Behaviour of Asphalt Mixtures with Recycled Polyethylene Terephthalate and High Density Polyethylene Pellet as Fine Aggregate Replacement

Wan Mohd Nazmi Wan Abdul Rahman[1], Achmad Fauzi Abdul Wahab[2] Siti Noorain Zulkifly[3]
Faculty of Civil Engineering and Earth Resources,
Universiti Malaysia Pahang, Lebuhraya Tun Razak,
26300 Gambang, Kuantan, Pahang.
Email: nazmi@ump.edu.my

The main objective of this study is to evaluate the behaviour of asphalt mixtures with recycled Polyethylene Terephthalate (PET) and High Density Polyethylene (HDPE) as fine aggregate replacement. The modified asphalts were determined by engineering properties of asphalt such as stiffness, permanent deformation and fatigue behaviour using Asphalt Testing System. The percentage of recycled PET and HDPE replace fine aggregate in asphalt mixture start up 25% percent. The recycled plastic subsitute aggregate of sieve size aggregate from 1.18 to 3.36mm content as follow with hot mix asphalt wearing course 14 (ACW14) in Standard Specification of Public Work Department of Malaysia. The bitumen content of asphalt mixture was 5.5% of weight of asphalt mixture. The Repeated Load Axial Test (RLAT), Indirect Tensile Stiffness Modulus Test (ITSM) and Indirect Tensile Fatigue Test (ITFT) were used to determine the permanent deformation, stiffness and fatigue properties of asphalt, respectively. In stiffness aspect, the result shows that all PET modified asphalt is less stiff than unmodified asphalt. All HDPE modified asphalts are stiffer rather than unmodified asphalt except 25% HDPE modified asphalt. In term of permanent deformation via RLAT, all modified asphalt slightly resists axial strain compare to unmodified asphalt. In ITFT view, the unmodified asphalt is more resistant to fatigue rather than HDPE modified asphalt except 10% of HDPE modified asphalt. The 5% and 15% PET modified asphalt are more resistant to fatigue compare to unmodified asphalt. In conclusion, the 10% HDPE modified asphalt could consider comply with all engineering properties requirement.

Keywords- recycle High Density Polyethylene; recycled Polyethylene Terephthalat; fatigue; permanent deformation; stiffness

I. INTRODUCTION

Nowadays, plastics are used as substitute for other materials to improve the performance of product and/or reduce cost of manufacture. For instance, the plastic bottles are used widely by water manufacturers to place their drink product in supermarket. This material is very cheap and at same time it is strong enough to accommodate water load. However the problem of plastic bottles raise after the costumers does not know to use plastic bottles after they drink. As the easiest and quickest solution, the consumers will most likely throw it away.

Plastic consumption in 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. According to the Waste and Resources Action Programme (WRAP) survey, majority plastics collected for recycling from the household waste stream are plastic bottles. While there are many polymer types, the most of bottles are made from either Polyethylene Terephthalate (PET) or High-Density Polyethylene (HDPE) material and approximated the ratio is 55-60% PET to 40-45% HDPE [1]. The environment and traffic volume are the factor of pavement life service. The environment like high temperature and heavy rain could accelerate permanent deformation and damage subgrade structure due to water penetration into subgrade.

The experimental research on the application of waste plastic bottles PET as additive has been applied with stone mastic asphalt (SMA). The 80/100 penetration grade bitumen, crushed granite, Portland cement (as mineral filler) and the waste PET were used in their project. The percentage of the added PET in this research was from 0 to 10% by weight of bitumen. The result show that the stiffness modulus of PET modified asphalts was higher than unmodified asphalt as high as 16% by using 6% PET. The wheel tracking test results illustrate that the PET modified asphalt has much higher rutting or permanent deformation resistance compare to unmodified asphalt. The lowest rut depth occurred at 4% PET modified asphalt which reduced the rut depth by 29% compared to the unmodified asphalt. The appreciate amount of PET was evaluated to be from 4% to 6% by weight of optimum bitumen content. [2].

