

RUTTING PERFORMANCE OF TREATED LOW-DENSITY POLYETHYLENE AS ADDITIVE ON THE SUSTAINABLE MIXTURE

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Abstract

Rutting is a major distress issue in conventional flexible pavements causing the service life of road pavement reduced. A lot of efforts had been carried out to modify the hot mix asphalt mixture to overcome the problems. However, asphalt modification mainly increased the initial cost of road construction, which had forced many road agencies and researchers to use waste materials as modifiers. In this study, the potential use of low-density polyethylene powder made by waste plastic bag (treated) as an additive on the performance of rutting resistance was investigated by Marshall, resilient modulus, dynamic creep and double wheel tracker tests. The results showed that 0.75% of treated plastic (TP) by weight of total aggregate attained higher performance in rutting resistance than the conventional mixture. It can be concluded that the waste material additive not only increases the mixture performance but more towards mixture sustainability.

Keywords: Low-density polyethylene, mixture sustainability, rutting, additive, waste material

Introduction

Rutting mainly refers to permanent deformation and is one of the main distress modes of asphalt pavement besides the issue of asphalt aging (Idham *et al.*, 2013; Abdullah *et al.*, 2014) that has an important impact on pavement performance over its durability and service life (Li *et al.*, 2014). Frequent vehicle braking and acceleration create rutting

through horizontal loads as tire-pavement friction causes surface depressions in wheel paths (Du *et al.*, 2018). This is highly because of the combination of densification and shear deformation as the main contributing factors, which are commonly due to weather (Hainin *et al.*, 2013) and traffic conditions (Zou *et al.*, 2017; Othman *et al.*, 2018; Marwan

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et al., 2019; Selamat *et al.*, 2019). In general, at the very early stage of opening asphalt pavement, densification becomes the initial contributor to rutting suspected due to high air void content in the asphalt mixture (Brovelli *et al.*, 2015). Meanwhile, shear-related deformation dominates the long-term rutting. Rutting reduces the performance of pavement and can also be hazardous to road users because of hydroplaning, which is due to water accumulating in the ruts (Chu *et al.*, 2015). Because of that, the maintenance or rehabilitation of the rutted pavement having to be performed long before the pavement structurally fails (Pasindu *et al.*, 2016). It can be said that deeper the ruts lead to more significant safety concerns and discomfort to passengers (Jassal, 1998).

To improve asphalt mixture performance, the modifiers or additives used as boosters include polymers, extenders, hydrocarbons, chemical, antistripping additives, and green technology such as cold mix asphalt (CMA) (Usman *et al.*, 2019) and warm mix asphalt (WMA) (Abdullah *et al.*, 2013). Polymer had been widely used in asphalt modification and can be classified into three different categories: elastomer, plastomer and reactive polymers (Hasan *et al.*, 2018). The plastomer is commonly used to improve resistance to rutting at high temperatures, such as low-density polyethylene (LDPE) (Punith and Veeraragavan, 2007) and Ethene-Vinyl-Acetate (EVA) (Yan *et al.*, 2020). However, the application of asphalt modification causes environmental and economic pressure, forcing many agencies and researchers to use recycled waste materials as modifiers in asphalt mixture (Leng *et al.*, 2018; Brasileiro *et al.*, 2019). An enormous amount of waste materials such as steel slag (Oluwasola *et al.*, 2014; 2016), tires (Ling *et al.*, 2010; Farouk *et al.*, 2017) and plastics (Ahmadinia *et al.*, 2011) are often stockpiled in open plants and then landfilled without any treatments, which induces environmental and public health problems that are prevalent in most nations (Yu *et al.*, 2014; Han *et al.*, 2016). These waste materials could also improve the asphalt pavement mixture's performance as additives during road construction (Yan *et al.*, 2020). The use of plastic waste (untreated) as an additive in asphalt mixture is widely used to improve fatigue resistance but less discussion in rutting performance. However, due to various properties of the polymer, resulting in the inconsistent performance of asphalt mixture when using the dry method where the interaction between additive and binder become crucial. Therefore, lack of studies to determine the specific mixture design utilizing plastic waste in asphalt mixture. This concern led to the idea to treat the plastic waste additive either physically or chemically treated.

Hence, this research investigated the rutting performance of asphalt mixture containing LDPE or treated plastic (TP) as an additive in dry method. TP was a potential additive to improve resistance of rutting in asphalt mixture and increase the amount of plastic waste used than non-treated plastic in asphalt mixture (Kamarudin *et al.*, 2021). Hence, its usage promotes a sustainable mixture.

