OPTIMISATION OF RECYCLED HIGH DENSITY POLYETHYLENE PELLET AS AGGREGATE REPLACEMENT FOR ROAD PAVEMENT

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ABSTRACT

The objective of this study is to investigate the optimum usage recycled high density polyethylene (HDPE) as aggregate replacement in modified asphalt. The modified asphalts were evaluated by engineering properties of asphalt such as stiffness, permanent deformation and fatigue behaviour. The aggregate substitution with recycled HDPE in asphalt ranges from 5% to 25% of asphalt with sieve size from 3.36 mm to 1.18 mm and optimum bitumen content including the hot mix asphalt wearing course 14 in standard specification of road work in Malaysia. The repeated load axial test, indirect tensile stiffness modulus test and indirect tensile fatigue test were used to evaluate the permanent deformation, stiffness and fatigue properties of asphalt, respectively. The density-void analysis indicates that the optimum bitumen content is 5.5% of weight of bitumen content. The obtained results shown that the HDPE modified asphalt could enhance the stiffness of asphalt at 15% and 20% aggregate replacement. This asphalt modification also improves permanent deformation at 1800 cycles. Finally, the HDPE modified asphalt also increase fatigue life of asphalt except 5% aggregate replacement. Therefore, the HDPE modified asphalt found suitable to used for road pavement in term of environmental and economical aspects.

***KEYWORDS**: Recycle high density polyethylene; fatigue; permanent deformation*

1.0 INTRODUCTION

Most of those recycled are come from industrial and commercial sources. Recycled plastics are mainly used in the form of street furniture, insulation, ducts, pipes and etc. However it is very little so far is used in pavement (WRAP, 2003; Huang et al., 2007). Waste re-cycling is especially important in dealing with certain waste materials like plastic bottles because their longer biodegradation period i.e. very harmful to

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the environment and ecosystem balance (Ahmadinia et al., 2012). Thus, to decrease the negative impact of these plastics waste materials on environment and nature, it seems to be logical to propose ways to re-use waste materials of kind in engineering and industrial construction and production projects such as road pavement (Ahmadinia et al., 2010; and Ismail & Al-Hashmi, 2010). At the same time, plastic consumption in the Malaysia has grown in recent years. This situation, increasing plastic consumption as well as consumption of other waste materials has led to pressure on landfill sites to accommodate this waste. HDPE is used in household applications required greater stiffness or strength. For instance, milk, water, detergent and bleach bottles are HDPE because they are usually made with very thin walls to save material, cost and retain their shape. In addition the trash carts and chemical storage tanks are usually made of HDPE because of its superb chemical resistance. The automotive fuel tanks also are produced from HDPE because its require strength, chemical resistance and low permeability (Strong, 2006).

In Turkey, the investigation of the waste material containing powdered HDPE in the hot mix asphalt as a bitumen modifier was studied (Hínísloğlu & Ağar, 2004). Hinislioglu and Agar used HDPE between 4% and 8% of the weight 50/70 penetration grade bitumen and crush limestone to create 19 mm continuously graded asphalt mixture. The machine blending was operated at 200 rpm and at the same time, they applied varies mixing temperature from 145°C to 165°C and from 5 minutes to 30 minutes of mixing time to produce HDPE modified bitumen. After obtaining the HDPE modified bitumen, aggregate and HDPE modified bitumen were heated separately between 155°C and 165°C. Then all materials mixed together in a mechanical mixer. The asphalt mixture was placed in a Marshall mould and compacted by applying 75 blows on each side of the specimen at 145°C. In Marshall Stability and Flow tests, they claimed this modified asphalt mixture was highly resistance to permanent deformation because it has Marshall Quotient (MQ) values higher than conventional mixture. MQ is the ratio of stability to flow and is an indication of stiffness of the mixture in Marshall Mix design method.

