Construction and Building Materials 65 (2014) 487–494

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental characterization of rutting performance of Polyethylene Terephthalate modified asphalt mixtures under static and dynamic loads

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HIGHLIGHTS

- Properties of PET modified asphalt mixtures were investigated.
- Rutting behavior of asphalt mixtures was assessed.
- Static and dynamic loadings were designated.
- PET modified mixtures demonstrated different behaviors under static and dynamic loadings.

ARTICLE INFO

Article history:
Received 3 March 2014
Received in revised form 25 April 2014
Accepted 2 May 2014

Keywords:
Asphalt mixture
Waste Polyethylene Terephthalate
Mixture property
Static loading
Dynamic loading

ABSTRACT

During the last decades by increasing vehicles' number and weights on roads, road pavement has been subjected to greater damages which in many cases occurred even before expected pavement service life. Hence, in order to tackle with this problem road designers and engineers are to find solutions to improve pavement characteristics. One of the most common solutions is constructing asphalt mixture with modified characteristics. This paper aims to evaluate effects of using waste Polyethylene Terephthalate (PET) as a modifier on properties of asphalt mixture in three steps. In the first step, bulk specific gravity test, Marshall test, indirect tensile stiffness modulus test and indirect tensile strength test were conducted on mixtures containing different percentages of PET. In the second step, permanent deformation of PET modified asphalt mixture were assessed under static and dynamic loads. Finally in the last step, relationships were found between the results achieved in the first and second steps. The results showed that using PET as additive can change the properties of asphalt mixture. PET modified mixtures had entirely different behaviors under static and dynamic loadings and when it could not be considered as a proper additive for pavements experiencing static loading, it was a superior additive which can considerably improve rutting properties of asphalt mixture under dynamic loading condition.

1. Introduction

In recent years, road pavement has been subjected to greater damages as result of increase in number and weight of vehicles passing on roads. One of the most common types of road damaging is rutting which has a noticeable impact on performance of road pavement during its service life. Rutting is defined as the accumulated permanent deformation of road pavement which occurs under applied loading [1–3], and in this case, asphalt layer has shown a prominent magnitude [4]. Rutting is not only reduces the service life of asphalt mixture, but also influences basic vehicle handling manoeuvres in a negative manner which can threaten passengers' lives [5].

Different factors can influence rutting properties of asphalt mixture, including: aggregate type and gradation, amount of air void in asphalt mixture, type and amount of binder content, environmental temperature as well as mode and amount of loading applied on road pavement [6–8]. It is reported that Stone Mastic Asphalt (SMA) mixture which consists of coarse aggregate skeleton and provides stone-on-stone contact between aggregates has considerably better resistance against rutting damage compared to conventional dense graded mixture [9,10]. In addition, using, large size, angular, rough texture aggregate particles as well as stiffer binders can improve rutting resistance of asphalt mixture [11]. Environmental temperature is an important factor can influence the rutting properties of asphalt mixture and this is due to the asphalt

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http://dx.doi.org/10.1016/j.conbuildmat.2014.05.006
0950-0618/

properties which are highly influenced by ambient temperature [7].

In literatures, different laboratory tests have been used in order to evaluate rutting properties of asphalt mixture namely: wheel tracking test, static and dynamic creep tests [7,12], Marshall Quotient (MQ) [13,14] and indirect tensile test. Besides, it is believed that creep test has a very good correlation with actual rut depth and has a high capability to estimate rutting behavior of asphalt layer [15]. MQ which is the ratio of stability to flow (rigidity ratio), and is a well-recognized criteria to measure resistance of materials to shear stress, permanent deformation and hence rutting [12,13]. It is thought that higher value of MQ represents higher mixture stiffness which contributes to higher resistance against permanent deformation in asphalt mixture [12,14].

This study aims to evaluate permanent deformation characteristics of Polyethylene Terephthalate (PET) modified asphalt mixtures under static and dynamic loads and their relationships with other properties of mixture.

2. Literature review

2.1. Polyethylene Terephthalate (PET) modified asphalt mixture

Polyethylene Terephthalate (PET) is semi-crystalline thermoplastic polymer, and is considered as polyester material [16]. PET is one of the important technical plastic materials in the last two decades because of its superlative characteristics such as being safe, light, transparent, chemical resistance and economical [17]. Nowadays, large amount of waste PET are being produced worldwide and due to non-biodegradability of PET it causes serious environmental challenge [18].

