Properties of SMA Mixtures Containing Waste Polyethylene Terephthalate

Taher Baghaee Moghaddam, Mohamed Rehan Karim

Abstract**—**Utilization of waste material in asphalt pavement would be beneficial in order to find an alternative solution to increase service life of asphalt pavement and reduce environmental pollution as well. One of these waste materials is Polyethylene Terephthalate (PET) which is a type of polyester material and is produced in a large extent. This research program is investigating the effects of adding waste PET particles into the asphalt mixture with a maximum size of 2.36 mm. Different percentages of PET were added into the mixture during dry process. Gap-graded mixture (SMA 14) and PG 80-100 asphalt binder have been used for this study. To evaluate PET reinforced asphalt mixture different laboratory investigations have been conducted on specimens. Marshall Stability test was carried out. Besides, stiffness modulus test and indirect tensile fatigue test were conducted on specimens at optimum asphalt content. It was observed that in many cases PET reinforced SMA mixture had better mechanical properties in comparison with control mixture.

Keywords**—**Asphalt mixture, Environment, Mix properties, Polyethylene terephthalate

I. Introduction

ASPHALT concrete (AC) mixture is subjected to many distresses during its service life which eventually cause to failure. Different types of failures exist such as rutting damage, low temperature cracking and fatigue damage which is mostly happened at medium temperature [1]. Nowadays, due to passing numerous vehicles, specially vehicles with higher axel loads, on roads service life of asphalt mixtures is going to be decreased. Thus, many investigations have been conducted to find ways to improve AC mixture characteristics with longer service life.

Stone mastic asphalt (SMA) is a type of hot mix asphalt which contains more coarse aggregate particles. SMA was developed in Germany in 1960s and has been using among European countries for more than 20 years [2]-[3]. SMA showed better characteristic against permanent deformation (rutting) damage; however, SMA have lower fatigue life compare to conventional hot mix asphalt and this is due to inherent structure of SMA mixtures [4]-[5].

Taher Baghaee Moghaddam is with University of Malaya, Department of Civil Engineering. 50603 Kuala Lumpur Malaysia. (phone: 603 – 79675339; fax: 603 – 79552182; e-mail: p.baghaee@gmail.com).

Mohamed Rehan Karim is with University of Malaya, Department of Civil Engineering. 50603 Kuala Lumpur Malaysia. (phone: 603 – 79675203 / 5339; fax: 603 – 79675318 / 79552182; e-mail: rehan@um.edu.my).

Using additives such as different types of polymers and fibers in AC mixture is a common way in order to increase service life of road pavement. Additives can be added into the mixture during the wet or dry process. In the wet process the additives are blended with asphalt at specific temperature and time before mixing with aggregate particles; however, during the dry process the additives are added directly to mixture. In previous studies it was reported that polymers and fibers can make three-dimensional networking effect in AC mixture and provide better adhesion between aggregate particles and asphalt binder [6]-[7].

However using virgin additives can improve asphalt mixture characteristics, it will increase road construction cost. So, in recent years many investigations have been conducted on AC mixtures containing waste materials as additives. Using waste materials as secondary materials in road pavement would prevent from additional road construction cost in one hand, and in other hand it would be a solution to decrease environmental pollution. Effects of adding different types of waste materials on AC mixtures have been investigated in asphalt pavement [8]. Among these waste materials waste plastics (polymers) had a noticeable usage in asphalt mixture. These materials can be used as aggregate replacement, binder modifier or mixture reinforcement. Hınıslıoğlu and Ağar investigated the effects of different percentages of High Density Polyethylene (HDPE) as asphalt modifier [9]. They observed that Stability and Marshall Quotient (MQ) decreased considerably by adding higher amount of HDPE and flow value showed an increasing trend. In other research program, it was observed that the stability and MQ values increased while the flow values decreased by using HDPE modified asphalt [10]. In a related study, Low Density Polyethylene (LDPE) was used in asphalt mixtures as an aggregate replacement. It was reported that Marshall Stability increased by 250%, and mix density reduced by 15% with the replacement of 30% LDPE with aggregates particles with the size of 2.36-5mm. Furthermore, Stability Retain (SR) value raised and MQ nearly doubled when 15% of aggregate was replaced with LDPE particles with the size between 0.30-0.92mm [8]. In other investigation due to the low compatibility of LDPE and asphalt, Glycidyl methacrylate (GMA) was used. The results showed that GMA-g-LDPE modified asphalt had better elastic and rutting performance. Also, temperature sensitivity and fatigue characteristic of asphalt binder was improved in that investigation [1]. Furthermore, based on the findings obtained by Ergun et al it was concluded that bending strength of mixture containing recycled Polyvinyl Chloride (PVC) bottles increased in comparison with the mixture without PVC [11].

