA) has recently been proposed as an alternative to HMA because it decreases the temperatures of mixing and compaction of asphalt mixtures without significant unscrupulous effects on their engineering properties; in addition to consider enhancements in their workability and durability. Decrease in mixing and compaction temperatures can significantly reduce energy consumption, which leads to money saving and pollution reduction. The employment of waste materials [9-12] in modifying asphalt mixtures as part of waste utilization in sustainable development [13-15] and environment protection [9, 16-22] has underwent recent revolution. Polyethylene terephthalate (PET) waste material is widely used to improve the properties of construction materials. PET is a semi-crystalline polymer with high tensile strength [18], high chemical resistance and melting point of 260±10 °C [23]. Therefore, using this waste material (PET) in modified asphalt mixtures can promote sustainable construction. Several studies examined the effects of using PET waste on properties of HMA [24-26]. However, to the best of authors' knowledge, no research has implemented such a technique in the domain of WMA. Thus, the implementation of this approach is an essential objective. The present study selected PET waste bottles due to their great availability. A laboratory-oriented study was conducted to investigate the effects of using different PET contents (0.1, 0.3, 0.5, 0.7, 0.9 and 1.1%

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Please cite this article as: A. M. Mosa, I.T. Jawad, L.A. Salem, Modification of the Properties of Warm Mix Asphalt Using Recycled Plastic Bottles, International Journal of Engineering (IJE), IJE TRANSACTIONS C: Aspects Vol. 31, No. 9, (September 2018) 1514-1520

by the weight of aggregate) on the engineering properties of WMA. PET content was considered to replace an equivalent amount of fine aggregates; given the particle size of PET used in this study was within the size range of fine aggregate. This approach (equivalent replacement) ensured constant asphalt contents in prepared samples. WMA was produced by adding aspha-min, which is the widespread commercial form of zeolite in this domain [27], to reduce mixing and compaction temperatures. The testing procedure included a number of tests to specify the properties of materials used and viscosity tests to determine mixing and compaction temperatures related to predetermined asphalt viscosities. The testing programme applied to unmodified and modified samples comprised Marshall, rutting susceptibility and indirect tensile tests. The results exhibited significant improvements in the engineering properties of modified samples compared with those of control (unmodified) samples.

2. MATERIALS

A number of tests were performed to investigate the properties of materials used (aggregate, asphalt and PET). The properties of aspha-min were obtained from the manufacturer's manual. Commercial aspha-min was purchased from Xiangsong Chemical Co.(China). Aspha-min was added to the mixture at a rate of 0.3% by the total weight of the mixture. PET waste bottles used in this study were collected from local trash and mechanically ground into fine particles (not more than 2.36 mm) to replace an equivalent portion of fine aggregate of WMA.

3. TESTING PROGRAMME

In addition to the tests performed to study the properties of materials used, a number of tests were implemented to determine the mixing and compaction temperatures and the optimum asphalt content (OAC) and investigate the effects of PET on the properties of WMA. These tests are shown in Table 1. The details of these tests are described in the following subsections.

3. 1. Viscosity Tests The viscosity values of asphalt were determined with different temperatures (120 °C, 135 °C, 150 °C and 165 °C) in accordance with ASTM D2170 to specify suitable mixing and compaction temperatures. These temperatures were adopted to prepare Marshall specimens.

3. 2. Marshall Test This part of the testing programme involved preparation of a number of control asphalt mixture samples (each involved three specimens) at the determined mixing and compaction temperatures using Marshall method. The prepared samples were tested using the Marshall method to specify the OAC and investigate the properties of control mixture. The investigation covered bulk specific gravity, stability, flow, air voids, total voids in mineral aggregate (VMA) and stiffness. On the basis of the OAC, the Marshall method was repeated for samples modified with the predetermined contents of PET, in order to investigate their effects on the properties of WMA.