PET can be recycled by chemical and physical procedures. Chemical recycling of PET is costly because it is performed at high pressure, temperature and in presence of chemical materials as catalysts. Further, in mechanical recycling, quality of recycled PET would be decreased due to the presence of adhesive contaminants [19]. Hence, recycling cannot be considered as only solution to overcome the crisis arises by producing large amount waste PET, thus it would be promising to find alternative solution to tackle with this problem such as using as secondary materials in asphalt mixture. Here, it is aimed to bring the history of using post-consumer PET in asphalt mixture.

Post-consumer PET was used in asphalt mixture in two different concepts. One is using PET as aggregate replacement in asphalt concrete mixture (plastiphalt), and another is modification of asphalt mixture by utilizing PET particles.

Hassani et al. have investigated the possibility of using waste PET in asphalt concrete mixture as an aggregate replacement. In this study, mineral coarse aggregates with size of 2.36–4.75 mm were replaced with PET granules with diameter of 3 mm. The mechanical properties of mixtures including Marshall stability and flow, MQ and specific gravity of compacted mixtures were evaluated. As a result it was achieved that plastiphalt with the partial aggregate replacement (20% by volume) with PET granules met most of specification requirements which made it proper for practical use [20]. In a related study, the waste PET as partial fine aggregate replacement was evaluated. The repeated load axial test and indirect tensile stiffness modulus test were performed. Results showed that though plastiphalt had less stiffness compared to the conventional mixture, it had higher resistance against permanent deformation [21].

There are two different methods for using additives in asphalt mixture namely: wet and dry methods. In the wet method procedure, the additives are added to the asphalt cement before mixing with aggregate particles. In the dry method, however, the additives are added directly to the mixture. In 2008, Casey et al, attempted to investigate suitability of different polymer materials as asphalt modifiers. In this investigation it was thought that PET cannot be considered as a suitable asphalt modifier due to its high melting point that might hinder the mixing. Hence, because PET could not be incorporated into the asphalt, it was supposed that adding PET in asphalt mixture through the wet method would not be practical [22].

Recently, PET particles have been added to asphalt mixture as an additive using dry process. In 2011, Ahmadinia et al, utilized waste PET with maximum size of 1.18 mm as additive in SMA mixtures. The Marshall and volumetric properties of mixtures were assessed and it was concluded that re-using waste PET as an additive had positive effects on properties of SMA mixture in an environmentally friendly and economically way [23]. In the next year, more investigations were performed on PET modified SMA mixtures by Ahmadinia et al. Wheel tracking, moisture susceptibility, resilient modulus and drain down tests were performed on PET modified SMA mixtures. They used the same PET particle size and percentages as they used earlier. It was found from this study that the performance of PET modified mixture has satisfied the standard requirements and that the appropriate range for the PET amount is between 4% and 6% by weight of asphalt content [24].

The fatigue properties of asphalt mixtures modified by PET particles were evaluated in another study. PET flakes with the maximum size of 2.36 mm were used and fatigue properties of PET modified asphalt mixtures were assessed. The results showed that the fatigue life increased considerably under dynamic loading and the mixtures containing higher amount of PET content showed higher resistance against fatigue cracking [25]. In other study, permanent deformation characteristics of PET modified asphalt mixture under dynamic loading was investigated at various temperatures and stresses, and it was shown that permanent strain decreased considerably by application of PET modification [7].

2.2. Static and dynamic creep tests for modified mixtures

Static and dynamic creep tests have been considered as two important test methods that can determine the rutting susceptibility of asphalt mixture. In the past literatures, more studies have assessed the permanent deformation of asphalt mixture using dynamic creep test though less studies focused on static testing. In this section, it is aimed to bring an overview on static and dynamic creep testing of modified mixtures which were conducted in the last few years.

Effect of using cellulose and mineral fibers on rutting properties of asphalt mixture was investigated by Behbahani et al. Dynamic creep test was conducted and the results suggested that rutting properties of asphalt mixture was improved by adding fibers under dynamic loads [26]. In related study, dynamic creep test was designated to evaluate the rutting performance of asphalt mixture with waste tire thread mesh reinforcement and with different percentages. It was obtained from the results that mixture containing 3% of tire thread had the lowest permanent strain and so highest rutting resistance [27].

In other investigation, effects of three elastomeric polymers have been identified on rutting properties of asphalt mixture. These elastomeric polymers were OL, EL and SB. In that study, it was concluded that using elastomeric polymers could enhance the rutting resistance of asphalt mixture; however, the results were not correlated well with each other at high and low temperatures [28].

In 2012, the effects of using mineral and cellulose fibers as well as SBS polymer were investigated on rutting properties of SMA mixture. The result of this study showed that SBS had the best effect on rutting properties of asphalt mixture [29]. Baghaee

Moghaddam et al. conducted a study to evaluate the effects of using different percentages of PET on permanent deformation of asphalt mixture under dynamic loads at different temperatures and stress levels. Obtained results showed that using PET can considerably improve the rutting resistance of asphalt mixture under dynamic loads [7].

