Investigating the Effects of Using Waste Rubber and Polyethylene Terephthalate (PET) on Mechanical Properties of Asphalt Concrete

H. Taherkhani and M. Reza Arshadi

***Abstract*—Scrap tires and plastics are among the main solid wastes generated in large amount throughout the world. Polyethylene Terephthalate (PET) is the most consumed and wasted plastic. In this study the effects of PET particles size and content on some engineering properties of asphalt concrete containing rubber modified asphalt has been investigated. Different concentrations of waste PET including, 0, 2, 4, 6, 8 and 10% (by the weight of binder) in two different ranges of size were to asphalt concrete and the Marshall stability, Marshall quotient, indirect tensile strength (ITS) and uniaxial dynamic creep properties were evaluated. Results show that the Marshall stability and Marshall quotient increase with increasing PET content. The indirect tensile strength (ITS) test results show that the highest ITS is obtained by adding 2% of PET into the mixtures and beyond that the ITS decreases with increasing PET content. Dynamic creep test results revealed that the resistance against permanent deformation decreases with increasing PET content. However, the mixture containing fine graded PET particles has more resistance against permanent deformation than the mixture containing coarse graded PET particles. Comparing the results on the rubber modified mixtures in this research with those on conventional mixtures accomplished previously reveals that the trend is different.**

***Index Terms*—Asphalt concrete, waste rubber, waste PET, ITS, creep.**

I. Introduction

Managing the voluminous solid wastes and reducing their negative impact on environment has become a main concern of societies. Disposal of the wastes into nature, in addition to occupying valuable lands, can be hazardous for human and other creatures' life. Therefore, suitable measures must be sought to reduce these impacts. Many different solid wastes are produced by households, industries and services. Scrap tires and plastics are among the major solid waste, which needs a long time to decompose in nature and are considered as harmful wastes. A large number of scrap tires are wasted annually in the world. Approximately 300 million scrap tires are generated annually in US. Only a small fraction of the waste tires are recycled and used in engineering applications [1]. The major fraction of using scrap tires in civil engineering projects is in asphalt paving industry, in which it is used as crumb rubber with sizes ranging from 4.75 mm to 0.075 mm. Scrap tires are mechanically grounded into crumb rubber under different conditions [2]. Crumb rubber is added into asphalt mixtures using two different processes, namely wet and dry process. In the more common method of wet process, rubber is first blended with the asphalt cement at high temperatures and using special mixers, and the modified asphalt is mixed with hot aggregate in the mixer of asphalt plant. In the dry process, crumb rubber particles are added into the aggregate and then they are mixed with hot asphalt cement in asphalt plant mixer. One of the key factors in the performance of rubber modified binder is the interaction of crumb rubber and asphalt. Swelling and dissolution are two mechanisms occurring simultaneously during the interaction of added rubber particles [3]-[6]. When crumb rubber particles are added into hot asphalt binder, the aromatic oils of the asphalt are absorbed into the polymer chains of crumb rubber, resulting in rubber particles swelling to two to three times their original volume and forming a gel-like material [4]. As a result of rubber particles swelling, the distances between particles decreases, by which binder viscosity is increased up to a factor of 10 [4], [6], [7], [8]. The studies on rubber modified binder and mixtures have revealed the improvement in the properties such as rutting resistance, and fatigue, thermal and reflective cracking resistance [9]-[13].

Among the waste plastics, Polyethylene Terephthalate (PET), which is mainly used for packaging drinks, foods, cleaners, oil etc. [14], is the most wasted. In US alone, 2675 tons of PET has been wasted in 2010, from which only 29.1% was recycled and the rest was disposed [15]. PET is not a degradable material, and needs centuries to decompose. Its disposal in environment causes pollution of rivers and oceans and endangers creatures' life. Therefore, managing waste PET is very important for protecting the environment. Finding applications, in which high quality material is not required, is a way to effectively reuse waste PET [16]. One of the potential applications for PET is in asphaltic mixtures [17]-[22]. Baghaee Moghaddam et al. found that the maximum stiffness is obtained at a PET content of 1% (by the weight of aggregate), after which it decreases with increasing PET content [23]. They also found that the fatigue performance of the mixture is considerably improved by PET inclusion. In another research work, Baghaee Moghadam et al. found that PET inclusion decreases the Marshall stability and indirect tensile strength of the SMA mixture [24]. They also found that the resistance against permanent deformation decreases with increasing PET content under static loading. However, the behavior under dynamic loading is opposite and the resistance against permanent deformation increases with

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increasing PET content. Similar results were found by Ahmadinia *et al*. [19] who found that at all testing conditions, the resistance against permanent deformation of the mixtures containing PET is higher than that of the control mixture without PET. Ahmadinia *et al*. found that the highest Marshall stability and Marshall quotient (MQ) is obtained by using 6% (by the weight of binder) of PET in SMA mixture [18]. They also found that the resilient modulus and resistance against drain down are improved by PET addition.

