IMPROVING MECHANICAL PROPERTIES OF HOT-MIXED ASPHALT USING PLASTIC WASTE (POLY-ETHYLENE TEREPHTHALATE)

G. MALKOC[1], A. TOPAL[2], B. SENGOZ[2]
[1]Chemical Eng. ASMÜD, The Turkish Association of Asphalt Contractors, Ankara, Turkey/e–mail:gulay@asmud.org.tr
[2]Assoc.Prof. Dr. Department of Civil Engineering, Faculty of Engineering, Dokuz Eylul University, Izmir, Turkey/e–mail: ali.topal@deu.edu.tr.
[2]Assoc.Prof. Dr. Department of Civil Engineering, Faculty of Engineering, Dokuz Eylul University, Izmir, Turkey/e–mail: burak.sengoz@deu.edu.tr.

ABSTRACT

In the last decades, increasing awareness about the environment has tremendously contributed to the concerns related with disposal of the generated solid wastes. With the scarcity of space for land filling area and due to its ever increasing cost, waste utilization has become an attractive alternative to disposal. Therefore, the use of waste products in asphalt not only makes it economical, but also helps in reducing disposal problems. The purpose of the experimental study is to investigate the possibility of using granular Poly-Ethylene Terephthalate (PET) waste in asphalt mixes which would replace a portion of mineral coarse aggregate. For this purpose the mechanical properties of asphalt mixes involving different contents PET waste were compared with control samples. This study focused on the parameters of Marshall stability, flow, Marshall quotient (stability-to-flow ratio), Indirect Tensile Strength as well as rutting test. Experimental results exhibited that the PET modified asphalt have potential to increase the mixture toughness and resistance to tensile stresses and it also contributes the recycling of Plastic waste (PET) in asphalt helps alleviate environmental problem and saves energy.

Keywords: Poly-ethylene terephthalate, Waste disposal, Environment, Hot-mix asphalt

1. INTRODUCTION

The amount of plastics consumed annually has been growing steadily with special features such as strength, fabrication capability, and long life as well as low cost. Plastics have been used in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. With such large and varying applications, plastics contribute to an ever increasing volume in the solid waste stream.

Table 1 presents the details about the amount of plastic consumption and plastic waste generated in the UK, USA and Western Europe. In the UK, a total of approximately 4.7 million tons of plastic products were used in various economic sectors in 2001 [1, 2, 3]. The amount of plastic waste generated annually in the UK is estimated to be nearly 3 million tons. An estimated 56% of all plastics waste is used packaging, three-quarters of which is from households. It is estimated that only 7% of total plastic waste arising is currently being recycled.

According to a 2003 Environment Agency report, 80% of post-consumer plastic waste is sent to landfill, 8% is incinerated and only 7% is recycled. In addition to reducing the amount of plastics waste requiring disposal, recycling plastic can have several other advantages. In the United States, approximately 11 million tons of plastic wastes are produced each year, which represents about 11.1% of total MSW generation Plastic wastes are very visible as they contribute to a large volume of the total solid wastes. Precisely because of their large visibility, plastic wastes (and particularly non-sustainable plastic products) have been viewed as a serious solid waste problem.

Table 1: Plastic consumption and waste data [1, 2, 3]

Data	Quantity (10^6 tons)
Plastic consumption in UK in 2001	2700
Plastic waste in UK in 2001	4120
Plastic consumption in Western Europe in 2004	5010
Plastic consumption in USA in 2003	2580
Plastic waste in USA in 2003	1990

The waste plastics collected from the solid wastes stream is a contaminated, assorted mixture of plastics. This makes the identification, segregation, and purification of the various types of plastics very challenging. In the plastics waste stream, polyethylene forms the largest fraction, which is followed by polyethylene terephthalate (PET). Lesser amounts of other plastics can also be found in the plastics waste stream, as given in Table 2.

An integrated approach is required in an attempt to manage such large quantities of a diverse, contaminated mixture of plastics in an energy efficient and environmentally benign manner. This would require examining critically various steps in the life of the plastics such as the raw materials for their manufacture, the manufacturing processes, design and fabrication of the finished products, possible reuse of those items, and the proper disposal of the wastes, in totality. Such an integrated waste management concept comprises: (i) source reduction; (ii) reuse; (iii) recycling; (iv) landfill and (v) waste-to-energy conversion.