Materials and Methods

Nominal maximum aggregate size 14 mm (AC 14) and bitumen PEN 60/70 were used in HMA mixture incorporating TP additive (size passes sieve at 0.425 mm). Figure 1 and Table 1 show the properties of aggregate and binder. TP additive, as shown in Figure 2, was treated by the grafting method and supplied from Ahn Vertex Sdn Bhd. The density and melting temperature of the TP additive was 0.9635 g/cm³ and 104.3°C, respectively.

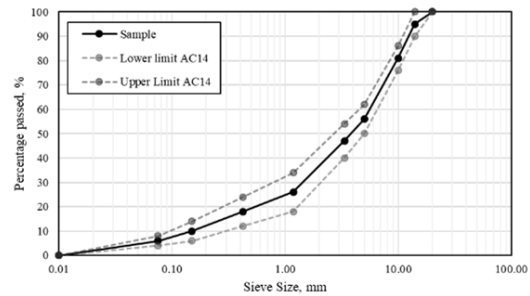


Figure 1. Sieve analysis of aggregate at AC14 gradation



Figure 2. TP powder

Table 1. The bitumen properties for 60-70 PEN

Properties	Results
Density (g/cm ³)	1.03
Penetration (PEN) at 25°C	60.9
Softening Point (°C)	50
Viscosity (Pa.s)	0.7 at 135°C

All samples were prepared in standard Marshall mould (average height of 65 mm and diameter of 100 mm) according to D 6926 (ASTM, 2011a) for Marshall, resilient modulus and dynamic creep tests. The aggregates and bitumen were heated in the oven before the mixing process. The heated aggregates were then mixed with 4-6% fresh bitumen (Jabatan Kerja Raya, 2008) at $\pm 180^{\circ}\text{C}$ to determine the optimum bitumen content (OBC) for the control sample (unmodified). Each sample was compacted with 75 blows per face using a Marshall compactor at $\pm 145^{\circ}\text{C}$ and cooled at room temperature for a day.

To prepare asphalt modification, the additives with a specified amount of TP (with 0.25%, 0.5%, 0.75%, and 1% by weight of total aggregate) were mixed with the hot aggregate and mixed until thoroughly coated before hot bitumen using dry mix method. Although the addition of plastic softens quickly around $130\text{--}140^{\circ}\text{C}$ during mixing, which is lower than mixing and compaction temperature, their application is non-dependent on their chemical properties without any gas emission at high temperature (Awoyera and Adesina, 2020). Furthermore, low melting temperature makes TP additive has good workability in dry method.

Meanwhile, for the double wheel tracker (DWT) test, the samples were prepared in a cylindrical mould of 150 mm diameter (Superpave sample) following D 6925 (ASTM, 2015a) and were compacted by using a Superpave gyratory compactor set. The percent of air void for each sample was targeted to $7\pm 1\%$.

Marshall Test

Marshall test was conducted by a universal compressive machine by D 6927 (ASTM, 2015b). Prior to the test, the specimens were conditioned by immersed in the water bath at temperature 60°C . After about 45 min, the stability of the sample was measured using the stability portion, and the maximum load was applied to the specimen at a constant loading rate of 50.8 mm/min. The properties were checked against JKR specification for wearing course (JKR, 2008). The optimum percentage of TP additive was selected, and further mechanical performance tests of the mixture were carried out.

Resilient Modulus Test

Figure 3 shows the Universal Testing Machine (UTM-5) that was used in this test. The test was run in accordance with D 7369 (ASTM, 2011b) at

temperatures 25°C and 40°C to evaluate the elasticity behaviour of the asphalt mixture under repetitive load. Before the test, the specimens were conditioned for at least 4 h. Each specimen was subjected to five pulses per test, and average reading was taken by rotating the specimen from 0° up to 90° position to obtain a resilient modulus value.

Dynamic Creep Test

This test was to analyse the densification of pavement at the early stages of rutting, characterize the pavement under repeated loads and determine the susceptibility of the mixture to permanent deformation, which is more simulative of traffic loading than static creep. This test was conducted according to 12697-25 (BS EN, 2005) using UTM-5 (Figure 4). Prior to the test, the sample was conditioned at 40°C for at least four hours. In this test, each sample undergone repeated pulsed uniaxial stress at 40°C . 300 kPa of axial cycle



Figure 3. UTM-5 with a resilient modulus test fixture



Figure 4. Dynamic creep sample using UTM-5

loading stress was set, and the test was conducted for 3,600 cycles for one complete test.