Modarres and Hamedi [14], [21] found that the stiffness and tensile strength of the mixture can be improved by adding of 2% (by the weight of binder) of PET into asphalt concrete. By adding PET to mixture using wet and dry method, Earnest found that PET modification increases the performance of the binder and mixture at high temperatures, without affecting the viscosity and workability [15]. Wet process was also found to be more effective than the dry process in improving the resistance against permanent deformation and moisture damage. Both Hamburg and indirect tensile strength (ITS) tests showed that the mixtures modified using dry process showed better performance against moisture damage. The dynamic modulus of the mixtures modified by PET was found to be lower than, and the phase angle was found to be higher than those of the control mixture without PET. Almeida et al. found that the mixture containing 5% of micronized PET has higher indirect tensile strength, resistance against moisture damage and fatigue cracking and resilient modulus than the control mixture without PET [25]. However, the flow number of the mixture was found to be lower than that of the control mixture, indicating that the resistance against permanent deformation decreases with PET modification. They also found that the improvement in resilient modulus at higher temperatures is less than that at intermediate temperature.

Exploring literature shows that the effects of adding waste PET on rubber modified asphalt concrete has not been conducted yet, while there are some contradictions among the research studied conducted on the effects using waste PET in conventional mixtures. Therefore, in this study, it was aimed to study the effects of adding waste PET on some engineering properties of asphalt concrete made of rubber modified binder.

II. MATERIALS

Four types of material including waste ground PET, limestone aggregate, and rubber modified pen grade asphalt cement have been used in this study. The ground waste PET particles were obtained from grinding waste water bottles. First, the caps and labels of the bottles were removed. Then, they were washed and cut into small pieces. Later, they were grounded into finer particles using a special crusher. In this research the PET particles were used in two different ranges of size. In this paper, the fine and coarse graded particles are denoted by P50, and P16, respectively. After sieving the crushed PET, P50 particles were obtained from those passing sieve No. 30 and remained on sieve No. 50, and P16 particles were obtained from those passing sieve No. 8 and remained on sieve No. 16. Fig. 1, Table I and II, show, respectively, the fine and coarse PET particles, the gradation of the fine and coarse PET particles and the properties of the PET used in this study.


Fig. 1. Coarse and fine PET particles.

TABLE I: SIZE DISTRIBUTION OF THE PET PARTICLES

Sieve size (mm)	Percentage of passing %
Coarse graded PET	
2.36	100
1.18	5
Fine graded PET	
0.6	100
0.3	5

TABLE II: SOME PROPERTIES OF WASTE PET USED IN THIS RESEARCH

Properties	Standard method	Value
Density (gr/cm3)	ASTM D792	1.35
Moisture absorption %	ASTM D570	0.1
Melting point (℃)	-	250
Tensile strength (kPa)	ASTM D638	850
Glass Transition Temperature (℃)	-	75

A 60/70 penetration grade asphalt cement modified by 6% of waste crumb rubber was used as the binder in the mixtures. The rubber was added to the binder using wet method, at a temperature of 180C, and mixed for 2 hours using a high shear mixer at 1000rpm.

The aggregates used in this research were limestone sourced and collected from local asphalt plant in Zanjan city, northwest of Iran. The requirements of national specification were met by the aggregates. The moisture absorption of the fine and coarse particles was measured to be 0.1 and 1.2%, respectively. The bulk density of the coarse, fine and filler fraction was 2.65, 2.66 and 2.65, respectively. According to the national specification [26], a dense gradation with a maximum aggregate size of 19mm was selected from the mixtures. Fig. 2 shows the gradation of the mixtures and the lower and upper limits of specification.

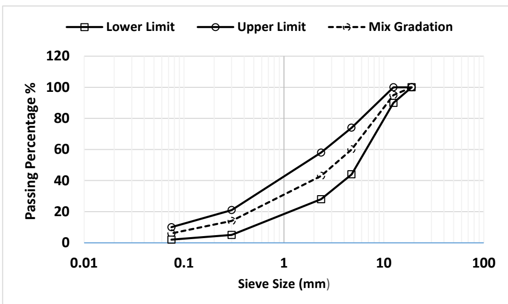

Fig. 2. Gradation of the mixtures used in this study.