In 2013, a research was conducted by Serkan Tapkın on rutting behavior of asphalt mixture containing polypropylene fiber. In this study static creep testing was performed on the specimens fabricated using both gyratory and Marshall compaction methods. According to the results it was found that the gyratory specimens had better resistance against rutting damage at lower amount of polypropylene; however, at higher amounts of polypropylene fiber Marshall specimens had the better results [30].

Another investigation was conducted by Tayfur et al. on rutting performance of polymer modified asphalt mixture using both static and dynamic creep testing. In that study, it was realized that the results achieved by static and dynamic creep tests were not properly correlated with each other and that the static test could not show the effect of modifiers in asphalt mixture [12].

3. Objectives and test procedures

The objective of this study is evaluating the rutting properties of PET modified asphalt mixture under different loading types. Besides, there is a need to uncover relationships between the properties of modified mixtures and parameters affecting these properties which have not been previously performed. To achieve these aims following steps are designated:

(a) Obtaining the basic properties of unmodified and PET modified asphalt mixture including: bulk specific gravity, Marshall, tensile stiffness and tensile strength.
(b) Obtaining the rutting properties of PET modified asphalt mixture under static and dynamic loads.
(c) Obtaining the relationships between the rutting characteristics of PET modified asphalt mixture and the other mixture properties.

3.1. Materials

80/100. penetration grade asphalt was used for this experimental work. The physical properties of asphalt cement can be found in Table 1. Moreover, used aggregate particles were obtained from Kajang Rock Quarry in Malaysia. Particle size distribution of aggregate is given in Table 2, and physical properties of aggregate particles are listed in Table 3.

PET particles were obtained from post-consumer PET bottles. For preparing PET particles, the bottles have been washed and dried. Then they were cut to small parts and crushed using crushing machine [25]. These crushed flakes were sieved and those passed sieve 2.36 mm were used with 11 different percentages (0%, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9% and 1% by weight of mixed aggregates).

3.2. Sample preparation

All conventional and modified specimens were fabricated at optimum asphalt contents according to ASTM D1559 [34]. In order to fabricate the mixtures, optimum amounts of asphalt cement and 1100 g of mixed aggregates were heated at temperatures of 130 °C and 160 °C respectively. As the method of dry process, the PET particles were added directly to the mixture. After mixing the aggregate particles, asphalt and PET at the temperature of 160 °C, 50 blows of compaction effort were applied on each side of specimens at temperature of 140 °C. In this investigation, PET particles added to the mix of aggregate particles and asphalt cement, because it is believed that mixing aggregate with PET would cause the aggregate surface be coated by the molten part of PET which eventually can contribute to less adherence between aggregate particles and the asphalt cement.

Table 1
Properties of asphalt cement.

Properties	Methods	Values
Penetration at 25 °C (0.1 mm)	ASTM: D5	87
Softening point (°C)	ASTM: D36	46
Viscosity at 135 °C (mPa s)	ASTM: D4402	325
Viscosity at 170 °C (mPa s)	ASTM: D4402	62.5
Flash point (°C)	ASTM: D92	300
Fire point (°C)	ASTM: D92	320
Specific gravity (g/cm^3)	ASTM: D70	1.03

Table 2
Aggregate gradation limits and used gradation.

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
0.075	8–10	9

Table 3
Properties of aggregates.

Properties	Methods	Requirements	Values
Coarse aggregates			
L.A. Abrasion (%)	ASTM: C131	<30	19.45
Flakiness index (%)	BS EN 933-3 [31]	<20	2.72
Elongation index (%)	BS 812-105.2 [32]	<20	11.26
Aggregate crushing value (%)	BS 812-110 [33]	<30	19.10
Bulk specific gravity (g/cm^3)	ASTM: C127	–	2.60
Absorption (%)	ASTM: C127	<2	0.72
Fine aggregate			
Bulk specific gravity (g/cm^3)	ASTM: C128	–	2.63
Absorption (%)	ASTM: C128	<2	0.4
Soundness loss (%)	ASTM: C88	<15	4.1

3.3. Methodology

3.3.1. Bulk specific gravity

Bulk specific gravity test was performed according to ASTM D2726 [35]. Each sample was weighted three times. First the dry compacted sample was weighted, and then it was immersed in water for 4 min and weighted again. Next, after it was removed from the water tank it was dried using a damp towel and its weight was measured. By having these three amounts Eq. (1) was used for calculating the bulk specific gravity of mixture:

$$BSG = A/(B - C) \tag{1}$$

BSG = Bulk specific gravity of compacted mixture.
A = Weight of dry specimen in air.
B = Weight of saturated surface dry specimen.
C = Weight of specimen in water.

