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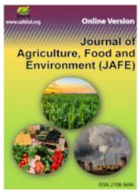

Original Article

Use of waste polyethylene terephthalate (PET) in stone mastic asphalt

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ABSTRACT

Re-use of waste materials Polyethylene Terephthalate (PET) in industrial construction projects such as road pavement can be an effective method of waste management. This study aimed at evaluating the performance of Stone Mastic Asphalt containing 6%, 8%, and 10% waste PET. In this experiment, gravel as coarse aggregate, river sand as fine aggregate, shredded waste PET, and bituminous pitch as binding material were used for making polymer-modified asphalt samples. The study also dealt with the determination of the physical and mechanical properties of the cylindrical samples and compared them with the conventional asphalt samples. The test result shows that the density decreased with the increase in the percentage of waste PET and the maximum 10% addition of waste PET with conventional asphalt resulted in a 3% reduction in density. Percentage water absorption at 0% PET was 2.21% which increased with the increase in the percentage of waste PET and a maximum 10% addition of waste PET resulted in a 13% increase in water absorption. A maximum of 10% addition of PET in the mixture causes 30% reduction in tensile strength. It was identified that the tensile strength ratio (TSR) of the mixtures decreased with the addition of waste PET and Tensile Strength Ratio (TSR) values were above 70% which denoted that all mixes might have enough resistance against damage caused by moisture. However, the usage of waste PET in asphalt could be effective for low-density bituminous pavements and surfaces. So, this method could be the best option for recycling waste PET and thus could contribute to reducing the waste materials from the environment.

Introduction

Plastic waste generation in developing countries has reached an alarming situation due to increased population, urbanization, and industrialization. The increased use of plastics generates an increasing volume of the solid waste stream where polyethylene forms the largest fraction, which is followed by Polyethylene Terephthalate. PET or Polyethylene terephthalate (PET) is a thermoplastic polymer that is semi-crystalline in nature and commonly known as a “plastic bottle” and considered a polyester material, (Raabe and Chen, 2004). PET is used widely in the form of automobile parts, lighting products, food packaging, electronics, sports tools, x-ray sheets, houseware, textiles, power tools, and photographic applications (Sinha *et al.*, 2010). During the last few decades, severe environmental challenges were occurred due to the generation of a significant amount of PET bottles as they are not recyclable for refilling. Adopting an effective technique for reusing these PET bottles can be immediate action to this serious problem. The reuse or recycling of waste plastic materials for construction purposes can be considered to be the most practicable application because of the characteristics of the plastics such as easy processing, low density, good mechanical properties low cost, and good thermal properties. High-density polythene and polyethylene bags could be added with aggregates at a different range of percentages to get high-strength bricks (Dinesh *et al*., 2016).

The increased use of heavy vehicles has a drastic effect on the existing road pavements. The usage of different waste substances like waste glass, steel slag, tires, and plastics (polymers) as auxiliary materials for road structures can substantially lower the expenditure of Asphalt concrete. There occurs much distress during the lifespan of the Asphalt concrete mixture resulting in different failures such as rutting damage, low-temperature cracking, and fatigue damage even at moderate temperatures (Moghaddam *et al.*, 2011). Different studies identified polymer conversion of asphalt mixes as a solution to the problem of permanent deformation (rutting), fatigue failure, cracking, etc.

From the previous research, satisfactory performance was found from Stone Mastic Asphalt **(**SMA) against permanent deformation (rutting) damage. However, polymer-modified asphalt mixes are comparatively more expensive which could be reduced to lower expenses by replacing those materials with inexpensive polymers, for example, waste polymers (Ahmadinia *et al.*, 2011). Waste polymers like PET can be potentially utilized as an additive or modifier in Stone Mastic Asphalt (SMA) as well which would increase the durability of asphalt pavement and reduce environmental pollution. Stone Mastic Asphalt (SMA) SMA is a bituminous mixture consisting of the crushed coarse mixture, crushed fine aggregate, asphalt binder, mineral filler, and a stabilizer such as cellulose, mineral fibers, or a polymer for the binder (Chiu and Lu, 2007). Polymers such as PET are used when better durability and performance are needed and are also known to decrease life cycle costs (Yuonne and Yajaira, 2001). The polymer which is used as a modified binder leads to improvement of cohesion and adhesion properties (Kalantar *et al.*, 2012).