TABLE 1. Testing programme

Property	Test	Specifications
Marshall Gmb		-
Marshall Stability		>8 kN
Marshall Flow	ASTM D6927	8-14 units
Marshall Air Voids	ASTM D 6926	3-5 %
Marshall VMA		>14 %
Marshall Stiffness		>2 kN/mm
Rutting Susceptibility		< 20%
Indirect Tensile Strength		TSR>80%

3. 3. Rutting Susceptibility Test Unmodified samples and samples modified by PET with different contents were prepared and tested according to AASHTO T324 to evaluate the rutting susceptibility of the mixtures under this study. Each sample involved two specimens with dimensions of 600 mm × 200 mm × 75 mm. The prepared samples were tested using a wheel-tracking apparatus under full-immersion conditions with a temperature of 50 °C. The applied pressure was approximately 730 kPa, which is simulated the contact tire pressure. Rut depth was recorded up to 20000 wheel passes.

4. RESULTS AND DISCUSSION

4. 1. Results of Viscosity Tests From the viscosity test for asphalt cement foamed by aspha-min, the temperature ranges of mixing and compaction were determined at 148 °C to 136 °C and 128 °C to 122 °C, respectively. These temperatures were related to the predetermined viscosities required for mixing (150 centistokes to 190 centistokes) and compaction (250 centistokes to 310 centistokes). Figure 1 illustrates the tests results. These temperatures were adopted for preparing Marshall specimens.

4. 2. Marshall Test Results A number of samples were prepared and tested on the basis of the standard requirements of the Marshall method to specify the

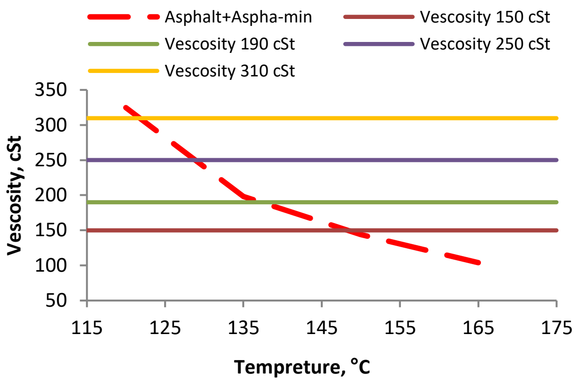
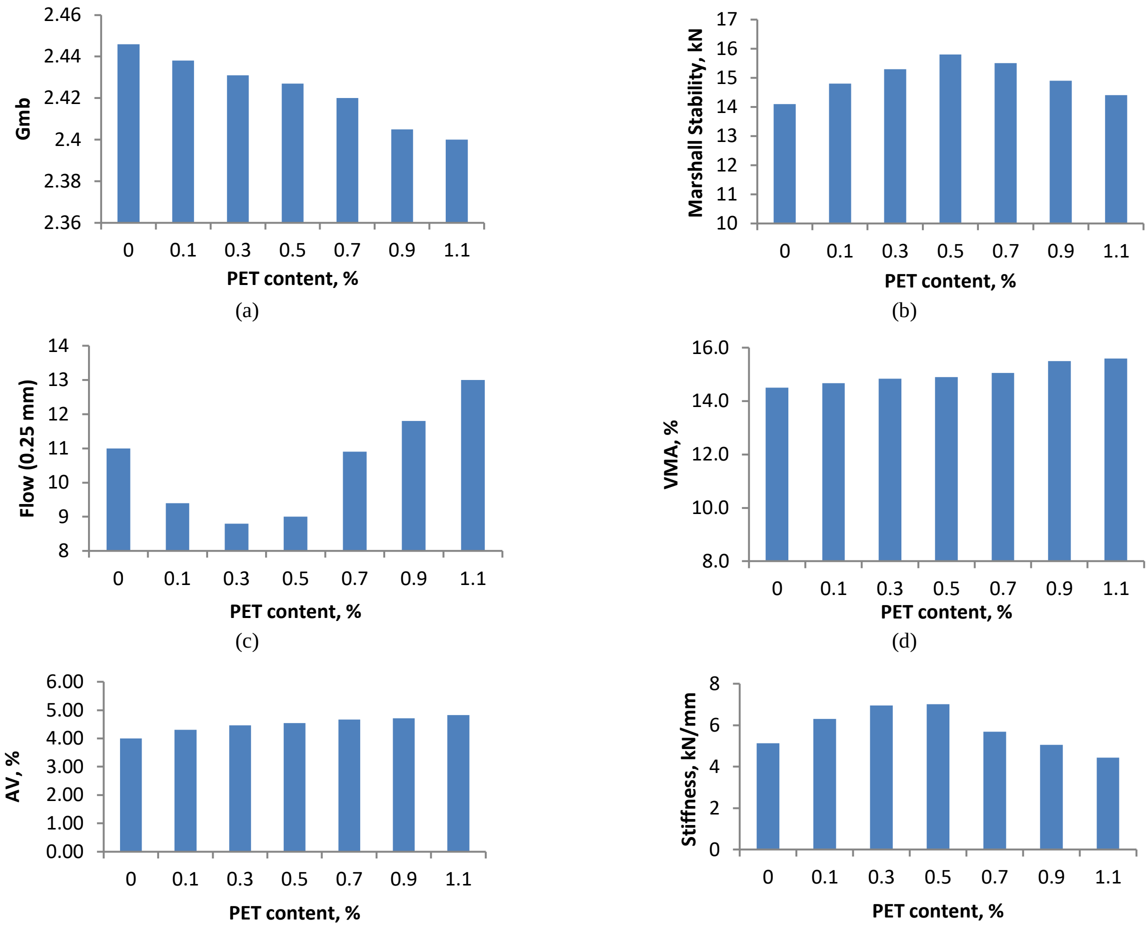