The investigation of the waste material containing powdered HDPE in the hot mix asphalt as a bitumen modifier was studied in Turkey. The 19mm continuously graded asphalt mixture was developed from HDPE modified bitumen and crush limestone. The weight of powdered HDPE was calculated between 4 and 8% of the weight 50/70 penetration grade bitumen. They found this modified asphalt mixture was highly resistance to permanent deformation because it has Marshall Quotient values higher than conventional mixture [3].

The stiffness, fatigue and permanent deformation are the main properties criteria of asphalt mixture. The main objective of this study is to evaluate the behaviour of asphalt mixtures with recycled Polyethylene Terephthalate (PET) and High Density Polyethylene (HDPE) as fine aggregate replacement.

II. EXPERIMENTAL PROGRAM

This study used 80/100 penetration bitumen grade as this grade is the most familiar used in road pavement in Malaysia. The percentage of recycled PET and HDPE replace fine aggregate in asphalt mixture start up 25% percent. The recycled plastic subsitute aggregate of sieve size aggregate from 1.18 to 3.36mm content as follow with hot mix asphalt wearing course 14 (ACW14) in Standard Specification of Public Work Department of Malaysia. The bitumen content of asphalt mixture was 5.5% of weight of asphalt mixture.

The modified asphalt mixture consists of recycled plastic, bitumen, aggregate and mineral filler. All these ingredients were mix and compacted at temperature 140˚C and 90˚C, respectively. The modified asphalt mixture was compacted 75 blows each surface because the application of this sample would be complies with high volume traffic. The palletised recycled PET and HDPE was obtained from supplier with diameter around 2cm, density between 930 kgm^{-3} and 1500 kgm^{-3} as well as melting point from 186˚C to 248˚C. However, the stability of both materials is stable although heating above temperature at 300˚C. This property is very important because the temperature compaction and mixing of asphalt between 90˚C and 150˚C is to avoid those materials become liquid.

The Repeated Load Axial Test (RLAT), Indirect Tensile Stiffness Modulus Test (ITSM) and Indirect Tensile Fatigue Test (ITFT) were used to determine the permanent deformation, stiffness and fatigue properties of asphalt, respectively [4]. The temperature of 25˚C was selected to conduct ITSM and ITFT because this temperature is suitable,common and relevant temperature in Malaysia. The temperature to implement RLAT was 30˚C due to permenant deformation or rutting occur in this temperature and the experiment will stop at 1800 cycles.

III. RESULT AND DISCUSSION

The PET and 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 1.18mm to 3.35mm with PET and HDPE recycled pallet. The replacement starts between 5% and 25% of the aggregate size.

Figure 1 indicates the comparison between stiffness modulus of unmodified and recycled plastic modified asphalt with 5.5% bitumen content as optimum bitumen content. The 0% modified asphalt on the left side in the bar graph is the unmodified asphalt around 3227MPa. This graph also reveals the trend PET modified asphalt very clear that stiffness modulus decrease continuously. However this pattern is same with recycled LDPE modified asphalt mixture and has been done by researcher in United Kingdom [5].

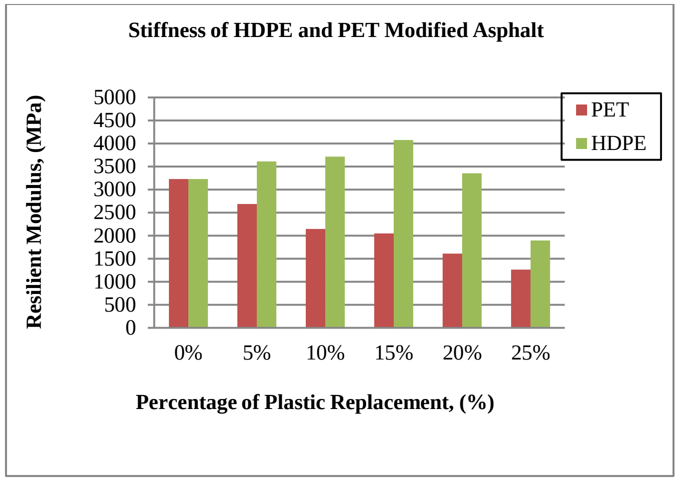

Figure 1: Stiffness Modulus of Control and Modified Asphalt

On the other hand, the 5%, 10%, 15% and 20% HDPE modified asphalt were greater stiffness modulus value than unmodified asphalt namely 3609MPa, 3715MPa, 4076MPa and 3356MPa respectively. After 20% HDPE modified asphalt, any additional of recycled HDPE pallet would not help the stiffness of asphalt. In general, the stiffness of HDPE modified was greater than PET modified asphalt. Therefore the additional of recycled HDPE pallet in asphalt could enhance stiffness of asphalt properties.