Three identical samples were fabricated for each percentage of PET and the average value of them was considered as the final result.

3.3.2. Marshall stability and flow

Marshall stability and flow test was conducted according to ASTM D1559 [34]. In order to conduct the test, Marshall specimens were placed in waterbath at temperature of 60 °C for 30 min before commencing the test. Then after removing the specimens from waterbath, they were put in Marshall apparatus and tested immediately. Marshall stability was the maximum load applied at a constant strain (2 in. per minute) which causes failure. During the test a dial gauge was used to measure the vertical deformation of the specimen. Marshall flow value was expressed as the vertical deformation happens at the failure point of specimen.

3.3.3. Indirect tensile stiffness modulus (ITSM)

AASHTO TP31 standard test method [36] was used for the indirect tensile stiffness modulus test. Universal Testing Machine (UTM) was utilized. The test was conducted at 20 °C and 250 kPa stress was considered. During the test the compressive haversine loads were applied across the vertical section across the thickness of specimen, and deformations of specimen were measured by using linear variable differential transducers (LVDTs) along diametrical section of specimen. Stiffness of mixture was calculated by using following equation:

$$S_m = \frac{P \times (\upsilon + 0.27)}{H \times t} \tag{2}$$

where S_m is the stiffness modulus of specimen; P, applied vertical peak load; H, amplitude of horizontal deformation; t, average thickness of specimen; and ν is Poisson's ratio (0.35 at temperature of 20 °C).

Stiffness modulus test is a non-destructive test and so it has been conducted twice for each specimen. It means after applying the first cyclic loads (the first 10 load cycles), the specimen was rotated for about 90° and the second load repetition was applied. Then the average amount of the first and second load repetitions was considered as the final result.

3.3.4. Indirect tensile strength (ITS)

Indirect tensile strength (ITS) is considered as the potential test method for determining the tensile properties of asphalt mixture which can be further related to rutting and cracking properties of asphalt mixture. This test method is performed in accordance with ASTM D6931 [37] at the temperature of 25 °C. In this test the cylindrical samples were placed in two loading strips and a compressive load was applied along a diametrical plane which can generate a relatively uniform tensile stress and acts perpendicular to the applied load plane. The loading was continued until the specimen failed. Then Eq. (3) was used for calculating the values of ITS.

$$\mathrm{ITS} = \frac{2P_{\max}}{\pi t d} \tag{3}$$

where

ITS = indirect tensile strength (Pa).
$P_{\max}$ = maximum applied load (N).
t = thickness of specimen (mm).
d = diameter of specimen (mm).

3.3.5. Static creep test

Static creep test has been used as a test method to evaluate the permanent deformation characteristic of asphalt mixture. UTM which is the most common device for measuring permanent deformation of asphalt mixture was used in this investigation. During the test a uniaxial static load was applied for a period of 1 h and the creep deformation of asphalt mixture was measured by LVDTs which were installed in vertical direction. Then by using Eq. (4) the accumulated permanent strain of specimen was calculated:

$$\varepsilon = \frac{h}{H_0} \tag{4}$$

ε is accumulated permanent strain, h is axial deformation and H_0 is initial height of specimen. Static creep test was performed at 200 kPa stress and temperature of 40 °C.

3.3.6. Dynamic creep test

The same device was used for dynamic creep test. During the test dynamic compressive loadings with the peak of 300 kPa were applied. The loading time was 100 ms and rest period of 900 ms was designated for this study. The amounts of cumulative permanent strains were recorded during applying 3600 loading cycles. Previous study showed applying lower amount of stress (e.g. 100 kPa) could not clearly show the effect of modification on deformation properties of modified asphalt mixture under dynamic loading [4]. Hence, higher stress value is considered for this study. The accumulated permanent strain was calculated with the same procedure as for static test. Dynamic creep test was conducted at 40 °C, and in order to reach a uniform mixture temperature all the specimens were placed in controlled temperature chamber for at least 1 h. A schematic view of creep test set up is shown in Fig. 1.