Figure 1. Viscosity test results of asphalt with Aspha-min

OAC of the control WMA and determine its properties. OAC was determined at 5% based on the weight of the mix. This content was adopted to produce the modified mixtures. The results of Marshall tests showed that all properties of control WMA related to the OAC conformed to the standard requirements. The Marshall testing procedure was repeated on a number of samples modified by different contents of PET. Figure 2 illustrates the effects of different PET contents on the mixture properties. The results showed that the mixture bulk specific gravity values of modified samples decreased with the increase in PET content, as shown in Figure 2a. This behaviour could be attributed to the decrease in overall specific gravity of aggregate as a result of the decrease in overall specific gravity of fine aggregate with the increase in PET content because the specific gravity of PET is less than that of fine aggregates. The decrease in bulk specific gravity values with the increase in PET content could also be a result of the decrease in mixture compressibility. The decrease in WMA compressibility might be attributed to the inconsistent structure of PET and the reduction in lubrication by warm asphalt during compaction due to the absorption of an amount of asphalt by PET.



(a) (b) (c) (d) (e) (f)

Figure 2. Results of Marshall tests

Figure 2b shows that the stability values firstly increased with the increase in PET contents up to 0.5% and then decreased with the further increase in PET contents. Moderate contents of PET produced stiffer mixtures, which caused them to be more stable than the unmodified ones [25]. This behaviour could be attributed to the additional bonds generated by PET within the mixture. The generated bonds might consist of friction and adhesion. The additional friction generated by PET was a result of the rougher surfaces of PET particles than those of aggregates. Adhesion might occur due to fluxing (partial melting) of PET particles under the heat of mixing and compaction. In this stage, PET particles might adhere to the aggregates with the aid of compaction forces. PET particles might also absorb a small amount of asphalt due to the nature of the PET surfaces, which were relatively more porous than those of aggregate particles. This behaviour consequently led to a stiff mixture without a significant decrease in adhesion. However, an excessive PET content possibly absorbed a high amount of asphalt. This outcome decreased adhesion among the particles attained by asphalt, increased mixture heterogeneity and reduced compressibility and stability. Figure 2c shows that Marshall flow values firstly decreased with the increase in PET contents up to 0.5% and then increased with the further increase in PET contents. As mentioned, adding PET produced stiff mixtures which decreased flow. However, an excessive PET content decreased stability, and it increased flow consequently. The values of Marshall stiffness followed a trend similar to that obtained for Marshall stability, as shown in Figure 2d. These results were expected given that stiffness value pertains to stability divided by flow. Figure 2e shows that the air void values increased with the increase in PET content. This behaviour might be attributed to three possible reasons, namely, PET absorbed an amount of asphalt, decreased mixture homogeneity and reduced compressibility. These factors increased air voids. Figure 2f shows the VMA values changed by the increase in PET contents with a trend similar to that for air voids (Figure 2e). The justification of this trend was similar to that stated in case of air void trend. However, the differences amongst VMA values related to the addition of different PET contents were smaller than those of air void ones.