III. Mix Design and Fabrication of Specimens

The optimum binder content of the mixtures without PET was obtained following Marshall mix design method, according to ASTM D1559. The optimum binder content of the mixture made by rubber modified 60/70 asphalt was determined to be 4.5 and 6%, respectively. Previous studies have shown that the optimum binder content of PET-modified mixtures is similar to that of the mixture without PET [20], [24]. Therefore, the mixtures were made by 6% of binder content. The volumetric properties of the mixtures were checked to satisfy the requirements of specification [26].

Marshall method, following ASTM D1559 standard, was used for fabrication of cylindrical specimens used for testing. First, the heated aggregate and binder were mixed for 5min, after which, the required amount of PET particles were added into the mixture and were thoroughly mixed for 2 minutes until the aggregate and PET particles were fully coated with asphalt. This method of mixing ensures maintaining the semi-crystalline state of PET and occurrence of minimum changes in the properties and shape of PET particles. PET has a glass transition around 70°C. The amorphous part of PET is melted at the mixing temperature, resulting in the increase of binder cohesion, while the crystalline part does not change. The voids between aggregate particles are filled with the crystalline part of PET, resulting in the increase of mixture stiffness. The mixture was placed in the mold and compacted by applying 75 blows to each side. The compacted specimens were removed from the molds after 24 hours of compaction, and were stored until using in experiments. In total 176 specimens were made in this research.

IV. Research Plan

The main objectives of this research were to investigate the effects of PET particles size and content on some engineering properties of rubber modified asphaltic concrete containing. PET particles within two different ranges of size were added into the mixtures at 5 different contents of 2, 4, 6, 8 and 10% (by the weight of binder) and the Marshall stability and flow, indirect tensile strength and dynamic creep properties have been investigated.

V. Testing Methods

Marshall tests were conducted on specimens according to the ASTM D1559 standard method. The specimens were placed in a water tank set at 60˚C for 30 minutes, after which, they were loaded using a Marshall test set up, at a constant rate of 50.8mm/min, and the force required for breaking the specimen was measured as the Marshall stability, and the diametrical deformation of the specimen at failure was measured as Marshall flow.

In this research, the indirect tensile strength (ITS) tests were conducted on specimens at 25˚C according to AASHTO T283 standard method. Three replicate specimens of each mixture were made with an air voids content of 7±0.5%, as required in AASHTO T283 standard method. The indirect tensile strength (ITS) was measured after placing them in plastic bags and submerging in a water tank set at 25˚C. The ITS of specimens was measured by placing them in an ITS frame and loaded using the Marshall test set up at a rate of 50.8mm/min until failure. The required force for breaking the specimen was measured and the indirect tensile strength was calculated using Equation (1).

$$ITS = \frac{2000P}{\pi t D} \tag{1}$$

where, *ITS* is the indirect tensile strength in kPa, P is the maximum applied load for breaking the specimen in N, D is the specimen diameter in mm, and t is the thickness of the specimen in mm. The average of 3 specimens in each group was calculated and used as the ITS of the mixture.

The resistance against permanent deformation of the mixtures was evaluated using uniaxial dynamic creep test. Dynamic creep tests were conducted following EN 12697-25 standard method by a UTM-10 machine. Tests were conducted at the same temperature of 40°C, and by applying a constant vertical stress of 300kPa with a frequency of 0.5Hz. In each test, to ensure that the specimen is homogenously at the test temperature, the specimen was placed inside the temperature controlled cabinet two hours before starting the test. Each test was set to be finished after 10000 loading cycles or reaching to a vertical strain of 4%. During the test period, the vertical deformation and load was monitored by the software connected to the test set up. Before applying the main stress level of 300kPa in each test, a vertical stress of about 30kPa was applied for a duration of 10min. This stress was applied to ensure that the loading platens are fully seated on the specimen and remove any possible gap between the platens and specimen.

VI. Results and Discussion

Fig. 3 shows the Marshall stability of the mixtures containing different percentages of fine and coarse PET particles. The result for each mixture was obtained by averaging the results on 3 replicate specimens. As can be seen, the Marshall stability of all mixtures containing PET is higher than that of the mixtures without PET. As can be seen the Marshall stability increases with increasing PET content. In the mixtures containing rubber modified asphalt, PET interacts with rubber and the stability increases with increasing PET content. The highest Marshall stability of 17.74kN, is associated with the mixture containing 10% of fine PET particles. The Marshall stability of the mixtures containing 10% of fine and coarse PET particles is 4.3 and 3.8%, respectively, higher than that of the mixture without PET. It can be concluded that the addition of PET in the mixtures with rubber modified asphalt is not significantly effective on Marshall stability.

