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UTILIZATION OF WASTE PLASTIC BOTTLES IN ASPHALT MIXTURE

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Abstract

Nowadays, large amounts of waste materials are being produced in the world. One of the waste materials is plastic bottle. Generating disposable plastic bottles is becoming a major problem in many countries. Using waste plastic as a secondary material in construction projects would be a solution to overcome the crisis of producing large amount of waste plastics in one hand and improving the structure's characteristics such as resistance against cracking on the other hand. This study aimed to investigate the effects of adding plastic bottles in road pavement. Marshall properties as well as specific gravity of asphalt mixture containing different percentages of plastic bottles were evaluated. Besides, Optimum Asphalt Content (OAC) was calculated for each percentages of plastic bottles used in the mix. The stiffness and fatigue characteristics of mixture were assessed at OAC value. Results showed that the stability and flow values of asphalt mixture increased by adding waste crushed plastic bottle into the asphalt mixture. Further, it was shown that the bulk specific gravity and stiffness of mixtures increased by adding lower amount of plastic bottles; however, adding higher amounts of plastic resulted in lower specific gravity and mix stiffness. In addition, it was concluded that the mixtures containing waste plastic bottles have lower OAC values compared to the conventional mixture, and this may reduce the amount of asphalt binder can be used in road construction projects. Besides, the mixtures containing waste plastic showed significantly greater fatigue resistance than the conventional mixture.

Keywords: Asphalt mixture, Waste plastic, Mixture properties.

1. Introduction

Utilization of waste material as secondary material is being developed world wide. One of these waste materials is plastic bottles which are being produced in large amount. In food industries, plastic bottle is mostly made by Polyethylene Terephthalate (PET), and PET become very popular during the last decade because it is known as safe, durable and good material for packaging [1].

Today, producing waste plastic becomes a main problem in many societies when it can be found almost everywhere specially in landfills. Hence, waste plastic may cause environmental pollution because it is not a biodegradable material [2]. Thus, it would be rewarding if waste plastics can be reused, for instance, in projects such as pavement construction as a useful material in order to improve service life of road pavement in one way and preventing from environmental pollution as well.

On the other hand by increasing number and frequency of passing vehicles, especially heavy vehicles such as trucks and vans which have higher gross weight than passenger cars, service live of road pavement decreases. There are different ways to improve asphalt mixture properties. First is constructing road pavement with higher thickness and second is using different types of additives as modifier (e.g. different types of fibers and polymers) in asphalt mixture [3]. Constructing high-thickness pavement will cause considerably higher construction cost. Thus, using additives might be a better solution to overcome the pavement deterioration problem. These additives can be used in two ways: wet or dry processes. In wet process the additives will be added in asphalt, modified asphalt, before mixing with aggregate particles; however, in a different procedure, the dry process will be considered by adding the additive directly into the mixture rather than asphalt.

In this case, using waste materials as additives would be a better solution in order to prevent from additional cost by using additives in asphalt mixture [4]. Hence, this paper completed the Marshall characteristic and specific gravity of asphalt mixture containing waste PET plastic bottles following by obtaining optimum asphalt contents. Additionally, stiffness and fatigue characteristics of asphalt mixture were evaluated with and without plastic modification.

2. Laboratory Investigation

2.1. Materials

80-100 penetration-grade asphalt cement was used for this investigation. Aggregate particles that were prepared from Kajang quarry in Malaysia sieved and packed according to JKR (Malaysian Standard) specification for Stone Mastic Asphalt (SMA) 14. The gradation limit for aggregate particles can be seen in Fig. 1. Further, Table 1 shows the properties of the materials used in this study.

Waste plastic bottles that used in this study were obtained from waste PET bottles. In order to, provide appropriate plastic particles the bottles were cut to small parts then crushed and sieved. The particles which were smaller than 2.36 mm were considered for this investigation. It should be noticed that different percentages of crushed plastic bottled were designated for this study namely: 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1 % by weight of aggregate particles.