In this study, waste Polyethylene Terephthalate (PET) was used as reinforcement. Marshall properties were obtained for mixtures containing different percentages of asphalt binder and PET particles. Besides, stiffness and fatigue properties of SMA mixture were investigated for mixtures at optimum asphalt content.

II. Laboratory Investigation

A. Materials

In this study, in order to make all the mixtures Granite-rich aggregate was prepared. Stone mastic asphalt was designated as a type of wearing coarse material in accordance with Malaysian Standard (JKR 05-06). Particle size distribution of the aggregate is shown in Table I.

TABLE I
Particle Size Distribution of Used Aggregate

Sieve size (mm)	Gradation limit(%)	Used Gradation(%)
12.5	100	100
9.5	72-83	77.5
4.75	25-38	31.5
2.36	16-24	20
0.6	12-16	14
0.3	12-15	13.5

In addition, 80/100 penetration asphalt cement and 9% filler were considered. PET particles were prepared from PET bottles. To obtain desirable PET particles, PET bottles were cut and crushed to small sizes, then sieved. The particles which were smaller than 2.36mm have been considered for this investigation.

B. Experiments

In order to characterize mechanical properties of PET reinforced mixture some standard laboratory tests were conducted. Marshall Stability and flow test was performed by standard Marshall Apparatus according to ASTM D 1559. Furthermore, stiffness modulus test and indirect tensile fatigue test (ITFT) were done in accordance with AASHTO TP31 and EN 12697, respectively. Stiffness modulus test and ITFT were conducted by UTM equipment at 20˚C and three different stress levels (250 KPa, 350 KPa and 450 KPa).

C. Sample Preparation

In order to prepare all the samples 1100 gm of SMA graded aggregate and filler were blended, and packed. In order to perform Marshall test the specimens were prepared at 5%, 5.5%, 6%, 6.5% and 7% of asphalt cement, and Marshall specimens were prepared by adding 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% PET particles (all by weight of aggregate content) into the mixtures at 160˚C as the method of dry process. In addition, for performance tests (stiffness modulus test and ITFT) the specimens were prepared at optimum asphalt content (6.77%, 6.45%, 6.43%, 6.29%, 6.36% and 6.51% of OACs corresponding to each PET content of 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1%, respectively).

The specimens were compacted by Marshall Compactor Machine at 140˚C, and 50 blows of compaction were applied on each side of specimens. 75 blows of compaction are not suggested for SMA mixtures because it would break down the coarse aggregate particles [12].

III. Results and Discussion

A. Marshall Stability Result

Marshall Stability is one of the most important factor of asphalt mixture. For Marshall test, the specimens immersed in waterbath at the temperature of 60˚C for 30 minutes. After removing the specimens from waterbath, they were placed in Marshal loading head. Marshall Stability is defined as the maximum load that the specimen fails at. Stability values were adjusted respect to specimen's volumes as mentioned in the related standard.

Fig. 1 shows that PET reinforced mixtures had higher stability values compare to the control mixtures (mixtures do not contain PET particles). It is shown that Stability values increased by adding PET particles up to 0.4% PET contain, then decreased by adding higher amount of PET (e.g. 1% PET), so it seems that 0.4% of PET content is the optimum value in case of stability. Besides, it is shown that mixtures containing higher amount of PET (0.8% and 1%) showed to have increasing trend although there is a decreasing trend for the mixtures reinforced by lower amount of PET.