The results in Fig. 3 also reveal that the Marshall stability of the mixtures containing fine PET particles is higher than that of the mixtures containing coarse PET particles. Fine PET particles can be well distributed in the mixture, fill the voids, and increase the stiffness of binder. They have also a lower melting rate, resulting in more remaining of the crystalline part and increasing the stiffness. In addition, visual inspection of PET particles revealed that coarse particles are not flat and have a curly shape, which results in the increase of voids in the mixture and lower stability.

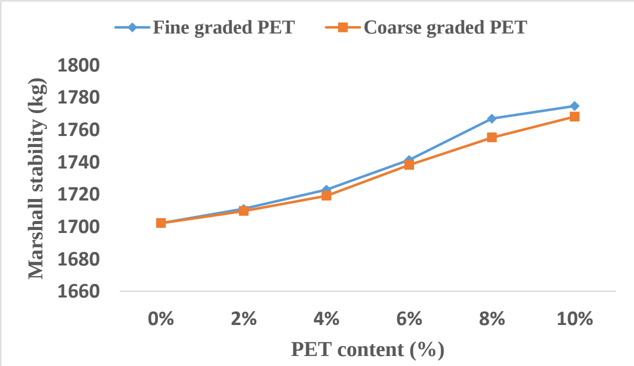

Fig. 3. Marshall stability of the mixtures made of rubber modified asphalt and containing coarse and fine graded PET.

The Marshall quotient (MQ) was calculated by dividing the Marshall stability by the flow, which is usually used as an indicator of the strength against permanent deformation [27], [28]. A mixture with a higher MQ is stiffer and believed to be more resistant against permanent deformation. However, comparing the MQ results with those of dynamic creep tests for hydrated lime and polymer modified asphalt concrete, Sengul et al. found that MQ is not a good indicator of resistance against permanent deformation [29]. Same results was found by Tayfur *et al*. [30] for SMA mixtures modified with polymer.

Fig. 4 shows the variation of Marshall quotient (MQ) with PET content for the mixtures containing rubber modified binder. As can be seen in Figure 6 the MQ increases with increasing PET content. The highest MQ is achieved by addition of 10% PET. The MQ of the mixtures containing 10% of fine and coarse PET particles are, respectively, 7.5 and 5% higher than that of the mixture without PET. In addition, the results indicate that, the higher MQ is obtained by using fine PET particles than using coarse PET particles.

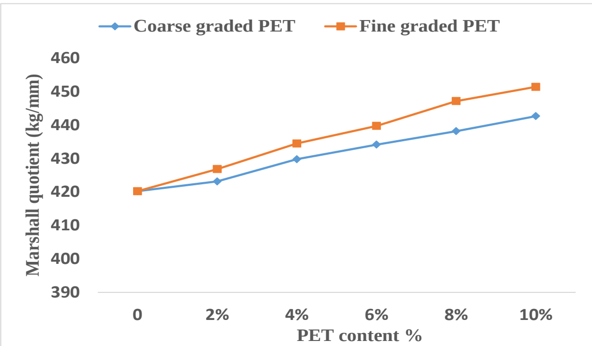

Fig. 4. Marshall quotient of the mixtures made of rubber modified asphalt and containing coarse and fine graded PET.

Tensile strength is one of the main properties of asphaltic mixtures, which is related to the strength against cracking and permanent deformation. A mixture with a higher tensile strength is more resistant against cracking and permanent deformation. The ITS of the mixtures was measured at 25 ℃. Three specimens were used for each test condition and the average was used for analysis. Fig. 5 shows the variation of ITS with PET content for the mixtures made by rubber modified asphalt. As can be seen the ITS increases with increasing PET content, up to 2%, beyond which the trend reverses and ITS decreases with increasing PET content. This is consistent with the results of Modarres and Hamedi [21b] who found that, for conventional asphalt concrete made of unmodified binder, at 5 and 20 ℃, the highest ITS of asphalt concrete is achieved by inclusion of 2% of PET, after which the ITS decreases with increasing PET content. These results indicate that PET modification can improve the resistance of asphalt concrete against cracking. From the results, it can be concluded that the ITS of the mixtures containing 2% of fine and coarse PET, are, respectively, 3.4 and 2.8% higher than that of the mixture without PET, which is not a significant effect. Results also reveal that finer PET particles are more effective than the coarse particles in improving ITS.