The influence of HDPE concentration on the rheological properties and microstructure of HDPE modified bitumen has been recorded in Journal Energy and Fuel (Perez-Lope et al., 2005). The 60/70 penetration grade bitumen was used as base bitumen while HDPE pallet was used as a bitumen modifying agent. This polymer modification concentration ranges from 1% to 5% of the weight of bitumen. The blends of bitumen and HDPE were manufactured at 180°C and rotation speed of 8200 rpm. The frequency and temperature sweep tests in oscillatory shear and steady-state flow measurements were conducted using dynamic shear rheometer to evaluate rheological properties of HDPE modified bitumen. By using master curve (plot of storage modulus and loss modulus versus frequency at high temperature), Perez-Lepe and his colleagues found HDPE modified bitumen enhanced viscoelastic characteristic at high temperature and in other master curve (plot of tan δ versus frequency), the result shows HDPE modified bitumen improved mechanical properties at high temperature as well. In addition they also plot Black diagram. The 3% and 5% HDPE modified do not show a tendency toward viscous behaviour at high temperature in their Black diagrams and display an apparent thermorheologically complex behaviour. Hence, the additional 3% and 5% HDPE to bitumen enhances the elastic properties of the bitumen, yielding this modified bitumen improve resistance of permanent deformation at high temperature. Asphalt consists of bitumen, filler, fine and coarse aggregate. Asphalt mixtures in pavement are subjected to a wide range of load and environmental conditions. The response to these conditions is complex and involves the elastic, viscoelastic and plastic behaviours of the material (Roberts et al., 1996). The main properties criteria of asphalt mixture are stiffness, fatigue and permanent deformation. The primary objective of this study is to investigate the optimum usage recycled HDPE as aggregate replacement in modified asphalt.

2.0 EXPERIMENTAL PROGRAM

The modified asphalts were evaluated by engineering properties of asphalt such as stiffness, permanent deformation and fatigue behaviour. The research used 80/100 penetration bitumen grade as this bitumen grade is the most common used in road pavement in Malaysia. The aggregate substitution with recycled HDPE in asphalt ranges from 5% to 25% of asphalt with sieve size from 3.36 mm to 1.18 mm and optimum bitumen content as follow hot mix asphalt wearing course 14 (ACW14) in Standard Specification of Road Work in Malaysia. The optimum bitumen content of unmodified asphalt mixture was evaluated from bitumen content ranges from 5% to 7% of weight of asphalt mixture.

The bitumen and aggregate were mix and compacted at temperature 140˚C and 90˚C, respectively. The asphalt was compacted 75 blows each surface by Marshall Compactor as design to use this asphalt for high volume traffic. The pelletized recycled HDPE was obtained from supplier with diameter of 2 cm in white colour, odourless, density around 940 kgm^{-3} and melting point from 126°C to 134°C. This polymer concentration in the asphalt mixture was in the range from 5% to 25% of the weight of asphalt mixture. The replacement aggregate occur at sieve size from 1.18 mm to 2.36 mm due to this polymer size.

The asphalt mixture samples were subjected to indirect tensile stiffness modulus test (ITSM) and indirect tensile fatigue test (ITFT) to determine the stiffness and fatigue properties of modified asphalt sample at 25°C. The temperature to conduct ITSM and ITFT is 25°C because this temperature is suitable, common and relevant in Malaysia. Meanwhile, the repeated load axial test (RLAT) to evaluate permanent deformation of modified asphalt mixture. The RLAT is familiar testing method to measure the resistance to permanent deformation of asphalt mixture. This test is also known as dynamic creep test or repeat creep test (Read & Whiteoak, 2003). The temperature to conduct RLAT is 30°C due to permenant deformation start occur in this temperature and the experiment will stop at 1800 cycles.