The effect axial strain of recycled HDPE and PET pallet as aggregate replacement in asphalt mixture using RLAT at 1800 load application cycles is shown in Figure 2. This figure also indicates that the straight line graph of HDPE modified the axial strain decrease slowly as additional of quantity of recycled HDPE plastic as aggregate on asphalt mixture. Meanwhile, the line graph of PET modified asphalt also show that the axial strain steadily decline except at 20% PET modified asphalt as the axial strain drop sharply and followed by rise axial strain again at 25% PET modified asphalt around 0.6%.

All both HDPE and PET modified asphalt resist axial strain deformation at 1800 cycle. Both 10% HDPE and PET modified shows same reading of axial strain around 0.78%. The 15% and 25% HDPE modified asphalt less axial strain relative to PET modified asphalt. In contrast, 5% and 20% PET modified asphalt are more resistant to axial strain compare to HDPE modified asphalt. The different axial strain for both modified asphalt is not too much different except at 25% aggregate replacement. Thus both recycled HDPE and PET plastic could help resist permanent deformation and would be suitable as pavement in urban area.

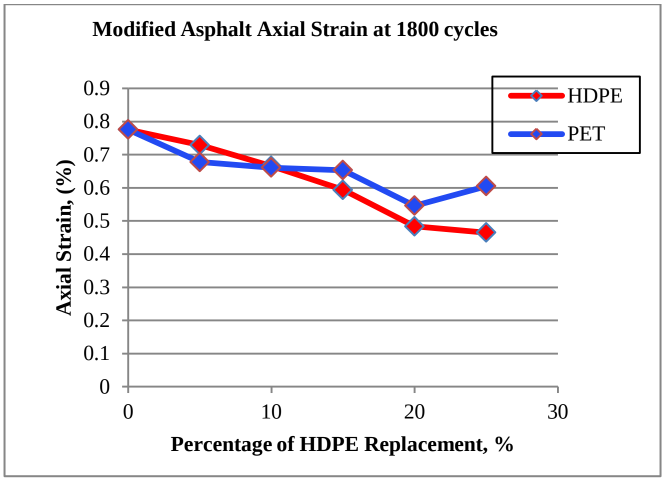

Figure 2: Axial Strain of Modified Asphalt at 1800 Cycles

The fatigue life of HDPE and PET modified asphalt are shown in Figure 3 and Figure 4, respectively. The graph result is plotted as initial strain against number of cycle to failure (N_f) on a log-log graph [6].

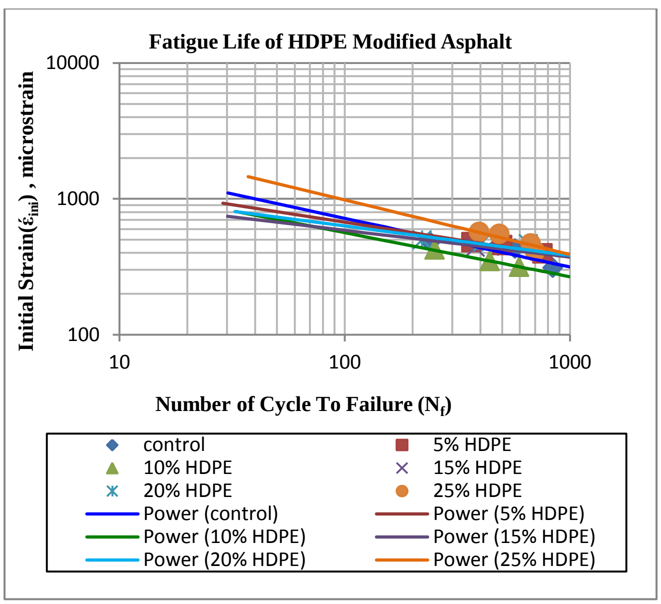

Figure 3: Fatigue Life of HDPE Modified Asphalt

For instance, in unmodified asphalt case, the equation of the fatigue life trend line is $y=3766x^{-0.359}$ and R^2 is 0.869. The slope of the fatigue trend line is -0.359. The negative value indicates that the $\acute{\varepsilon}_{ini}$ decrease as N_f increase. The greater slope or steeper fatigue trend line reveals that the sample of asphalt performance is more sensitive to the strain [7].