Ahmadinia *et al.*, 2011 studied that the mechanical properties of stone mastic asphalt (SMA) were affected due to the use of waste plastic bottles at different ranges of proportions of PET (0%, 2%, 4%, 6%, 8%, and 10%) on mixture where the optimum quantity of PET was noted to be 6% by weight of bitumen.

Choudhary *et al.*, 2018 investigated that the properties of asphalt mixes were affected due to the incorporation of shredded waste PET bottles with three variables: two processes (dry process, and modified dry process), three PET contents (2.5%, 5.0%, and 7.5% by weight of binder), and two PET sizes (2.36–1.18 mm, and 0.30–0.15 mm) where significant influence on the measured properties because of those three variables was found from the results. Sojobi *et al.*, 2016 conducted an experiment to use PET plastic bottle wastes on bituminous asphaltic concrete (BAC) produced in North Central Nigeria and used for ductile pavement structure. In their experiment, the mix design consists of 5% (60/70 penetration-grade) asphaltic concrete, 68% coarse aggregate, 6% fine aggregate, and 21% of filler where the optimum amount of bitumen for conventional BAC was obtained as 4% by weight of total aggregates and filler and the BAC modified by Polymer-coated aggregate gave a satisfactory performance for the highest amount of plastic content of 16.7% by weight of total aggregates.

Amid this situation, manufacturing Stone mastic asphalt concrete by using gravel, river sand, and polymer-modified bitumen mixed with polymer glue made from shredded waste plastic could be a practical technique. Keeping eye on the above, the study was performed with the following objective: (1) To analyze the suitability of PET as an alternative element in asphalt and (2) To compare the physical and mechanical properties of modified asphalt with conventional asphalt.

Materials and Methods

This study and the tests were conducted at the Concrete and Material Testing Laboratory of the Department of Farm Structure & Environmental Engineering at Bangladesh Agricultural University. In this experiment, waste PET bottles, sand, gravel, and dark bituminous pitch (Figure 1) were used as the required materials.

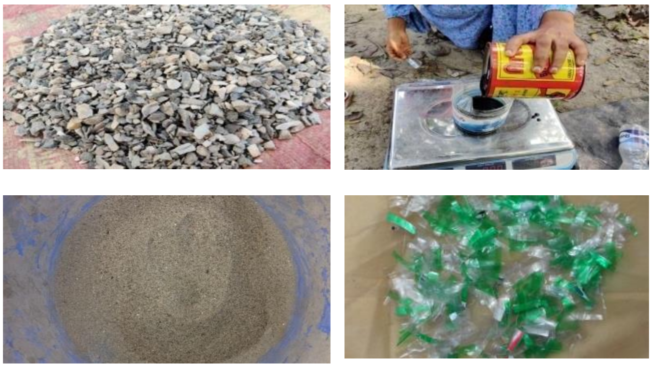

Figure 1. Waste PET, sand, gravel, and bitumen used in this study.

Waste PET bottles: From the neighborhood markets in the Mymensingh region, used PET bottles for asphalting were gathered. Waste bottles were shredded into smaller pieces of 10–12 mm before being blended and melted with the conventional asphalt at different proportions for example 6%, 8%, and 10%, respectively, by weight, of the standard bituminous pitch.

Sand: As a fine aggregate, river sand was utilized. The shape of sand particles is angular, sharp, and rounded. The fineness modulus of used sand was 1.62. The sand was used at 7% of the overall weight of stones.

Gravel: Gravels or coarse aggregates are the major components in asphalt mastic stone, making 70% to 80% of the total volume. The aggregates used in this study had an angular shape. The aggregate was 9.5mm in size.

Dark Bituminous Pitch: The thermoplastic nature of bitumen (stiff when the temperature is too low, liquid when warmed) is what makes it so convenient. Before blending with the aggregate, the black bituminous pitch was obtained from the LGED office in Narail and heated to 150°C for roughly one hour.

Preparation of sample specimens

Mixing of the material

Before blending with the aggregate, the bitumen was heated to 150°C for about an hour. The mixture was brought to 200°C temperature for 2 hours before adding coarse aggregate or gravel. The aggregate was combined and melted with the shredded, 10 to 12 mm-sized particles of collected trash PET bottles. The combination of aggregate, bitumen, and filler was mixed at 160±5°C temperature of for around 5 minutes (Figure 2). Table 1 contains the mixing ratios.