3.0 RESULTS AND DISCUSSION

The density-void analysis was used to determine the optimum bitumen of asphalt mixture. The unmodified asphalt followed the Public Work Department (PWD) specification using the ACW14 requirement (PWD, 1988). 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 resilient modulus and asphalt density-voids analysis of unmodified asphalt is shown in Table 1. All the results are obtained from an average of three test samples. The result shows that the optimum bitumen content is 5.5% of weight of bitumen content. The HDPE modified asphalts were developed by using the ACW14 aggregate recipe and 5.5% bitumen content. This modified asphalt replaced the aggregate size range from 1.18 mm to 3.35 mm with HDPE recycled pallet. The replacement starts between 5% and 25% of the aggregate size. Table 2 reveal the average stiffness modulus of HDPE modified asphalt. All the result was obtained from an average of three tests sample. As far as the data was concern, the trend stiffness modulus of HDPE modified asphalt increase as replacement aggregate increase until reaching the peak optimum value at 15% aggregate replacement and afterward the stiffness modulus will decrease. The peak of stiffness modulus of HDPE modified asphalt laid at 15% HDPE modified asphalt with 5743 MPa. This pattern also shows that after 25% HDPE modified asphalt, the stiffness modulus of HDPE modified asphalt could be decrease. Therefore the additional of recycled HDPE pallet in asphalt could enhance stiffness of asphalt properties. However this finding is same with recycled PET modified asphalt mixture discover by Nazmi & Fauzi (2013).

Table 1: Summary of density-void analysis and stiffness modulus of unmodified asphalt

Bitumen Content (%)	G_{mb}	VTM (%)	VMA (%)	VFA (%)	Stiffness Modulus (MPa)
5	2.36	4.39	15.41	71.63	2894
5.5	2.37	3.52	15.71	77.62	3227
6	2.36	2.98	16.30	81.71	1962
6.5	2.35	2.69	17.10	84.30	1079
7	2.34	2.33	17.83	86.94	918

Table 2: Stiffness modulus of modified asphalt

Percentage of Plastic Replacement (%)	Stiffness Modulus (MPa)
	HDPE
5	2275
10	2548
15	5743
20	3356
25	1894

The effect of HDPE pallet as aggregate replacement on the modified asphalt on the permanent deformation in axial strain characteristic was investigated using the RLAT is presented in Figure 1. All the result was obtained from an average of three tests sample. The load application cycle was plot for every 100 cycle. In the end of the RLAT, the axial strain occur less than 0.8%. As far as the data was obtained, the characteristic of axial strain rapidly increase in the first 200 cycle and followed by steadily rise until 1800 cycle. In the first 100 cycle, only 15%, 20% and 25% HDPE modified asphalt are less deformed as compared to unmodified asphalt. However, the 10% HDPE modified asphalt perform less deform begin at 300 cycle. Finally, at 1100 cycle, the unmodified asphalt exceeded those at 5% HDPE modified asphalt and at the end of testing, all HDPE modified asphalt show more resist axial strain. In conclusion, the 15%, 20% and 25% HDPE modified asphalt resist permanent deformation (axial strain) as compared with unmodified asphalt from 0 cycle to 1800 cycle. Thus HDPE recycled pallet could help asphalt to resist rutting at 30°C. In summarise, the 25% HDPE modified asphalt resist rutting compare to unmodified asphalt from the beginning until complete RLAT at 1800 cycle.

Fatigue characteristic was identified using a plot graph of number of cycles (*N*) against N divided by vertical deformation (*N/vd*). The N and vertical deformation values were recorded during ITFT testing via asphalt testing system. This graph plot was used by Read to define the initiation and propagation phases of fatigue (Read, 1996). Besides, in this study, the plot was utilised to characterise the fatigue life of the modified and unmodified asphalt. The $N_{critical}$ is the number of cycle at peak highest value of graph plot *N* versus N/vertical deformation whereas $N_{failure}$ is the number of cycle value at sample of asphalt sample failu re as the vertical deformation of asphalt sample at least 9 mm. There are five different percentage of recycled HDPE pallet as aggregate replacement from 5% to 25% aggregate replacement. The fatigue characteristic of HDPE modified asphalt at 400 kpa maximum tensile stress is shown in Figure 2. As far as the fatigue life is concern, all HDPE modified asphalt indicates more $N_{critical}$ and $N_{failure}$ value except 5% HDPE modified asphalt. Thus, the HDPE modified asphalt resist fatigue deformation rather than unmodified asphalt.

