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Green Pavement Using Recycled Polyethylene Terephthalate (PET) as Partial Fine Aggregate Replacement in Modified Asphalt

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Abstract

Most plastics collected for recycling from the household waste stream are plastic bottles. The majority of bottles are made from Polyethylene Terephthalate (PET) estimated that the ratio is 55-60%. The objective of this research is to determine optimum quality and the effect usage of recycled PET as partial fine aggregate replacement in modified asphalt mixture by determining the permanent deformation and stiffness behaviour. The modified asphalt mixtures were produced from content concentrate of recycled PET pallet range between 5 and 25% of the weight of asphalt mixture with sieve size from 2.36mm to 1.18mm and 5% weight of bitumen content as follow hot mix asphalt wearing course 14 (ACW14) in Standard Specification of Road Work in Malaysia. The samples were subjected to Repeated Load Axial Test (RLAT) loading for 1800 cycles and axial load applied 100 kN at to determine permanent deformation of modified asphalt mixture. The Indirect Tensile Stiffness Modulus Test (ITSM) was used to evaluate stiffness modified asphalt sample at 25˚C. The result obtained from the lab testing reveals the maximum permanent deformation of modified asphalt mixture reach at 20% replacement with recycled PET. However the stiffness of PET modified asphalt mixtures tend to decrease compare to unmodified asphalt mixture. The finding indicates that PET has ability to improve permanent deformation properties of asphalt mixture. In the environmental and economical aspects, PET modified asphalt mixture is found suitable to be used for road pavements.

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Keywords: permanent deformation; stiffness; recycled Polyethylene Terephthalate; modified asphalt.

1. Introduction

Permanent deformation or rutting is characterized by a surface cross section that is no longer in its designed position. This is due to its represents an accommodation of small amounts of unrecoverable deformation that occur each time a load is applied. Rutting typically happens during at high temperature. There are two principal causes i.e. rutting from weak subgrade and rutting from weak mixture [1].

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Rutting from weak subgrade occurs as too much repeated stress being applied for the subgrade (or subbbase or base) to withstand as shown in Figure 1. It is considered a structural problem and happens in the underlying layer. The thickness of pavement layers not enough strength to reduce the applied stress to a tolerable level as well as it is weakened by the intrusion of moisture.

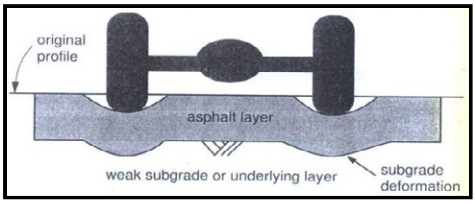

Fig. 1: Rutting From Weak Subgrade

Meanwhile, the familiar rutting occurs is deformation in asphalt layers as illustrated in Figure 2.14. This situation happens due to asphalt mixture without enough shear strength to resist repeated heavy loads and defect appears in asphalt surface course. The weak asphalt mixture will accumulate small area (but permanent defect) and foaming a rut characterized by a downward and lateral movement of the pavement.

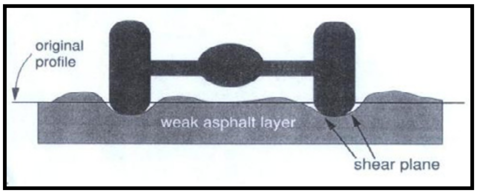

Fig. 2: Rutting From Weak Mixture

Plastics are used in a wide range of applications. Some plastics items such as plastic bottles become waste only a short time after being purchased. After collect plastics from customer or plant cycle, recycle plastic is more preferable method because plastics can lend themselves to be recycled many times over. According to the Waste and Resources Action Programme (WRAP) survey, most plastics collected for recycling from the household waste stream are plastic bottles. The majority of bottles are made from Polyethylene Terephthalate (PET) estimated that the ratio is 55-60% [2].

PET is selected in the soft-drink container market or plastic bottle because this material is tough (so that it can withstand when it drops), cheap, clarity, durability, excellent odour resistance and low permeability to carbon dioxide. PET also is used as high performance films such as photographic, magnetic tape, electrical insulation and decorative film laminates [3]. The performance of PET as aggregate replacement had been done in concrete technology. For example, in Algeria, Boutemeur et al., have investigated the usage of PET as aggregate for concrete [4].