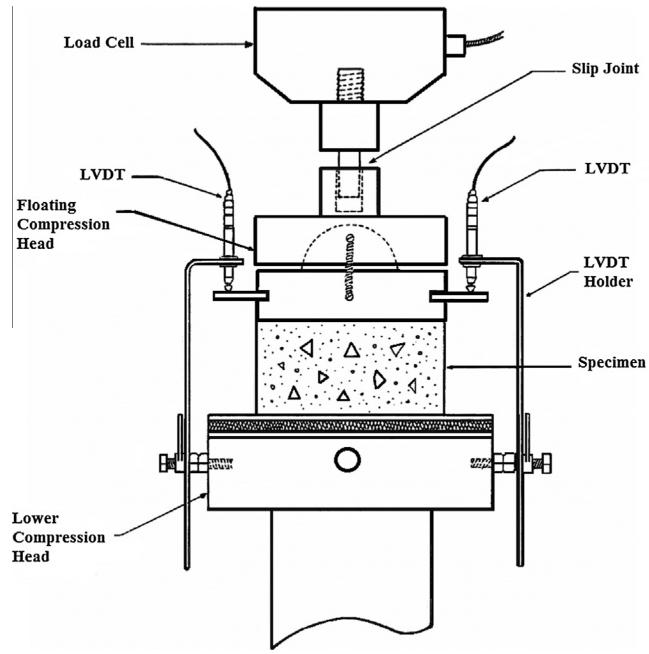

Fig. 1. Schematic diagram of the creep setup [38].

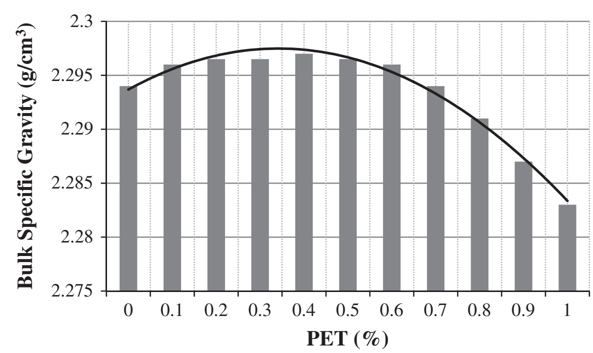

Fig. 2. Effect of adding different percentages of PET on bulk specific gravity of compacted mixture.

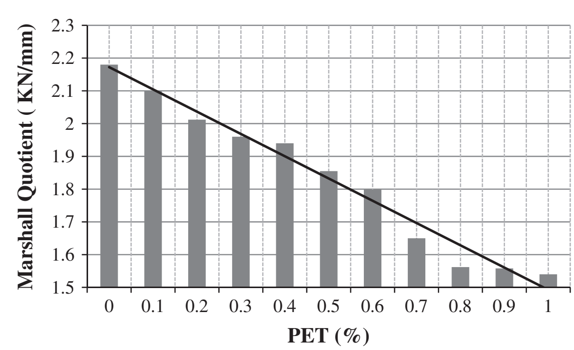

Fig. 3. Effect of adding different percentages of PET on Marshall Quotient of compacted mixture.

4. Results and discussion

4.1. Effect of PET modification on properties of asphalt mixture

Fig. 2 illustrates that Bulk Specific Gravity (BSG) of asphalt mixture varies by application of different percentages of PET modification. As it can be seen in Fig. 2, the BSG of mixture increases initially at lower amount of PET contents although it falls dramatically at higher percentages of PET. This result might be due to the melting point of PET which is a high (250 °C) and is more than specimen fabrication temperature. That is to say, by adding lower amount of PET the solid PET particles fill the pores between the aggregate particles which results in higher BSG and when the amount of PET exceeds 0.4%, these rigid particles locate between the aggregate particles which can contribute to higher specimen volume and lower BSG.

Marshall Quotient (MQ) results are shown in Fig. 3. As it can be seen in this figure, the values of MQ are decreased by application of PET modification from approximately 2.2 kN/mm for control mixture to around 1.55 kN/mm for 1%-PET modified mixture. This result illustrates that PET modified mixtures are less rigid than unmodified mixture, and this might be due to lower internal friction of compacted mixture containing PET.

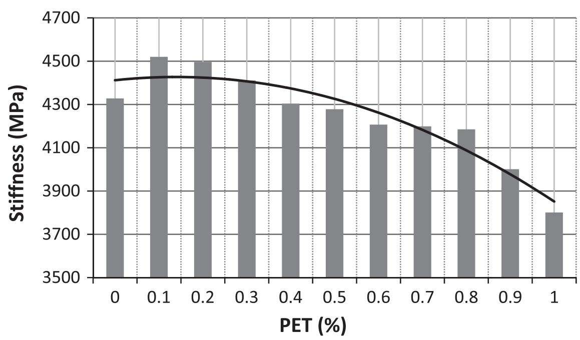

Fig. 4. Effect of adding different percentages of PET on stiffness of compacted mixture.