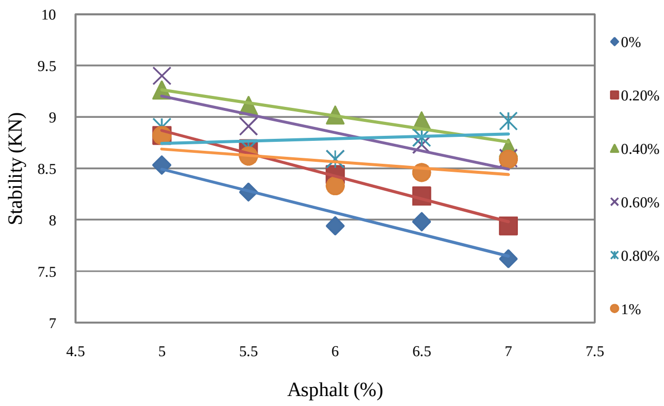

Fig. 1 Stability results for different asphalt and PET contents

B. Marshall Flow Result

Flow is referred to the maximum vertical deformation which is happened at failure point. As can be seen in Fig. 2 the flow values raised while asphalt content increased. In addition, the mixtures reinforced by higher amount of PET had higher flow values. The results may declare that PET reinforced mixtures have lower internal friction in comparison with the control samples.

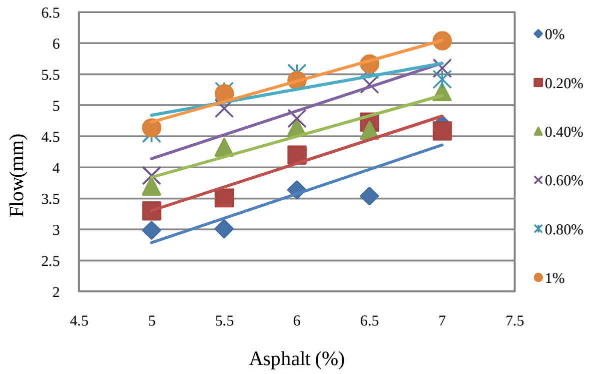

Fig. 2 Flow results for different asphalt and PET contents

C.Stiffness Result

Stiffness of the mixtures was obtained as a relationship existing between applied stress and specimen's deformation. During the test cyclic haversine waveform loads were applied along the vertical diameter of the specimen and the resulting deformations along the horizontal diameters are measured. Stiffness value can be calculated by "(1)":

$$S_m = \frac{P}{H.t}(\nu + 0.27) \quad (1)$$

Where S_m is stiffness, P is applied peak load, ν is Poisson's ratio (0.35 at 20˚C), H is horizontal deformation and t is thickness of specimen.

Fig. 3 illustrates changes in stiffness values versus PET content at different stress levels. It can be seen that mixture's stiffness decreases at higher stress levels. Furthermore, adding higher amount of PET makes mixtures less stiff. It is also good to note that the mixtures reinforced by 1% PET had nearly the same stiffness values at three different stress levels. Findings may indicate that PET reinforced mixtures are more flexible than control mixture especially the specimens reinforced by higher amount of PET.

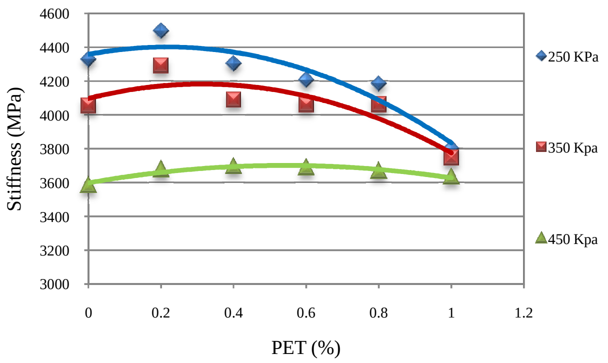

Fig. 3 Stiffness results for different PET content and Stress levels

D.Fatigue Result

Fatigue damage which usually occurs at medium temperature is a common problem of asphaltic mixture. This phenomenon is mostly appears as the cracking form in road pavement which is called alligator cracking and giving an undesirable feeling to the passenger while the vehicle passing fatigue area. Fatigue damage is a harmful phenomenon for road pavement and if it will not be repaired on-time, it may cause hole by providing pores and conditions for the moisture to go into asphalt layer (Fig. 4). This may cause vehicle accident on the roads which threaten passengers' life. So, every year, large amount money must be spent by governments to repair fatigue damages.