Figure 2. Mixing aggregate, bitumen and filler at 160±5°C temperature of for around 5 minutes.

Table 1. Mix proportions used in polymer modified asphalt.

Sample name	Amount of Gravel (gm)	Amount of Sand (gm)	Amount of Pitch(gm)	Amount of waste PET (gm)
0% PET	3300	230	260	0
6% PET	3300	230	260	15
8% PET	3300	230	260	21
10% PET	3300	230	260	26

Casting

After the mixing operation, the hot mixture was cast into the cylindrical molds (3” ×6”)(Figure 3(a)) Before casting, the cylinder molds were greased with oil thoroughly inside for easy removal of the specimen. The materials were cast in three layers and each layer was compacted with more than 25 strokes. The top surface of the cylinder was finished smoothly through a trowel. The final samples (Figure 3(b)) were taken out of the molds after 3 days and then The samples' weights were recorded.

(a) (b)

Figure 3. (a) The cylindrical mold (b) The finished sample

Laboratory Tests

Density test

A substance's density is defined as its mass per unit volume. At first Mass of every cylindrical sample was determined using a balance. The size of every sample was measured using the scale to determine the volume using the equation (1)

$$V= \pi r^2 h \qquad (1)$$

Where π= 3.1416

r= radius of the cylinder, m

h=height of the cylinder, m

Density was then computed using equation (2), where, ρ stands for the density, m for the mass, and V for the volume.

$$\rho = \frac{m}{V} \qquad (2)$$

Water absorption test

In this test, firstly weight of the dry specimen (W_1) was recorded. Then the sample was placed in a water bath for 24 hours. After 24 hours of immersion, samples were taken out of the water bath. Then the weight of the wet sample (W_2) was recorded. The following equation (3) is then used to compute the percent absorption of water:

$$W = \frac{W_2 - W_1}{W_1} \times 100 \quad ..... (3)$$

Here,

W= moisture content, %

W_2= Wt. of the wet sample, gm

W_1= Wt. of the dry sample, gm

Split tensile strength test

Split-cylinder tensile strength is the ability of a material to withstand a tensile force. It is expressed as force per cross-sectional area. The specimen was kept horizontally underneath the tensile strength testing machine, and a gradual force was applied in order to test the specimen's tensile strength. The maximum applied load up to the ultimate point was recorded. The tensile strengths of the cylinders were determined by using the following equation:

$$S= 2P/\pi DL \qquad (4)$$

Here,

S= Tensile strength of the cylinder (KN/m^2)

P= Maximum applied load as determined by the testing machine (KN)

D= Diameter of the cylinder (m)

L = Length of the cylinder (m)

Moisture susceptibility test

The vulnerability of the asphalt mix is known as the moisture susceptibility of bituminous mixes that are susceptible to water damage. This test was performed on four SMA mixes using the AASHTO T283 procedure. Three specimens with 0% waste PET (unconditioned dry group) and nine specimens with 6%, 8%, and 10% shredded waste PET (conditioned wet group) were prepared. Using the results of the tensile strength test, a tensile strength ratio (TSR) of the wet to dry group was computed.

Results and Discussion

Density

Figure 4 depicts the density of samples with 0%, 6%, 8%, and 10% polymer-modified asphalt. From the figure, it is clear that density decreases gradually with the increase of waste PET content. When PET was added to normal asphalt at 6%, it reduced density by 0.84%. The density was reduced by 2.6% when trash PET bottles were added to conventional asphalt at an 8% concentration, and by 3% when they were added at a 10% concentration. This decrease in density is caused by the inclusion of waste content of PET, which is lighter than bitumen and creates some pore space between aggregates. Awwad and Shbeeb, 2007 studied that adding polyethylene polymers to hot melted asphalt mixes improved mixture durability, marginally increased air gaps and mineral aggregate voids, and decreased the density of the asphalt mix. The inclusion of PET bottles in the asphalt mix had a similar effect on the voids and consequently the density in this investigation.