4. 3. Results of Rutting Tests This test was performed to investigate the effect of traffic loading on the serviceability of pavements in terms of capability to resist rutting. Figure 3 illustrates the results of this test for unmodified samples and those modified with different PET contents. The results showed that the rutting susceptibility of the modified samples was less than that of the control samples. The values of rut depth after 20000 wheel passes for the samples modified by PET contents of 0.1, 0.3, 0.5, 0.7, 0.9 and 1.1% were 8.5, 7.2, 6.9, 8.0, 8.3 and 8.7 mm, respectively. These values were less than that of the control WMA which is 9.7 mm. The rut depth values in all samples were less than 20% of the samples' thickness, which was acceptable in pavement technology [28]. However, rut depth values firstly decreased with an increase in PET content up to 0.5% and then increased with the further increase in PET contents. This behaviour could be attributed to the generation of a stiff mixture using a moderate PET content [24] and the decrease in its compressibility, as previously described. PET materials exhibited strain more than that exhibited by aggregates under equivalent stresses, but its value could be neglected as the strain value under a pressure of 730 kPa (wheel pressure) is not more than 0.0002, especially if PET particle size and content were considered; hence, a portion of strain was recoverable after unloading. PET had low transportability within the mixture due to the irregular shape of the particles and their surface texture and roughness, which reduced overall consolidability and, consequently, rutting. By contrast, aggregates had high transportability as a result of their relatively more regular shapes than those of PET particles, and they might degrade under wheel loading which caused rutting. Nevertheless, using excessive PET contents decreased stability and increased air voids, which increased rutting susceptibility. Mixtures with low rutting susceptibility typically exhibit low resistance to cracking [29], which causes them to be suitable for hot regions, but not for cold regions where cracking is probable [30]. The modified WMA (especially those modified with the optimum PET content), exhibited properties suitable even for cold regions, given the flow values were within the acceptable range. WMA is generally less susceptible to cracking than HMA because it has softer consistency than HMA [29].

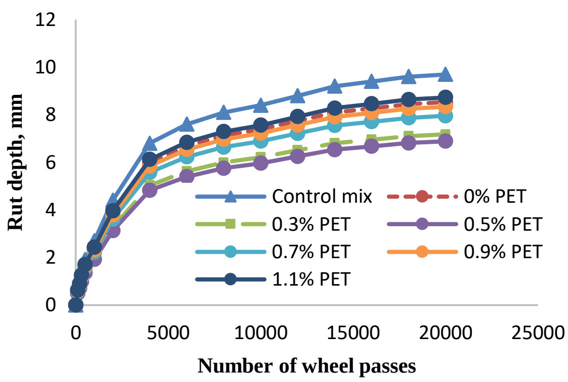


Figure 3. Results of wheel track rut depth

The modified WMA could be applied to cold regions with some adjustments, including increasing asphalt content and using soft asphalt cement initially. Precautions must be adopted when applying these adjustments to cover all the engineering properties required in the mixture.

5. DISCUSSION

The test results indicate that addition of PET to WMA improves engineering properties in terms of increased stability, stiffness and ITS values and decreased rutting susceptibility. PET content of 0.5% can be considered the optimum because it produces the highest stability and the lowest rutting susceptibility and fulfils the requirements of the other parameters. The role of optimum PET content can be abstracted in the following points. Firstly, the macro and micro roughness of PET surfaces increase the friction within the mixture. Secondly, partial melting of PET particles during the mixing and compaction stages increases the adhesion amongst aggregates with the aid of compaction efforts. Thirdly, PET particles absorb a small amount of asphalt, which leads to decrease in mixture softness as a result of the increase in friction and the decrease in lubrication. This justification is supported by the decrease in bulk specific gravity value as a result of the decrease in compressibility due to similar reasons. Fourthly, PET particles work as reinforcing fibres that resist tensile stresses. Fifthly, PET exhibits negligible strain under wheel pressure. However, PET particles exhibit low transportability due to their irregular shapes, which justifies the decrease in rutting under wheel passes. Improvement of the engineering properties of WMA can produce strong asphalt pavement layers, which reduces thickness with equivalent structural properties. This process can lead to a significant reduction in initial (construction) cost. In addition, improvement of the structural properties of asphalt pavement layers enhances their performance, increases their serviceability and decreases the maintenance cost. Therefore, this study recommends using PET waste material as an effective additive in WMA technology.