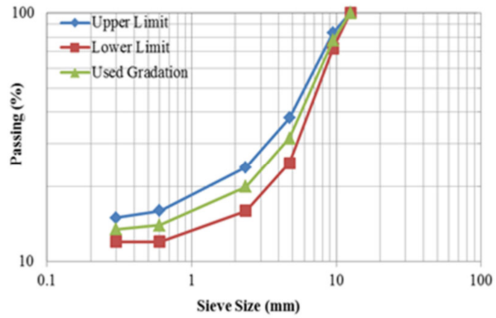


Fig. 1. Aggregate Particle Size Distribution (SMA 14).

Table 1. Aggregate and Asphalt Cement Properties.

Properties	Value
Aggregate	
Abrasion (%)	19.45
Flakiness Index (%)	2
Elongation Index (%)	11
Bulk specific gravity	2.6
Asphalt cement	
Penetration at 25°C (0.1mm)	87
Softening Point (°C)	46
Specific gravity	1.03

2.2. Sample preparation and test procedure

Marshall cylindrical samples were fabricated at 160-165˚C and 140˚C of mixing and compaction temperatures, respectively. Different percentages of asphalt cement were designated (5%, 5.5%, 6%, 6.5% and 7% by weight of aggregate particles) in this investigation.

Marshall stability and flow test were conducted on cylindrical sample according to ASTM D 1559. The specimen is placed in the water bath at the temperature of 60°C for 30 min just before commencement of the test. Marshall stability is the maximum load applied at a constant strain (2 in. per minute) which causes failure. During the stability test the dial gauge is used to measure the vertical deformation of the specimen. Marshall flow value is expressed as the vertical deformation happens at the failure point of specimen and usually in the units of 0.25mm. High flow values generally indicate a plastic mix that was experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher voids than normal value and insufficient asphalt for durability and one that may experience premature cracking due to mix brittleness during the service life of the pavement. In addition, bulk specific gravity of compacted mixture determined in accordance with ASTM D 2726.

In this study a total of 6 different amounts of Optimum Asphalt Contents (OACs) have been established, at 4% air voids, with regards to six different percentages of plastic. OAC must be high enough to provide considerable stability and durability. It also should be low enough to prevent binder drain-down. Marshall mix design procedure is the most common way to optimize asphalt content value. Table 2 shows the requirement for stone mastic asphalt mixtures at OAC [5].

Table 2. Requirement for Stone Mastic Asphalt Mixtures at Optimum Asphalt Content.

Property	Criteria [6]
VIM[a]	3-4%
VMA[b]	17% min.
Asphalt content	6% min.
Compaction effort	50 Blows
Drain down	3% max.

[a]Void in mix, [b]Void in mineral aggregate

Stiffness modulus and indirect tensile fatigue test were designated for mixtures at OAC to obtain stiffness and fatigue characteristics of asphalt mixes according to AASHTO TP31 and EN 12697, respectively. The tests were conducted at three different stress levels (250, 350 and 450 kPa), which are near stress values that usually road pavement is designed, and temperature of 20˚C. Fatigue life of asphalt mixes were considered at the cycles where the sample fails or vertical deformation reaches to the maximum value of 9 mm. Totally, ninety samples were fabricated for asphalt mix design and fifty four samples for the stiffness and fatigue tests.

3. Results and Discussion

3.1. Marshall stability and flow

As can be seen in Fig. 2, in many cases, Marshal stability (MS) value increases by adding waste plastic bottles into asphalt mixtures up to 0.6 % plastic; however, at higher plastic contents MS decreases. It is also noted that MS value decreases at higher asphalt amount. This result may indicate that better adhesion provided between asphalt binder and aggregate particles by adding waste plastic bottle.