Fig. 6 and 7 show, respectively, the accumulated strain versus loading cycles for the mixtures made of rubber modified asphalt and containing different percentages of coarse and fine-graded PET particles. As can be seen, the resistance against deformation decreases with increasing PET content. The accumulated strain of the mixtures containing 10% of coarse and fine-graded PET particles is 51.8 and 41.3%, respectively, higher than that of the control mixture. This result is against the results of previous studies conducted by Baghaee Moghadam *et al*. [20], [24], who found that the resistance of gap graded stone matrix asphalt (SMA) mixture against permanent deformation increases with increasing PET content. The contradiction is thought to be due to the difference between the structure of dense graded asphalt concrete used in this research and the SMA asphalt mixture. However, Earnest [15] found that addition of PET particles into asphalt concrete by dry method results in decrease of resistance against permanent deformation. These results also show that the mixtures containing coarse graded PET particles have a lower resistance against permanent deformation than those containing fine graded PET particles.

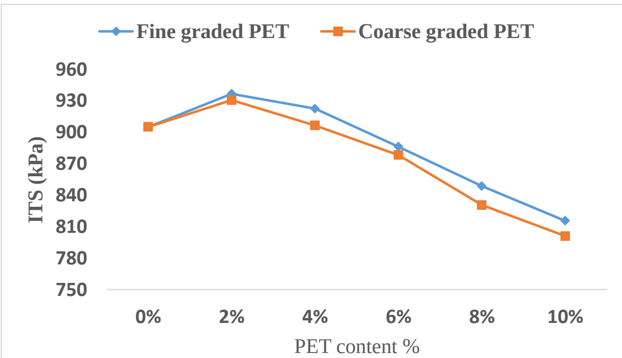

Fig. 5. ITS of the mixtures with air voids within 6.5 to 7.5% made of rubber modified asphalt cement and containing coarse and fine graded PET.

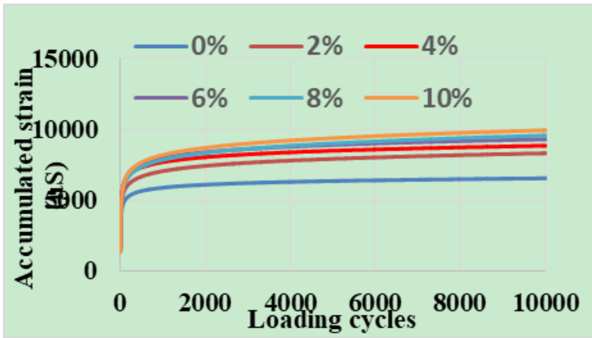

Fig. 6. Creep curves of the mixtures made of rubber asphalt and containing different percentages of coarse graded PET.

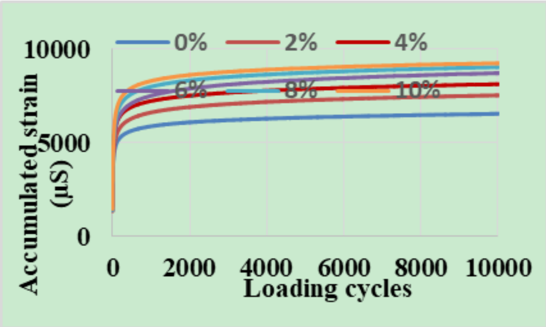

Fig. 7. Creep curves of the mixtures made of rubber asphalt and containing different percentages of fine graded PET.

VII. Conclusion

Different percentages of waste PET particles were added into an asphalt concrete made of rubber modified asphalt and the Marshall stability, indirect tensile strength and dynamic creep properties of the mixtures were evaluated. The following are the results in brief.

- Marshall stability increases with increasing PET content, with higher values for the fine graded PET than the coarse graded PET particles.
- Marshall quotient of the mixtures increases with increasing PET content with higher values for the fine graded particles.
- The indirect tensile strength increases up to addition of 2% PET into the mixture, beyond which it decreases with increasing PET content. Higher ITS can be obtained by using fine graded particles than coarse graded PET particles.
- Resistance against permanent deformation decreases with increasing PET content. Higher resistance can be achieved by adding fine graded particles than coarse graded particles.
- Comparing the results with those in literature on conventional mixtures show that PET addition into rubber modified asphaltic mixtures follow a different trend, which is thought to be due to the interaction between rubber and PET polymer.

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