6. CONCLUSIONS

WMAs exhibit advantages over HMAs in terms of reducing mixing and compaction temperatures by decreasing predetermined related viscosities using additives. This technology decreases energy consumption, saves money and reduces the environmental pollution. However, more studies were conducted to improve the properties of HMAs than those explored the domain of WMAs, especially using waste materials, such as PET waste. Therefore, the present study adopted a laboratory-oriented approach to investigate the effects of different contents of PET waste bottles on the engineering properties of WMAs. The results exhibited significant improvements in the engineering properties of modified mixtures in terms of increases in stability, stiffness, ITS and moisture damage resistance and decrease in rutting susceptibility under moist conditions without adverse effects on other properties. On the basis of these results, the present study recommends PET content of 0.5% by weight of aggregate as the optimum content. Using these waste materials decreases corresponding costs and supports sustainable construction.

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P A P E R I N F O

Paper history:
Received 13 March 2018
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Accepted 26 April 2018

Keywords:
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چکیده

در پروژه‌های راه‌سازی ساخت روکش‌های انعطاف‌پذیر با مخلوط آسفالت داغ انرژی زیادی را صرف می‌نماید که این امر تاثیر بسزایی بر روی منابع و محیط زیست جهان خواهد داشت. لذا روش آسفالت مخلوط می‌تواند یک جایگزین موثر و مطلوب باشد چرا که در این روش نسبت بروش آسفالت داغ، تولید و مخلوط کردن آسفالت با دمای نسبتاً پایین‌تر صورت گرفته و تراکم مناسب صورت می‌پذیرد. این روش (تکنولوژی) باعث کاهش مصرف انرژی، صرفه‌جویی در هزینه و کاهش آلودگی محیط زیست می‌گردد. روش آسفالت مخلوط اگر همراه با استفاده از مواد زائد برای بهبود خواص آسفالت مخلوط باشد می‌تواند انقلابی در ساخت و ساز پایدار در راه‌سازی ایجاد نماید. ضایعات پلی اتیلن ترافتالین بطور فزآینده‌ای در سراسر جهان انباشته شده است. لازم به توضیح است که تاکنون تحقیق مناسبی درخصوص استفاده از مواد دور ریز در راستای بهبود خواص آسفالت مخلوط صورت نپذیرفته است. بنابراین مطالعه حاضر، استفاده از ضایعات پلی اتیلن ترافتالین برای تغییر خواص آسفالت مخلوطی را پوشش می‌دهد. برای بررسی بهبود خواص آسفالت مخلوطی استفاده از ضایعات با حداکثر اندازه ذرات ۲/۳ میلی‌متر با درصدهای وزنی مختلف (۰/۱، ۰/۳، ۰/۵، ۰/۷، ۰/۹ و ۱/۱ درصد وزنی مواد جامد) استفاده گردید. این مطالعه شامل تعدادی تست‌های آزمایشگاهی برای بررسی اثرات محتوای مختلف بر خواص بود که این آزمایشات شامل آزمایش مارشال و آزمایش حساسیت به چرخش بود. نتایج به دست آمده نشان‌دهنده بهبود قابل توجهی در خواص مهندسی شامل افزایش پایداری و سختی و کاهش حساسیت چرخش بدون عوارض جانبی مخلوط‌های اصلاح شده با محتوای با مقدار بهینه ۰/۵ درصد مواد گزارش شده است.

***doi**: 10.5829/ije.2018.31.09c.06*