Double Wheel Tracker (DWT) Test

The test was run using a DWT analyzer as shown in Figure 5 to measure the rut depth formed under repeated passes of the loaded wheel at temperature 50°C, following TP 324 (AASHTO, 2019). Each sample was subjected to a repetitive wheel load of 700 N (100 lbs) for 10,000 cycles as a complete test for about 8 hours and 30 min. The DWT pass-fail criteria were based on maximum rutting of 5.0 mm or 10,000 load passes, whichever came first.

Results and Discussion

Marshall

Table 2 shows the selected OBC 4.9% for control samples based on the requirements outlined by Jabatan Kerja Raya specifications (JKR, 2008). It can be seen that all parameters complied with all requirements.

Meanwhile, Table 3 shows the verification results of the mixtures based on the JKR requirements (JKR, 2008). It shows that all mixtures achieved all the requirements except 1.0% of TP content, which failed at flow requirement. Based on the result, there was no improvement when TP content starts to add with 0.25 and 0.5%, but it showed significant improvement after TP additives were added 0.75% and more. For stability, 0.75% and 1.0% of TP content showed higher stability than the control mixture with increments of 20% and 7%, respectively. Meanwhile, only 0.75% TP mixture obtained a higher stiffness value than the control mixture with an increment of 5%. Overall, 0.75% TP mixture was selected as the optimum mix design as it attained highest stability and stiffness values. In addition, it was the highest amount of TP additive can be added in the mixture. Higher stability and stiffness values depicted higher strength in asphalt mixtures (Jaya *et al.*, 2018) because of an increased internal friction between aggregate particles and binder cohesion (Ahmed, 2007), hence, distributed to higher resistance to the permanent deformation (Alataş and Yilmaz, 2013). The performance of 0.75% of TP was analyzed further in terms of rutting resistance.

Resilient Modulus

Figure 6 shows the resilient modulus of the control and 0.75% TP mixture at 25 and 40°C. As predicted,

the resilient modulus value at 40°C was lower than at 25°C because the higher the temperature, the binder tends to soften and reduces its elasticity. The result shows that the 0.75% TP mixture exhibited a higher resilient modulus than the control mixture at both temperature levels. At 25°C, the resilient modulus value of 0.75% TP mixture showed improvement twice greater than the control



Figure 5. DWT equipment

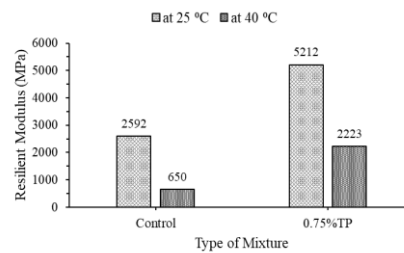


Figure 6. Resilient modulus for control and 0.75%TP mixtures

Table 2. Verification for OBC 4.9%

Mixture requirement (JKR, 2008)		Results	
Stability, kN	>8.0	15.89	✓
Flow, mm	2.0-4.0	3.5	✓
Stiffness, kN/mm	>2.0	4.54	✓
Void in total mix (VTM), %	3.0-5.0	4.0	✓
Void filled with bitumen (VFB), %	70-80	74	✓

Table 3. Verification for control and TP mixtures

Mixture requirement (JKR, 2008)		Percentage of TP contents (%)				
		0	0.25	0.50	0.75	1.0
Stability, kN	>8.0	15.89	12.53	13.21	17.72	16.96
		✓	✓	✓	✓	✓
Flow, mm	2.0-4.0	3.5	3.0	3.2	3.7	4.1
		✓	✓	✓	✓	x
Stiffness, kN/mm	>2.0	4.54	4.25	4.18	4.75	4.14
		✓	✓	✓	✓	✓
VTM, %	3.0-5.0	4.0	4.3	4.6	4.8	4.9
		✓	✓	✓	✓	✓
VFB, %	70-80	74	72	71	70	74
		✓	✓	✓	✓	✓

mixture with 5,212 MPa, indicated the modified mixture had higher elasticity to resist the applied load and had better resistance to fatigue cracking. The 0.75% TP mixture also obtained a higher resilient modulus value with 2,223 MPa at 40°C than the control mixture. It means that 0.75% TP mixture reduced the rutting deformation of asphalt mixture by about 66% at high temperature than the control mixture.