Table 2: Types and quantities of plastics in municipal solid waste in the USA [4]

Type of Plastic	Quantity (10^3 tons)
Polyethylene terephthalate (PET)	2700
High density polyethylene (HDPE)	4120
Low density polyethylene (LDPE)	5010
Polypropylene (PP)	2580
Polystyrene (PS	1990
Other	3130

Among them recycling of plastics has gained importance in the last ten years [5]. In addition to reducing the amount of waste disposed in landfills, recycling can also significantly contribute to the conservation of raw petrochemical products, as well as energy savings [3, 6.]

Rebeiz and Craft have grouped the recycling of plastics into four categories: mechanical recycling; thermal processing; chemical or feedstock recycling and fillers.

In the case of utilizing the waste materials as filler, the chemical composition of the plastic is generally not significant. Plastic wastes may also be used with some effectiveness as a partial replacement of inorganic aggregates in concrete and asphalt applications to decrease the dead weight of structures.

The purpose of this experimental study was to investigate the possibility of using PET waste in asphalt mixes as aggregate replacement to reduce the environmental effects of PET disposal. For this purpose the mechanical properties of plastiphalt mixes were compared with control samples.

2. EXPERIMENTAL

2.1 Materials

The base bitumen was 50/70 penetration grade obtained from Aliaga/Izmir Oil Terminal of the Turkish Petroleum Refinery Corporation. In order to characterize the properties of the (neat) base bitumen, conventional test methods such as; penetration test, softening point test, ductility test, etc. were performed. These tests were conducted in conformity with the relevant test methods that are presented in Table 3.

Table 3: The properties of the neat bitumen

Test	Specification	Results	Specification Limits
Penetration (25ºC; 0,1 mm)	ASTM D5 EN 1426	63	50-70
Softening Point (ºC)	ASTM D36 EN 1427	49	46-54
Viscosity at (135ºC)-Pa.s	ASTM D4402	0.51	-
Thin Film Oven Test (TFOT); (163ºC , 5 hr)	ASTM D1754 EN 12607-1		
Change of mass (%)		0.07	0,5 (max)
Retained penetration (%)	ASTM D5 EN 1426	51	50 (min)
Softening Point after TFOT (ºC)	ASTM D36 EN 1427	51	48 (min)
Ductility (25ºC), cm	ASTM D113	100	-
Specific Gravity	ASTM D70	1.030	-
Flash Point (ºC)	ASTM D92 EN 22592	+260	230 (min)

The asphalt was produced with limestone aggregate procured from Dere Beton/Izmir quarry. In order to find out the properties of the aggregate used in this study, sieve analysis, specific gravity, Los Angeles abrasion resistance test, sodium sulphate soundness test, fine aggregate angularity test and flat and elongated particles tests were conducted. Grading of aggregate has been chosen in conformity with the Type 2 wearing course of Turkish specification. Table 4 presents the properties of the aggregates

Table 4: The properties of the aggregate

Test	Specification	Grading passing (%)	Specification Limit
Sieve No	ASTM C 136		
¾”		100	100
½”		86	83-100
3/8”		80	70-90
No 4		48	40-55
No 10		32	25-38
No 40		15	10-20
No 80		10	6-15
No 200		6	4-10
Specific Gravity (Coarse Agg.)	ASTM C 127		
Bulk		2.686	-
SSD		2.701	-
Apparent		2.727	-
Specific Gravity (Fine Agg.)	ASTM C 128		
Bulk		2.687	-
SSD		2.703	-
Apparent		2.732	-
Specific Gravity (Filler)		2.725	-
Los Angeles Abrasion (%)	ASTM C 131	24.4	max 45
Flat and Elongated Particles (%)	ASTM D 4791	7.5	max 10
Sodium Sulfate Soundness (%)	ASTM C 88	1.47	max 10-20

The waste PET filling material (Fig.1) used in this study was in the form of pellets which would replace (by volume) a portion of mineral aggregates of an equal size (0.425–0.180 mm). In this investigation five different percentages (10,20, 30 and 40) replacement were used. The characteristics of the PET materials are presented in Table 5.

Figure.1: PET pellets

Table 5: Characteristics of PET strips

Specification	Value
Molecular weight, gr mol	192
Specific gravity, gr cm³	1.36
Melting point, °C	265
Tensile strength, Mpa	1700
Impact resistance, J m	90
Water absorption (24 h), %	0.5