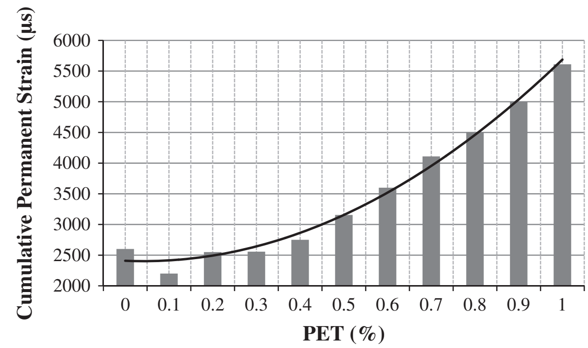

Fig. 6. Effect of adding different percentages of PET on permanent strain of compacted mixture under static loading.

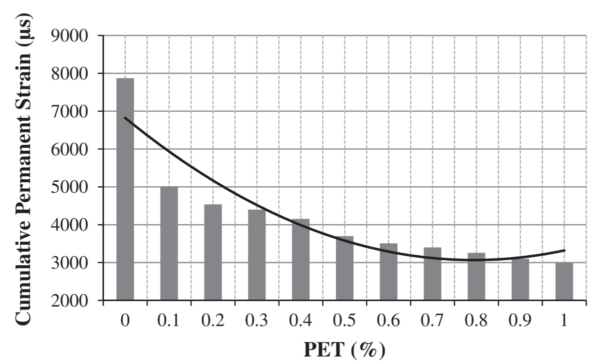

Fig. 7. Effect of adding different percentages of PET on permanent strain of compacted mixture under dynamic loading.

The changes in stiffness of asphalt mixtures are depicted in Fig. 4. It can be clearly seen from this figure that although the addition of PET initially increases the mixture stiffness, it falls at higher amount of PET. It is worth noting that the maximum mixture stiffness achieves at 0.1% of PET content which is above 4500 MPa. The lower stiffness value of PET modified mixture might be due to the enhancement of mix flexibility which results in higher deformation of mixture under applied load [25].

Fig. 5 shows the results of Indirect Tensile Strength (ITS) test. From this figure it can be determined that PET modified mixtures have lower tensile strength value under static loading when tensile strength of compacted mixture decreased by about 200 kPa for 1%-PET modified asphalt mixture compared to the control mixture. This result might suggest that the PET modified mixtures are more susceptible against low temperature cracking [39].

The permanent deformation characteristics of unmodified and PET modified asphalt mixtures were evaluated under static and dynamic loading applications. Figs. 6 and 7 show the results of static and dynamic tests respectively. It can be observed from these figures that PET modified mixtures have different behavior under static and dynamic loadings. As it is realized from Fig. 6 the lowest amount of permanent deformation is for 0.1% PET modified mixture however the amount of deformation increases at higher PET content and it is peaked by application of 1% PET. On the other hand, as can be seen from Fig. 7 for the PET modified mixture the amount of permanent deformation decreases under dynamic loading compared to the control mixture and the mixtures fabricated using higher PET contents showed higher resistance against permanent deformation. It is worth noting that for the mixture modified by 1% PET the increment in permanent deformation under static loads is about 3000 μs and the amount of decrement is about 5000 μs under dynamic loading. This result can be referred to the flexibility of modified mixture. That is to say by improving the flexibility of mixture at higher PET contents the amount of deformation increases under applied compressive loads. Although in case of dynamic loading the deformed mixture can find recovery time to return to initial condition.

4.2. Relationships between permanent deformation of PET modified asphalt mixture and other mixture properties

4.2.1. Permanent strain and bulk specific gravity

The changes in the BSG of PET modified mixtures against Cumulative Permanent Strain (CPS) under static and dynamic loadings are shown in Fig. 8. As it can be realized from this figure, the overall trend of BSG are different for each loading types, and when the PET modified asphalt mixture with lower BSG experiences higher CPS under static loading, the mixtures with higher BSG show to have higher permanent strain under dynamic loading. It can also be

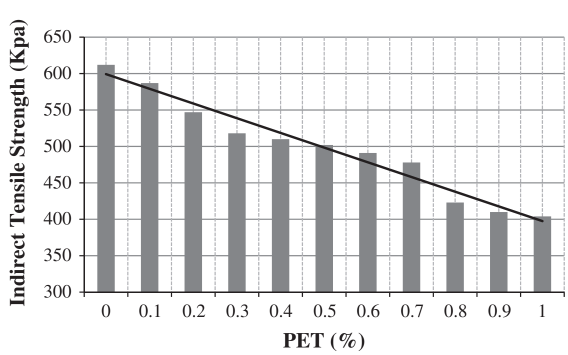

Fig. 5. Effect of adding different percentages of PET on tensile strength of compacted mixture.