Dynamic Creep

Figure 7 shows the cumulative strain results for 3,600 cycles from the ratio of the permanent deformation to the cross-sectional area of the asphalt mixture. In contrast, Figure 8 summarizes the findings for permanent strain, creep stiffness modulus, and creep strain slope (CSS) for the control and 0.75% TP mixtures. Based on both figures, the 0.75% TP mixture attained a higher creep stiffness modulus of 82.4 MPa due to its lower permanent strain (3,655 Microstrain) compared to the control mixture with 70 MPa and 4,310 Microstrain for creep stiffness modulus and permanent strain, respectively. Higher creep stiffness modulus indicated higher resistance strength against rutting. For CSS, both mixtures showed a value lower than 0.25 (JKR, 2008). As predicted, the 0.75% TP mixture showed slightly lower CSS value than the control mixture.

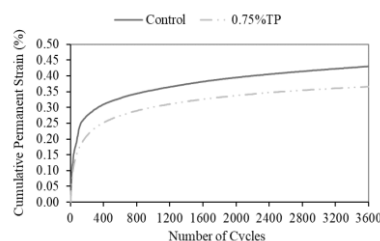


Figure 7. Cumulative permanent deformation for control and 0.75% TP mixtures

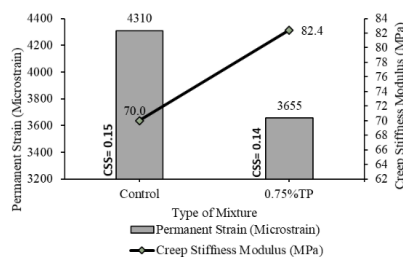


Figure 8. The comparison of permanent strain, creep stiffness modulus and CSS for control and 0.75% TP mixtures

The 0.75% TP mixture consistently showed higher strength against permanent deformation existence (rutting) by about 40% relative to the control mixture.

Double Wheel Tracker (DWT)

Figures 9 and 10 shows the sample after tested and illustrated a graph of rut depth reduction for the control and 0.75% TP mixtures. By observation, it can be stated that the 0.75% TP mixture has a flatter specimen surface than the control mixture, indicating that the modified mixture showed less rutting depth than the conventional mixture. Based on the data, both mixtures obtained rut depth less than 5.0 mm, which is accepted, and as predicted, the 0.75% TP mixture showed lesser rut depth compared to the control mixture with 0.637 mm and 2.328 mm, respectively. This finding indicated that the modified mixture improved resistance to rutting by about 73% over the control mixture, related to its higher stability, stiffness, resilient modulus, creep stiffness and lower permanent strain and CSS value. The addition of 0.75% TP additive in asphalt modification enhanced resistance to permanent deformation, showing that the cohesion strength between the aggregate and binder increased (Guo and Nian, 2020).

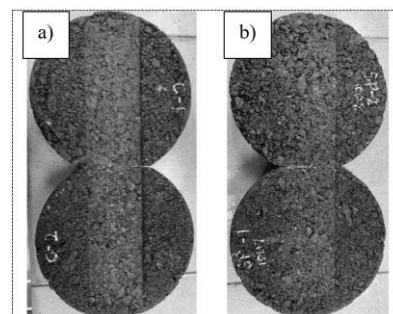


Figure 9. Rutting after DWT test for a) control and b) 0.75% TP mixtures

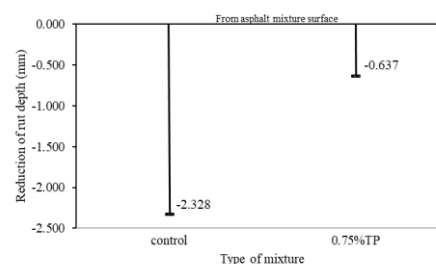


Figure 10. Reduction of rut depth for control and 0.75% TP mixtures

Conclusions

Based on the results and analysis:

(a) 0.75% TP mixture recorded the highest stability and stiffness with 17.72 kN and 4.75 kN/mm, respectively. The mixture improved by about 20 and 5% relative to the control mixture compared to others mixtures. Hence, 0.75% TP mixture was selected as the optimum mix design.

(b) The addition of 0.75% of TP content showed higher performance than control mixture with 66, 12, 7, and 73% for resilient modulus at 40°C, creep stiffness, CSS and rut depth, correspondingly.

It can be concluded, 0.75% of TP content in asphalt mixture gave a significant improvement in the performance of resistance to rutting at hot climate and the serviceability of road pavement increased. In addition, the use of TP additive not only gives benefits in terms of strength to against rutting but also as an alternative to use waste materials into road construction. Thus, this finding was significant as one of the efforts to reduce the waste material at landfill and provide a better environment.

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