2.2 Test Methods

The effect of PET waste on the mechanical properties of asphalt has been determined by the stability, flow, air void content and voids in mineral aggregate (VMA) data gained through the Marshall test (ASTM D1559). The test was conducted on both mixtures that contain PET and mixtures prepared with the neat bitumen (control specimens). Three samples were produced for each PET content.
The Marshall quotient (MQ) (kN/mm) is also calculated as the ratio of stability (kN) to flow (mm). MQ can be used as a measure of the material's resistance to permanent deformation in service.
The indirect tensile strength test (ITS) has also been performed at loading rate of 51mm/min by using the Marshall apparatus. The ITS test involved loading a cylindrical specimen with compressive loads that act parallel and loading the vertical diametrical plane. The ITS test carried out to define the tensile characteristics of the asphalt which can be further related to the cracking properties of the pavement. In order to compute the ITS, the following equation is used:

$$ITS = \frac{2P_{maz}}{\pi t d}$$

Where; Pmax is the maximum applied load (kN), t is the thickness of the specimen (mm), d is the diameter of the specimen (mm).
The permanent deformation characteristics of the samples have been determined by Hamburg Wheel Tracking Device (EN 12697-22). The device tests two slabs simultaneously with two reciprocating solid steel wheels. Slabs are 320 mm long and 260 mm wide; they can be 38, 76, or 119 mm, respectively thick. The wheels have a diameter of 203 mm and width of 22.87 mm. Test specimens are typically compacted to 7±1 percent air voids using a linear kneading compactor. The test uses a water chamber as a means of obtaining the required test temperature. The water temperature can be set from 25-70°C, with 50°C being the most common test temperature. The load consists of applying a 705 N force and the average contact stress is approximately 0.73 MPa with a contact area around 970 mm^2. This contact pressure simulates the effect produced by a rear tire of a double-axle truck. The contact area increases with rut depth, and thus the contact stress is variable. Testing is typically accomplished for a total of 20,000 passes or until 20 mm of deformation, whichever occurs first. The average speed of each wheel is approximately 1.1 km per hour. Each wheel travels approximately 320 mm before reversing direction, and the device operates at 53 ± 2 wheel passes per minute.

3. RESULTS AND DISCUSSION

In order to find out the optimum bitumen content (o.b.c) for gradation specified in Table 2, Marshall specimens were made and tested according to ASTM D1559. Asphalt specimens were prepared with a compaction effort of 75 blows simulating the heavy traffic loading conditions. The bulk specific gravity of the specimens was measured according to ASTM D2726-88. The specimens were kept at ambient temperature for 1 day. To carry out the Marshall stability tests,

the samples were kept in water at 60°C for 30 min. The apparent specific gravity of the samples was measured according to ASTM D2041-90 and then the air voids were determined. The bitumen corresponding to 4% air void is selected as optimum bitumen content which is 4.75% both for control specimens as well as for the specimens involving pet pellets.
The mechanical properties of asphalt containing different contents of PET pellets are presented in Fig.3.
As illustrated in Fig.2, the compacted density of the mixes was lower than that of the control mix. The replacement of various percentages of mineral aggregate by volume with thelower specific gravity aggregate PET, results in a reduction in the bulk density of the compacted mixes.
All the asphalt samples provide adequate stability (min. 900 kg related to wearing course specification) as presented in Fig.2. Besides, no variation in the stability values is observed up to 20%PET addition, however a sharp decrease is observed at 30% and 40% PET addition. The decrease in stability with increasing PET content (after 30% and 40%) may be attributed to low friction between the PET granules.
The Marshall flow values for mixtures involving 10% and 20% PET are within the specification limits (2–4mm), however the values increase with the increasing PET content. The results indicate that in mixes containing higher percentages of PET, the effect of lower friction between PET granules exceeds the good adhesion between the bitumen and PET granules.
As the MQ is an indication of the resistance against the deformation of asphalt, high MQ values indicate a mix with high stiffness, which has a greater ability to spread the applied load and resist creep deformation. The MQ results for both control and PET mixes are shown in Fig 3. Fig. 3 indicates that when PET is used as partial aggregate replacement, the corresponding MQ for the samples involving 10% and 20% PET are almost the same as for the control samples.