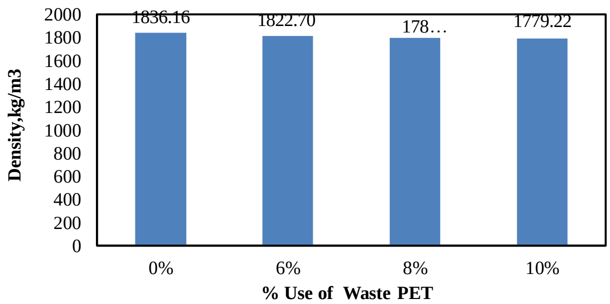

Figure 4. Densities of asphalt mixtures incorporating different amounts of waste Polyethylene Terephthalate (PET).

Water absorption

Figure 5 illustrates how the samples' ability to absorb water was affected by the increased quantity of waste Plastic. It was observed that as the proportion of waste plastic content increases, water absorption rises. The water absorbance value for 0% waste plastic in this investigation was 2.21%, and it steadily rises as waste PET is added to the mixture at different percentages (6%,8%, and 10%). With a 10% inclusion of PET in the mixture, water absorption increased by a maximum of 13%. This tendency can be described by the expansion nature of PET which produces spaces in the mixture when mixed in the bitumen. Voids are created between the aggregates when the samples are coated with binder after absorption of binder by the added PET. As a result, there would be fewer points of contact between the aggregates and more voids. The mix's increased void content is a result of the mix's increased PET concentration. A small amount of water remains in the mix due to an increase in voids.

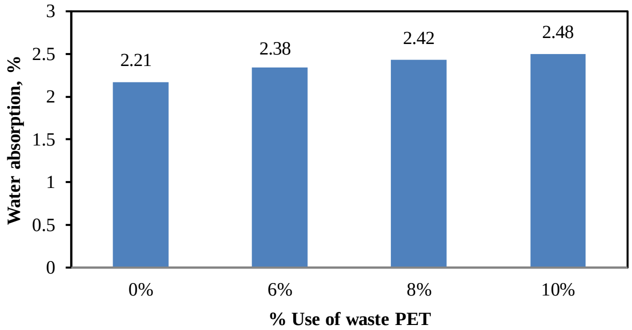

Figure 5. Percent absorption of water of asphalt mixes varying amounts of waste Polyethylene Terephthalate (PET).

Split tensile strength

Figure 6 illustrates the findings of the split tensile strength test. Tensile strength was found to decrease partially as the proportion of PET used within the sample increased. In a prior work by Ahmadinia *et al.*, 2012, the indirect tensile strength test yielded the same results where a 6% inclusion of PET with conventional asphalt led to a 19% reduction in tensile strength, an 8% addition led to a 24% reduction, a 10% addition in a 28% reduction in tensile strength. In this experiment, for the control sample (0% waste PET) the value for tensile strength was found 153.75KN/m^2 which decreases gradually to 17%, 26.2%, and 30% for the 6%, 8%, and 10% addition of waste plastic in mixture respectively. Further increasing the amount of PET from 8% to 10% was shown to result in a small reduction in the loss of tensile strength. The reason for the reduction in tensile strength of samples can be explained by the decrease in sample density induced by the generation of pore spaces between aggregates.

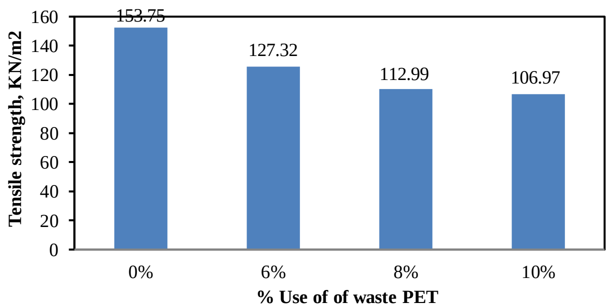

Figure 6. Split tensile strength of asphalt including varying amounts of waste Polyethylene Terephthalate (PET).

Moisture susceptibility

Depending on the test results of tensile strength, a tensile strength ratio (TSR) of the wet to dry samples was computed. According to Figure 7, the inclusion of waste PET decreased the mixtures' TSR value. The greater the TSR value, the more resistant the asphalt mixture is to moisture damage (Sung Do *et al.*, 2008). For normal Stone Mastic Asphalt (SMA) specification TSR value of 70% or higher than 70% is necessary (Al-Hadidy and Tan, 2009). According to the trend of earlier studies, in this experiment, all values of TSR are above 70% which denoted that all mixes might have enough resistance against moisture-related damage. Shen *et al.*, 2008 reported that the minimal criteria for TSR values have been established by AASHTO T 283 and ASTM D 4867 standards to be between 70% and 80%.