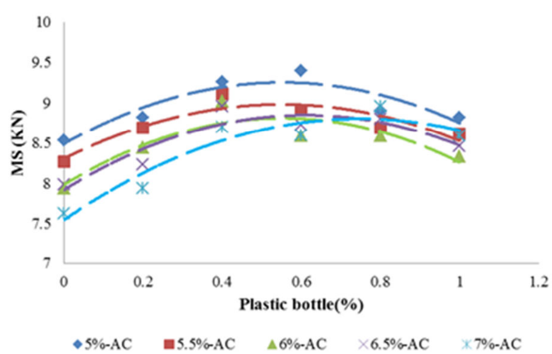


Fig. 2. MS vs. Plastic Bottle Contents.

Figure 3 shows that Marshall flow (MF) increases by adding waste plastic bottles, and that specimen constructed at higher asphalt content showed higher MF value. Thus, maximum MF value observed at the specimen made at 1% and 7% plastic and asphalt content, respectively. Obtained results may indicate that internal friction of mixture would be decreased by adding plastic into mixture which eventually results in higher flow. It is good to notice that high density polyethylene (HDPE), which is another type of plastic, had the same results on mixture flow [7].

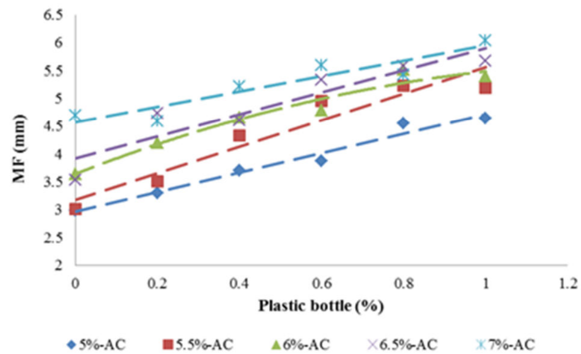


Fig. 3. MF vs. Plastic Bottle Contents.

3.2. Bulk specific gravity

Bulk specific gravity (BSG) of compacted mixtures is calculated using Equation 1, and the results are shown in Fig. 4. It is shown that BSG initiate with an increasing trend by adding plastic bottles then the trend decreased at higher plastic contents. Further, mixtures manufactured at higher asphalt contents showed to have higher BSG. It is good to notice the highest BSG is for the mixtures with 0.4% and 7% plastic bottle and asphalt content, respectively.

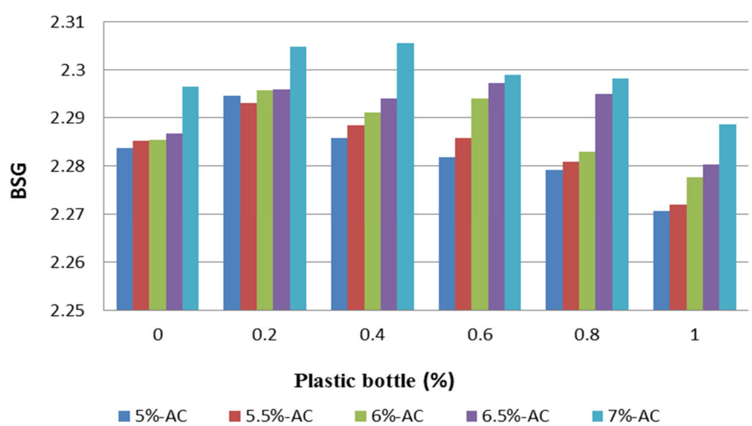


Fig. 4. BSG vs. Plastic Bottle Contents.

3.3. Optimum asphalt content

For stone mastic asphalt mixtures optimum asphalt content (OAC) was calculated to achieve 4% air voids in mix. Obtained results are depicted in Fig. 5. As it is shown, OAC value decreased by adding plastic bottle into asphalt mixtures (up to 0.6%), then rose by adding higher percentages of plastic. It is apparent from the results that lower asphalt binder is needed to achieve the proper air voids in mix by adding lower amount of PET which can be due to filling pores by PET particles in mixture; although at higher PET content more PET surface should be coated by asphalt binder which results in higher OAC value. Besides, elastic deformation of PET particles under compaction effort may be considered as second reason to cause higher OAC.