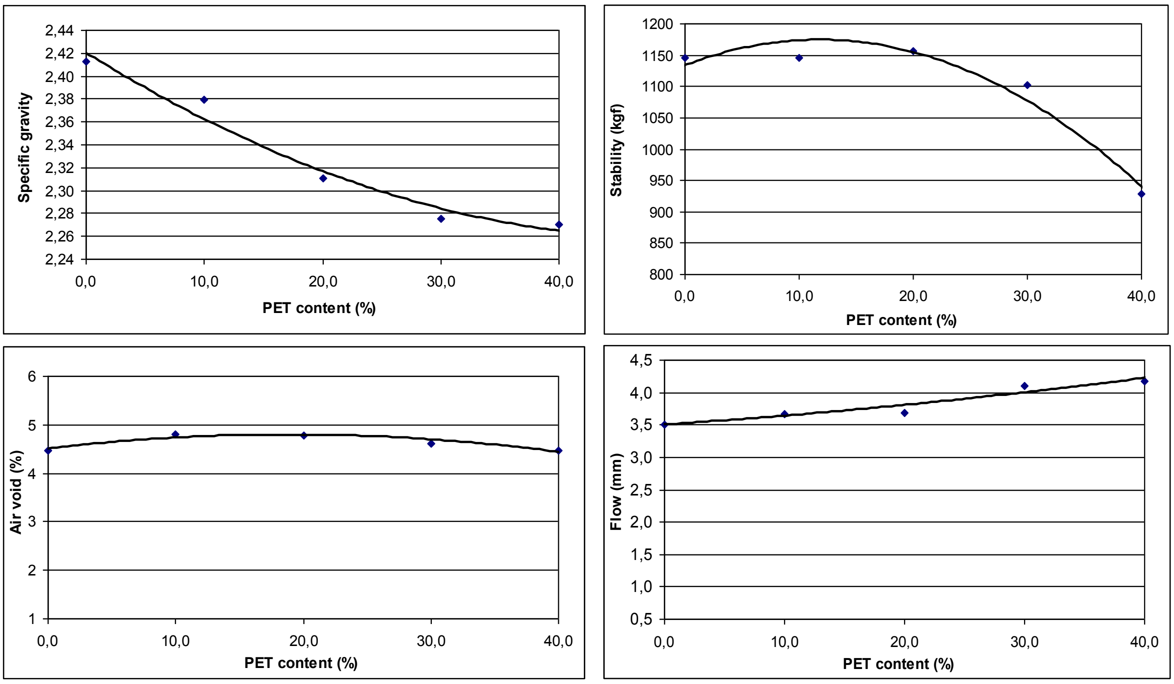


Figure. 2: Marshall parameters for asphalt containing PET pellets

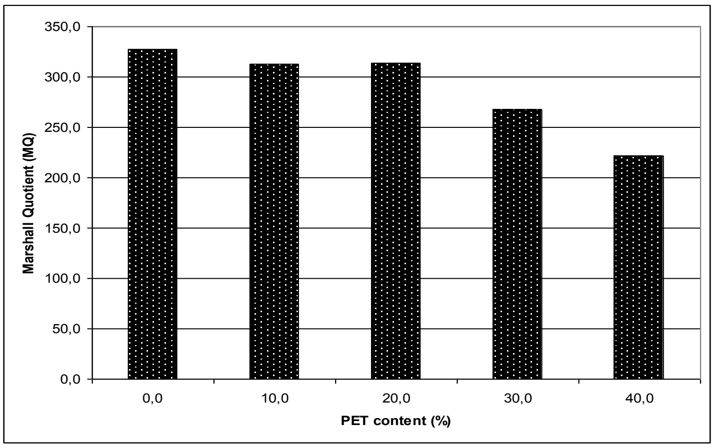


Figure 3 : Marshall Quatient values for asphalt containing PET pellets

The ITS results of the control samples as well as for the samples involving PET are presented in Fig. 4.

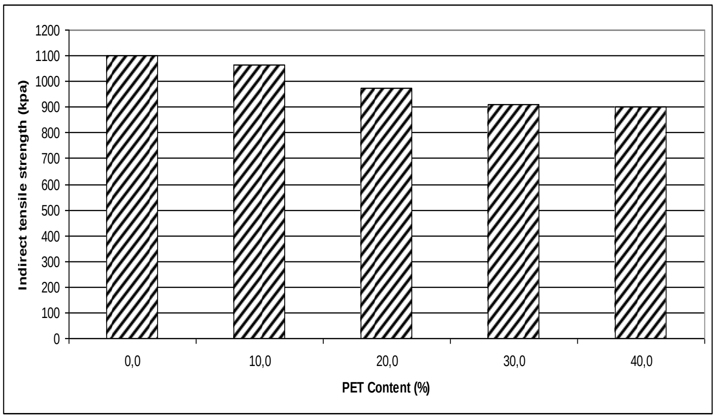


Figure 4 : Relationship between the PET content and ITS of the specimens

As presented in Fig.4, the ITS of the asphalt containing 10% PET is similiar as the control specimens. This indicates that the PET involving asphalt yields almost the same cohesive strength as the control specimens.

The results of the rutting test of the specimens incolving 10% and 20% PET is given in Fig 5. It should be noted that, the rut depth of the specimen involving 20% PET is smaller than the rut depth of the control specimen (Fig.6). The result indicates that the addition of PET improves the rutting resistance of the mixture considerably.