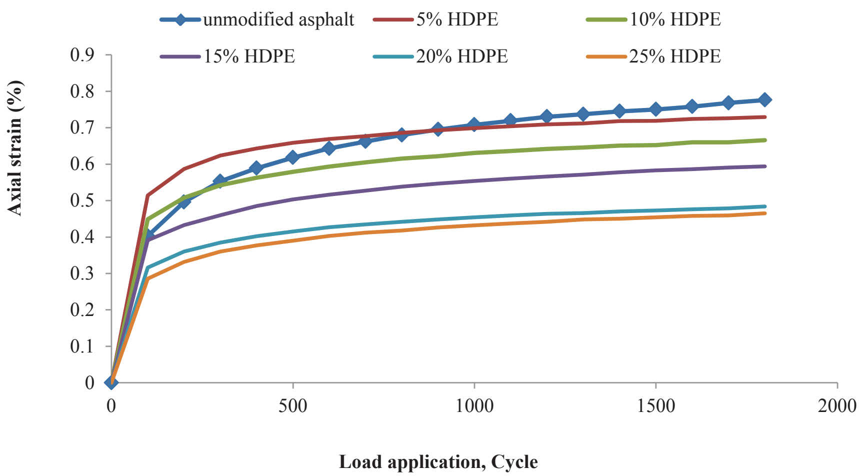

Figure 1. Axial strain of HDPE modified asphalt

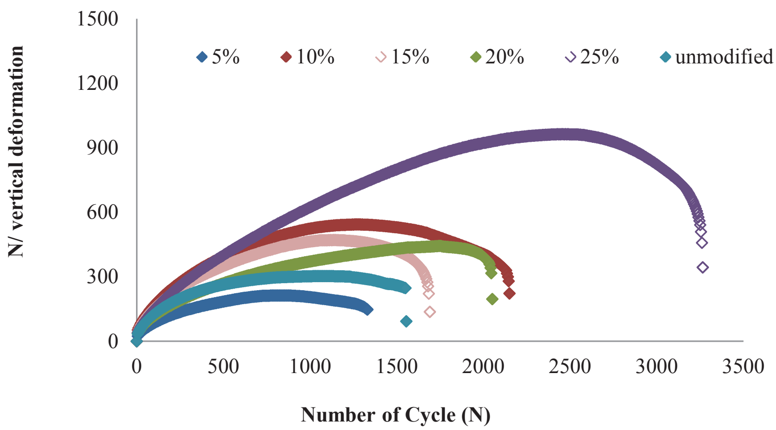

Figure 2. Fatigue fife of HDPE modified asphalt at 400kPa

4.0 CONCLUSIONS

The overall objective of this study was to evaluate performance of HDPE and PET recycled plastic as aggregate replacement in asphalt mixture. This study revealed that asphalt properties such as stiffness, permanent deformation and fatigue were found to be affected by HDPE recycled plastic. In stiffness aspect, the result show that on the other hand, only the 15% and 20% HDPE modified asphalt were greater stiffness modulus value than unmodified asphalt namely 5743 MPa and 3356 MPa, respectively. Therefore the recycled HDPE could increase stiffness of asphalt rather than recycled PET especially on 15% and 20% HDPE modified asphalt. Meanwhile, in permanent deformation properties, all HDPE modified asphalt sample resist axial strain at 1800 cycle with loading time of one hour at temperature 30°C. Thus recycled HDPE plastic could help resist permanent deformation and would be suitable as pavement in urban area. In summarise, the 25% HDPE modified asphalt resist permanent deformation compare to unmodified asphalt from the beginning until complete RLAT at 1800 cycle. The HDPE modified asphalt also more resist fatigue rather than unmodified asphalt at 25°C. In conclusion, only 15% and 20% HDPE modified asphalt could consider comply with all engineering properties requirement. This both modified asphalt would increase the stiffness of asphalt and more resist permanent deformation and fatigue. Thus, the HDPE modified asphalt found suitable used for road pavement in term of environmental and economical aspects.

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