The usage of waste PET granules pellet was experimented as a partial fine aggregate replacement in asphalt mixture [5]. The size of this material is 3mm. The asphalt mixture was produced from 60/70 penetration grade bitumen and 12.5mm aggregate grading. The aggregate and bitumen were mix between 140 and 180°C and then was compacted using Marshall Hammer with 50 blows on each side. By using Marshall Stability and Flow test, the result shows that the aggregate replacement of 20% fine aggregate (2.36-4.75mm) by volume with PET granulates (5% total weight of the asphalt mixture) was the effective use to get the highest Marshall Quotient with the lowest flow and the highest of stability.

It was tested to use waste plastic bags by conversion into recycled plastic waste aggregate (RPWA) in asphalt mixture [6]. This plastic material was identifiably Low Density Polyethylene (LDPE) principally used as a recycled material in manufacturing of plastic bags and allied products. However, the RPWA may contain traces of other plastic waste materials such as HDPE, PET, PP etc. The form of RPWA used was variable crushed to yield different irregular shapes with sharp edges. This material was selected between 1.18 and 2.30mm size. Then this asphalt modified mixture was developed using 20mm aggregation gradation. The 1200g / 3800g of aggregate containing RPWA in proportion from 0 to 15 percent by weight of total aggregate was used to produce Marshall Sample. The optimum bitumen content for the control mixture and modified mixture were 4.5 and 5 percent by weight, respectively. From Marshall Test, Qadir and Imam found that RPWA can be added in asphalt mixture up to 2.5% by total weight of the aggregate (or up to 6% on volumetric basis). Qadir and Imam suggested the RPWA could be applied both in surface course and base course of pavement.

The objective of this research is to determine optimum quality and the effect usage of recycled PET as partial fine aggregate replacement in modified asphalt mixture by determining the permanent deformation and stiffness behavior.

2. Experimental Program

A 80/100 penetration grade bitumen was used in this research. The experiments were start with develop control asphalt mixture as follow hot mix asphalt wearing course 14 (ACW14) in Standard Specification of Road Work in Malaysia. The optimum bitumen content of control asphalt mixture was determined from bitumen content ranges from 4 to 6% of weight of asphalt mixture. Then the bitumen and aggregate were compacted at temperature 150˚C with 75 blows each surface by Marshall Compactor. The palletized recycled PET was obtained from supplier with diameter of 2cm in transparent color and melting point is 248˚C. The polymer concentration in the modified asphalt mixture was in the range from 5 to 25% of the weight of asphalt mixture. The replacement aggregate occur at sieve size from 1.18mm to 2.36mm due to this polymer size.

The samples were subjected to Indirect Tensile Stiffness Modulus Test (ITSM) to evaluate stiffness modified asphalt sample at 25˚C. Meanwhile, the Repeated Load Axial Test (RLAT) to determine permanent deformation of modified asphalt mixture. The RLAT is common testing method (in laboratory) to measure the resistance to permanent deformation of asphalt mixture [7]. This test is also known as dynamic creep test or repeat creep test [8]. This experiment simulates and applicable asphalt mixture at laboratory with pavement at road especially wearing course, base course and road base. The condition to conduct the RLAT is shown in Table 1.

Table 1: Standard Conditions for the RLAT

Condition	Value
Axial stress	100 kPa
Load application period	1 second
Rest period	1 second
Number of load application	1800
Test duration	3600 second
Pre-load stress	10 kPa
Pre-load time	600 second
Temperature	30˚C

3. Result and Discussion

The optimum bitumen content for unmodified mixtures was evaluated using the ACW14 [9]. The ACW14 recommends that the optimum bitumen content should be obtain range 3 to 5% air void, 65 to 78% void filled with bitumen and 14 to 15% void mineral aggregate (VMA) and maximum resilient modulus. The VMA is defined as the intergranular void space between the aggregate particles in a compacted specimen and is expressed as a percentage of the bulk volume of the compacted specimen [1]. The bulk density, resilient modulus and asphalt density-voids analysis of control sample were obtained in laboratory as shown in Table 2. All the results are obtained from an average of three test samples. The result indicates that the optimum bitumen content of control sample is 5% of mass of asphalt mixture.