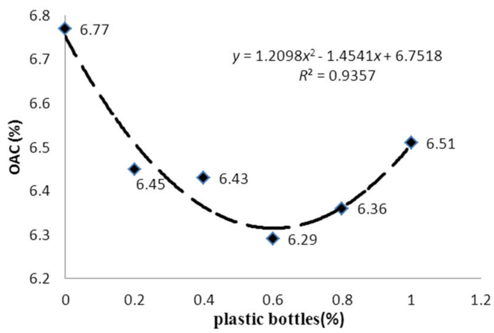
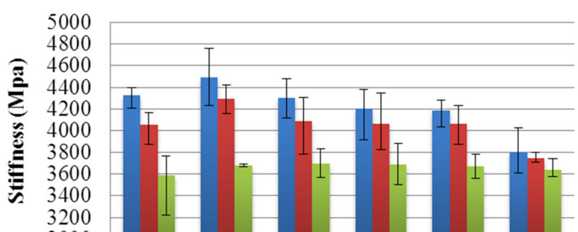


Fig. 5. OAC vs. Plastic Bottle Contents.

3.4. Stiffness

As depicted in Fig. 6, mixes including plastic bottles showed to have higher stiffness at lower amount of plastic bottle; however, by contrast, adding more plastic makes mixes less stiff. It can be concluded from the results that mixture containing higher amount of plastic has more recoverable displacement under cyclic loads compared to conventional mixture.



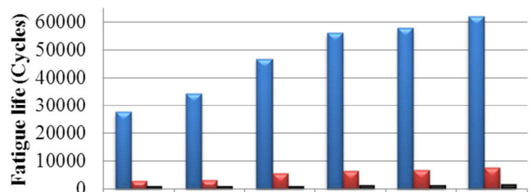
	0	0.2	0.4	0.6	0.8	1
250 kpa	4328	4496	4304	4207	4185	3801
350 kpa	4056	4293	4089	4062	4063	3747
450 kpa	3586	3679	3696	3689	3670	3634

Plastic (%)

Fig. 6. Stiffness vs. Plastic.

3.5. Fatigue

As it is shown in Fig. 7, fatigue life of asphalt mixes increases dramatically by adding plastic particles. It is illustrated that mixes with 1% plastic shows the highest fatigue lives which are more than doubled at lower stress levels (250 kPa and 350 kPa). On the contrary, in all stress levels, the mixes without plastic give the lowest value. The results might be because of improvement in mixture flexibility, as discussed in previous section [4]. In fact, PET particles would not melt due to higher melting point of PET and still exist as partially rigid materials in mixture, thus can improve the flexibility of mixture. Hence, because mixture's flexibility is improved by adding plastic particles, crack creation and propagation in asphalt mixture would be postponed which eventually results in higher fatigue life.



	0	0.2	0.4	0.6	0.8	1
250 KPa	27571	34371	46771	56031	57781	61981
350 KPa	3011	3191	5641	6551	6981	7761
450 KPa	1031	1091	1191	1341	1421	1641

Plastic (%)

Fig. 7. Fatigue Life vs. Plastic.

4. Conclusions

This paper discusses about basic properties as well as mix design of SMA mixture containing waste plastic bottle particles, and results are summarized as follows:

- Mixtures containing waste plastic bottles had more stability values compared to conventional mixture and the stability trends initially increased by adding lower percentages of plastic bottles and decreased at higher amount of plastic.
- Adding higher amount of plastic bottles resulted in higher flow value.
- BSG rose at lower amount of plastic bottles, and then decreased at higher percentages of plastic.
- Plastic-reinforced mixtures showed to have lower OAC value.
- Stiffness of asphalt mixes with lower plastic content (0.2%) initially increases; however, by a big contrast, stiffness decreases at higher amount of plastic contents. Besides, fatigue life of asphalt mixtures with plastic bottle was longer in comparison with the mixtures without plastic. These results may indicate that the flexibility of mixes was improved, and by improving the flexibility crack creation and propagation into asphalt mixes would be postponed.

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