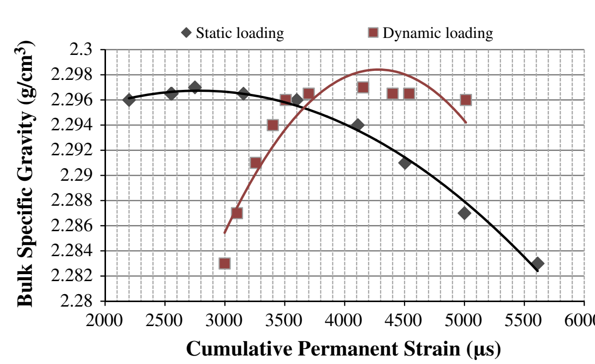

Fig. 8. Cumulative permanent strain vs. Bulk Specific Gravity.

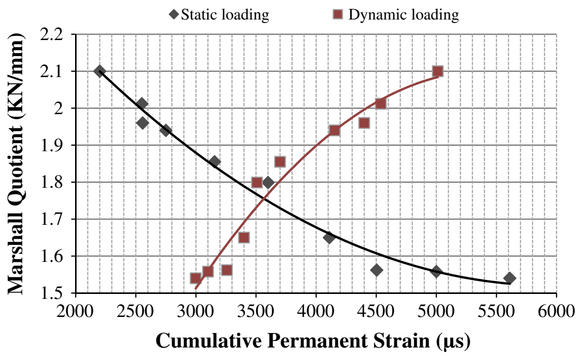

Fig. 9. Cumulative permanent strain vs. Marshall Quotient.

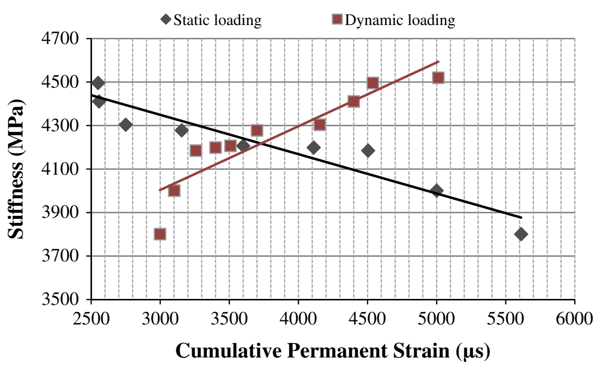

Fig. 10. Cumulative permanent strain vs. Stiffness.

understood from this figure that the CPS of PET modified mixture under static and dynamic loadings reach to the same value at the BSG of 2.2955. Additionally, mixtures with the BSG around 2.296 show to have different CPS values, and this might be referred to the percentages of PET in the PET modified mixture which can influence the mechanical properties of mixture without causing considerable changes to the BSG value.

4.2.2. Permanent strain and Marshall Quotient

It can be clearly seen from Fig. 9 that there is an inverse relationship between permanent strain and the MQ under static and dynamic loadings. MQ has a direct relationship with permanent deformation under dynamic loading when the CPS values increases by increment of MQ, however in case of static loading the trend line is downward and the mixtures having lower MQ show to have higher deformation. As it was mentioned earlier some literatures considered MQ as a criterion for evaluating rutting properties of asphalt mixtures, and it was supposed that mixture with higher MQ value have higher resistance against permanent deformation

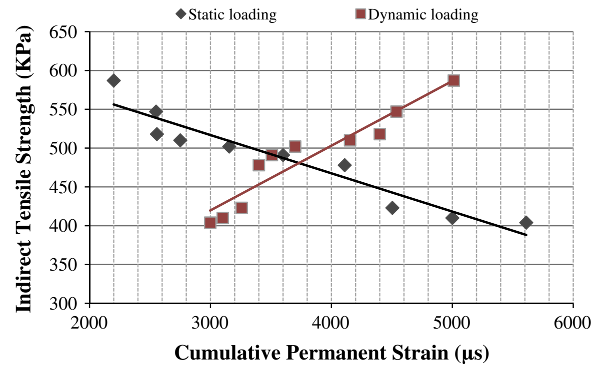

Fig. 11. Cumulative permanent strain vs. indirect tensile strength.

Table 4
Models for mixture properties and PET.

Parameters		Type of regression model	Model	Coloration coefficient
Y	*X*			
BSG	PET	Polynomial	$Y = -0.032X^2 + 0.022X + 2.293$	0.987
Stiffness	PET	Polynomial	$Y = -776.1X^2 + 215.6X + 4412$	0.899
MQ	PET	Linear	$Y = -0.679X + 2.172$	0.975
ITS	PET	Linear	$Y = -201.7X + 599.2$	0.962
CPS-(static)	PET	Polynomial	$Y = 3569X^2 - 290.3X + 2408$	0.988
CPS-(dynamic)	PET	Polynomial	$Y = 5966X^2 - 9466X + 6821$	0.860

[13,14]. Nevertheless, the results of this study show that though this criterion might be acceptable for permanent deformation resistance of PET modified mixture under static loads, it cannot be a true indicator in case of dynamic loading.