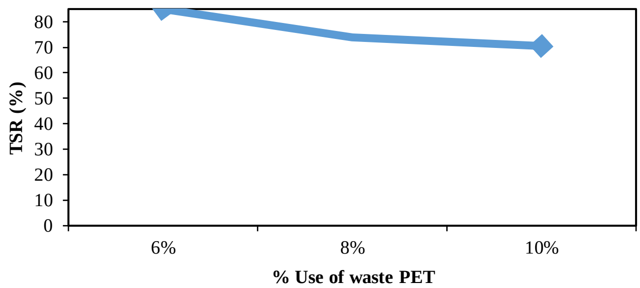

Figure 7. Ratio of the tensile strength of asphalt mixtures with various amounts of waste polyethylene terephthalate (PET).

Comparison between density and water absorption of asphalt samples containing various amounts of plastic scrap (PET)

Figure 8 compares the densities and water absorption of asphalt samples that contain various amounts of wasted PET. It was seen from the figure that PET was added to asphalt mixtures, which reduced density and thus increased water absorption. The reduced density, improved drainage properties, and good thermal insulation are identified as benefits of recycling trash PET (Sousa and Way, 2000). Similarly, the presence of waste PET reduced density and increased water absorption in the current study, resulting in improved drainage properties.

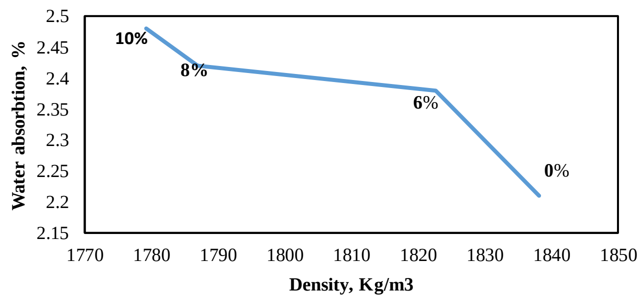

Figure 8. Comparison of the density and water absorption of asphalt samples with various waste polyethylene terephthalate (PET) content levels.

Comparison between density and tensile strength of polymer-modified asphalt samples containing varying amounts of wasted PET

Comparison between density and split tensile strength of polymer-modified asphalt samples containing various wasted plastics percentages are shown in Figure 9. As seen from the figure, the increase of PET in asphalt mixes resulted in reduced density, which has a knock-on effect on the splitting tensile strength. Since the percent of PET increased, the density decreased and so did the splitting tensile strength.

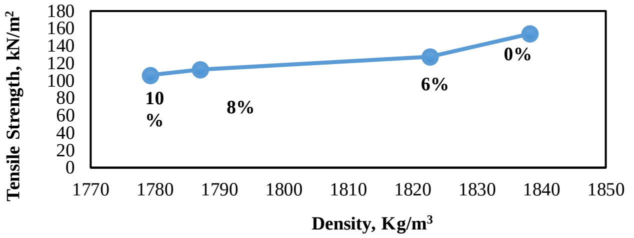

Figure 9. Comparison between density and tensile strength of asphalt samples containing various Polyethylene Terephthalate (PET) content ratios

Conclusion

The purpose of this research was to conduct an experimental assessment of the performance of Stone Mastic Asphalt containing various Polyethylene Terephthalate (PET) content ratios**.** The overall result of this study shows that the addition of waste PET reduces density while increasing water absorption because the lightweight waste plastic creates pore space between the aggregate. As the amount of waste plastic increased, the density decreased and so did the splitting tensile strength, and a maximum 10% increase in waste PET resulted in the highest 30% reduction in tensile strength. The tensile strength ratio (TSR) of the mixtures decreases with the inclusion of waste PET but all values of TSR are above 70%. From overall observation, it can be concluded that the current study may prove to be a more environmentally responsible and sustainable technology that encourages the recycling of wasted or discarded PET, notably for the development of pavements, roads, and other building materials.

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Conflict of Interest

The authors declare there is no conflict of interest regarding the publication of this paper.

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