Table 2. . Density-Voids Analysis and Resilent Modulus of Control Sample

Bitumen Content	Bulk Density	TMD	VTM	VMA	VFA	Resilient Modulus
4	2.324	2.457	5.419	14.281	62.052	2650
4.5	2.335	2.44	4.275	14.314	70.134	2714
5	2.342	2.422	3.331	14.535	77.083	3227
5.5	2.362	2.405	1.817	14.263	87.259	2223
6	2.365	2.388	0.966	14.581	93.373	1962

The PET modified asphalt mixtures were developed from 5 to 25% of the mass of asphalt mixture. This material substitute aggregate sieve size from 3.35mm to 14mm because their size is 2mm diameter. Figure 3 indicates the comparison between resilient modulus of unmodified and PET modified asphalt mixture with 5% bitumen content. The result shows that the resilient modulus value of unmodified asphalt is greater than recycled PET modified asphalt. Therefore additional of recycled PET in asphalt mixture do not enhance stiffness of asphalt properties. However this pattern is same with recycled LDPE modified asphalt mixture has been done by researcher at University of Leeds, United Kingdom [10]

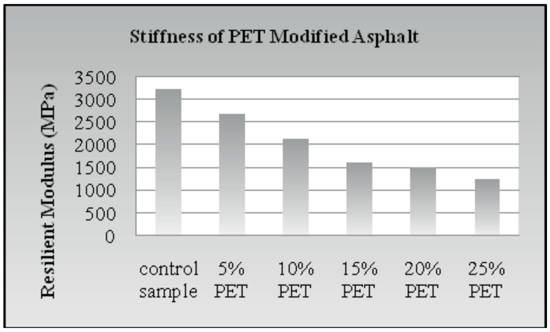

Fig. 3: Resilient Modulus of Control and PET Modified Asphalt Mixture

Figure 3 shows the effect of 1800 cycles with 100kPa on unmodified and PET modified asphalt. The outcome indicates that PET modified asphalt improve permanent deformation of asphalt mixture. The lowest permanent deformation occurs at 20% of replacement recycled PET on asphalt mixture and also half permanent deformation of unmodified asphalt at 1800 cycles. Therefore 20% PET modified asphalt mixture appears to be capable resist permanent deformation of road.

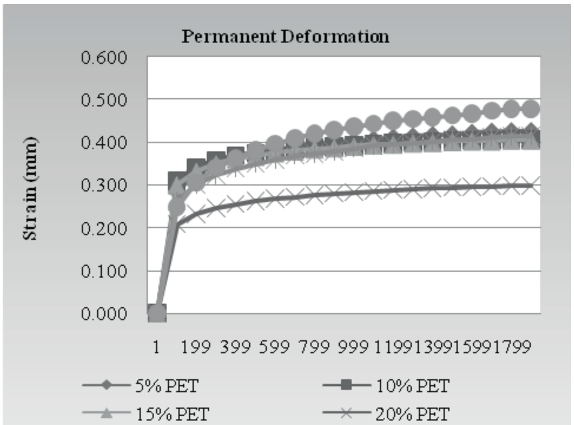

Fig. 4: Control Sample and PET Modified Asphalt of Permanent Deformation Properties

This finding indicates that recycled PET provide a remarkable recovery after 1800 cycles with loading time of 1 hour at temperature 30ºC. In addition the PET modified asphalt mixture can resist road failures as well as it increases the level of performance and the service life of the road. It could be useful to tropical country like Malaysia because this country always facing major problem of permanent deformation. This failure occurs due to the traffic load and high temperature [11]. However the PET modified asphalt cannot improve stiffness of asphalt mixture.

4. Conclusion

The result obtained from the lab testing reveals the maximum permanent deformation at 20% replacement with recycled PET. In term of economic value, it shows that this recycled PET could reduce cost of road construction because this recycled material is cheaper than bitumen and easy to obtain this material. Therefore PET modified asphalt can resist the previously mentioned road failures. Also, it improves the level of performance and the service life of the road. It can be concluded that the application of recycled PET modified asphalt gives more advantages compared to the conventional asphalt mixture especially in term of permanent deformation. Having considered the environmental and economical aspects, PET modified asphalt is found suitable to be used for road pavements.

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