Fig. 4 fatigue causes pothole

In this study, indirect tensile fatigue test was used in order to obtain fatigue life of SMA mixtures. The loads were conducted using havesine waveform loads with 500 ms repetition time and 100 ms pulse width. Fatigue life is defined as the number of load repletion until the specimen fracture, or the deformation reaches to the maximum value of 9mm [13]. Fatigue lives versus PET content are plotted in Figs. 5, 6 and 7 for 250KPa, 350KPa and 450KPa, respectively. Results show that PET reinforced mixtures had considerably higher fatigue lives in comparison with control mixtures. For instance, at 250 KPa stress level fatigue life is nearly doubled when the value increased from under 30000 for mixture without PET and reached to over 60000 cycles for the mixture reinforced by 1% PET.

This is probably due to the PET particles that improve elastic property of mixture and absorb the amount of energy which is produced by repetitive loads, and postpone crack initiation and propagation in the mixtures.

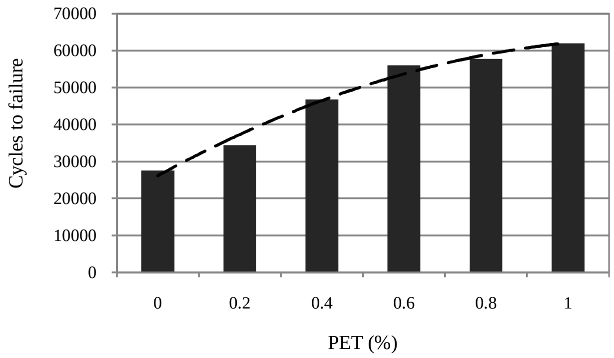

Fig. 5 Fatigue Life Vs PET content at 250KPa stress

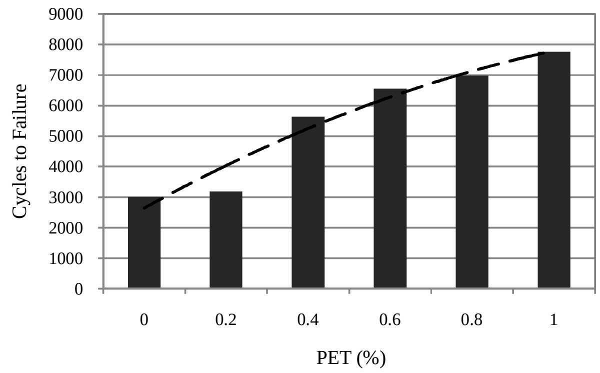

Fig. 6 Fatigue Life Vs PET content at 350KPa stress

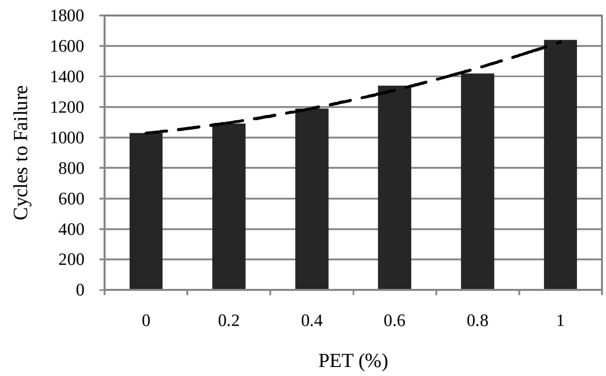

Fig. 7 Fatigue Life Vs PET content at 450KPa stress

IV. Conclusion

This study aims to investigate the possibility of adding waste PET in SMA mixtures as an additive to improve asphalt mixture characteristics in one hand, and in other hand prevent from environmental pollution by using waste material as secondary material in asphalt mixtures. Some properties of PET-reinforced SMA mixtures were obtained and compared to the control mixture. The test results indicated that PET reinforced mixtures had higher stability value in comparison with the mixtures without PET, and it was noted that 0.4% PET was concluded as the optimum value in case of stability. In addition, flow values increased by adding PET into the mixture. It was also investigated that although stiffness of mixtures decreased by adding higher amount of PET, fatigue life increased at higher PET content.

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