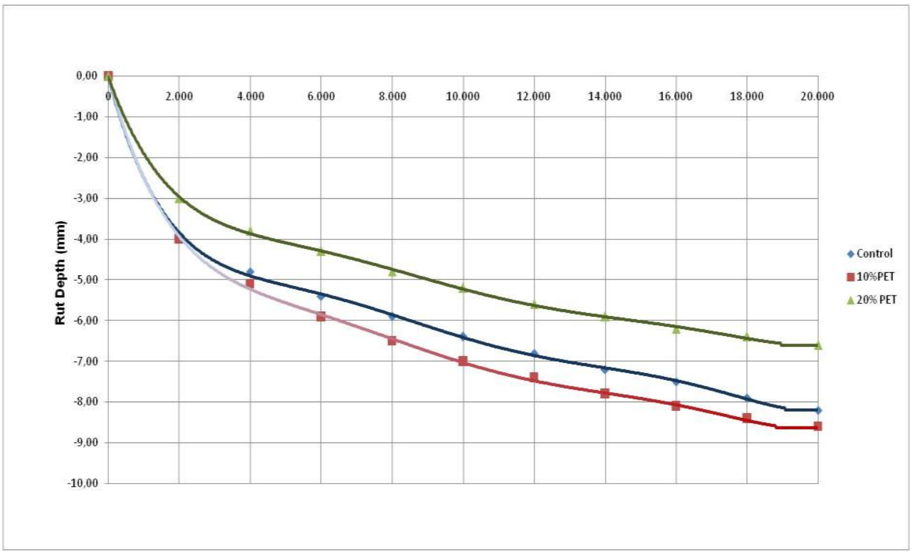
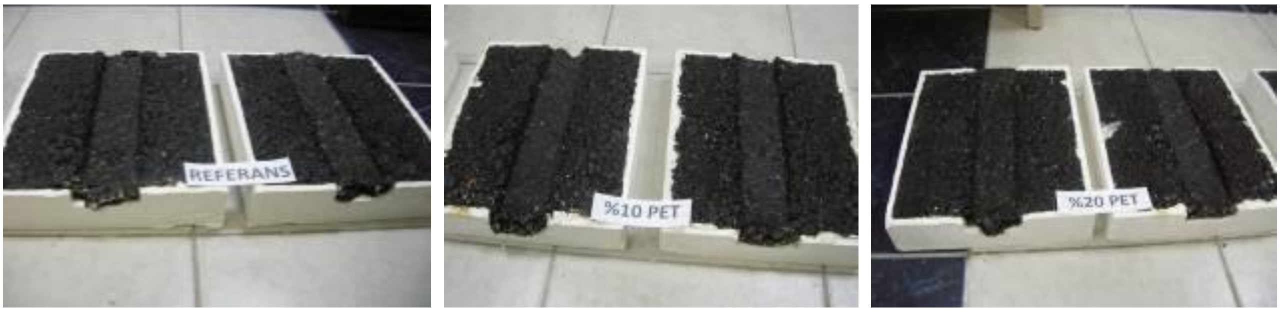


Figure. 5 Rutting test results



(a) Control specimen (b) 10% PET (c) 20% PET

Figure 6. Images of the rutting test samples

4. CONCLUSIONS

The increase in the awareness of waste management and environment-related issues has led to substantial progress in the utilization of waste/by-products like Poly-Ethylene Terephthalate. The objective of this study is to evaluate the utilization of shingle waste addition on the performance of asphalt in terms of stability and resistance to permanent deformation. The following facts are the main findings of this research:

1. The replacement of the mineral aggregate (0.425–0.180 mm).by volume with PET granules results in a reduction in unit weight of the plastiphalt mixes.
2. It is found that the effective utilization of asphalt with 10%-20 PET replacement of aggregate produced the same Marshall quotient with the lowest reduction of stability compared with control specimens, which is a challenge to road industry, as far as economic and environmental benefits are concerned.
3. The addition of 20%PETimproves the rutting resistance of the asphalt.
4. Aggregate is the major component of asphalt pavements. The amount required to build 1 km of road is about12 500 tonnes. The replacement of mineral aggregate with PET would save significant amount of natural resources. Hence, the landfill space required to dispose of the PET bottles, would not be used.

According to most of specification requirement, the results introduce an asphalt that has properties that makes it suitable for practical use and furthermore, the recycling of PET for asphalt roads helps alleviate an environmental problem and saves energy.

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