4.2.3. Permanent strain and stiffness

Stiffness or resilient modulus of asphalt mixture is the most popular form of stress–strain measurement used to assess the elastic properties of mixture. In Fig. 10 the stiffness values of PET modified mixtures are plotted against CPS values. As this figure shows, PET modified asphalt mixture with higher stiffness values have lower CPS values under static loading. On the other hand, in case of dynamic loading the CPS increases for the mixtures with higher stiffness values. In the past investigation on using mineral fiber, cellulose fiber and SBS in asphalt mixture, it was found that the stiffer mixture had the lowest permanent deformation under dynamic loading [29]. Moreover, another study by Tayfur et al. on different polymer modifiers showed mixtures with higher stiffness values had higher and lower permanent deformation under static and dynamic loadings respectively [12]. Nevertheless, the results achieved in this study are more compatible with previous study on replacement of fine aggregate with PET particles (plastiphalt) that showed though PET modified asphalt mixture had

Table 5
Models for mixture properties and cumulative permanent strain.

Parameters		Type of regression model	Model	Coloration coefficient
Y	*X*			
Stiffness	CPS-(static)	Linear	$Y = -0.180X + 4892$	0.915
Stiffness	CPS-(dynamic)	Linear	$Y = 0.293X + 3124$	0.826
BSG	CPS-(static)	Polynomial	$Y = -2E{-}09X^2 + 1E{-}05X + 2.282$	0.990
BSG	CPS-(dynamic)	Polynomial	$Y = -8E{-}09X^2 + 7E{-}05X + 2.154$	0.878
MQ	CPS-(static)	Polynomial	$Y = 4E{-}08X^2 - 0.001X + 2.976$	0.983
MQ	CPS-(dynamic)	Polynomial	$Y = -1E{-}07X^2 + 0.001X - 0.841$	0.959
ITS	CPS-(static)	Linear	$Y = -0.049X + 664.5$	0.912
ITS	CPS-(dynamic)	Linear	$Y = 0.083X + 169.8$	0.897

lower stiffness in comparison with unmodified mixtures, they had higher resistance against permanent deformation under dynamic loadings [21].

4.2.4. Permanent strain and indirect tensile strength (ITS)

As it is observed from Fig. 11 relationship trends between ITS and CPS for PET modified mixtures differ under static and dynamic loadings. From this figure it is obvious that the mixtures with higher ITS values have the higher CPS under dynamic loadings. Nevertheless, a different relationship can be observed for the static test when the amount of CPS decreases by increasing ITS amount.

4.3. Statistical analysis

In order to have better understanding about the relationships between permanent deformations of PET modified mixture and other mixture properties statistical analysis should be performed. In this study regression analysis was performed using SPSS software to inspect these relationships, and the results are summarized in Tables 4 and 5. Types of regression models and the correlation coefficients are represented in the tables, and as it can be seen, almost in all cases, there are strong correlations between the chosen parameters.

5. Conclusions

In this paper, it was attempted to characterize the rutting behavior of PET modified asphalt mixture under static and dynamic loadings, and find the relationships between the deformation and other mix properties. Based on the results, the following conclusion can be derived:

(1) The bulk specific gravity and stiffness values of asphalt mixture increased initially by using lower amounts of PET. Although they decreased at higher amounts of PET contents.
(2) Marshall Quotient and indirect tensile strength values decreased by application of PET, and using higher amounts of PET resulted in lower Marshall Quotient and tensile strength values.
(3) PET modified mixtures with higher bulk specific gravity, Marshall Quotient, stiffness and tensile strength showed to have lower cumulative permanent strains under static loading.
(4) In case of the dynamic test, the PET modified asphalt mixtures with lower amounts of specific gravity; Marshall Quotient, stiffness and tensile strength had lower cumulative permanent strain values.
(5) Based on the results achieved in this study, it can be concluded that PET modified asphalt mixture had different rutting behavior under static and dynamic loadings. When using PET might deteriorate the mixture rutting property under static loading, it can be a superior modification for the pavements facing dynamic loadings.
(6) The common test methods such as Marshall, stiffness and strength tests which previously were used to predict the rutting susceptibility of asphalt mixture cannot be appropriate criteria to evaluate the rutting resistance of PET modified asphalt mixture.

Acknowledgements

This study was supported by the University of Malaya Research Fund (Project No: ER030-2011A). The authors would like to thank to the University of Malaya Research Fund for providing us the opportunity to make this research project.

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