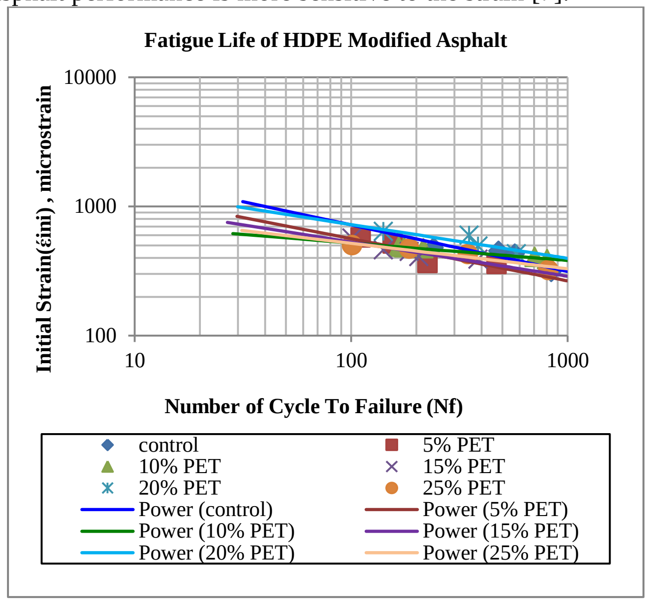

Figure 4: Fatigue Life of PET Modified Asphalt

The comparison of fatigue life trend line between unmodified and modified asphalt are also shown in Table 1. This Table also indicates that the prediction of strain of unmodified and modified asphalt for 1000 cycle. As far the data of fatigue is concerned, the strain of unmodified asphalt at 1000 cycle is 335.645 microstrain. The 10% HDPE, 5% PET and 15% PET indicate more resistant to fatigue than unmodified asphalt at 1000 cycle. For example, the 15% PET modified asphalt is the most resistance of fatigue with 288.183 microstrain at 1000.

TABLE 1: FATIGUE LIFE OF MODIFIED ASPHALT

Asphalt Type	**Equation**	**Strain at 1000 cycle(με)**
Unmodified	$\acute{\varepsilon}_{ini}= 3766.(N_f)^{-0.35}$	335.645
5% HDPE	$\acute{\varepsilon}_{ini} = 2195.(N_f)^{-0.25}$	390.332
10% HDPE	$\acute{\varepsilon}_{ini}= 2501.(N_f)^{-0.32}$	274.229
15% HDPE	$\acute{\varepsilon}_{ini} = 1455.(N_f)^{-0.19}$	391.618
20% HDPE	$\acute{\varepsilon}_{ini} = 1712.(N_f)^{-0.21}$	401.332
25% HDPE	$\acute{\varepsilon}_{ini} = 6194.(N_f)^{-0.4}$	390.815
5% PET	$\acute{\varepsilon}_{ini} = 2545.8(N_f)^{-0.327}$	265.965
10% PET	$\acute{\varepsilon}_{ini} = 970.53(N_f)^{-0.135}$	381.952
15% PET	$\acute{\varepsilon}_{ini} = 1797.5(N_f)^{-0.265}$	288.183
20% PET	$\acute{\varepsilon}_{ini} = 2412.6(N_f)^{-0.261}$	397.636
25% PET	$\acute{\varepsilon}_{ini} = 1284.1(N_f)^{-0.197}$	339.305

IV. CONCLUSION

In stiffness aspect, the result shows that all PET modified asphalt is less stiff than unmodified asphalt. All HDPE modified asphalts are stiffer rather than unmodified asphalt except 25% HDPE modified asphalt. In term of permanent deformation via RLAT and statistic analysis, all modified asphalt slightly resists axial strain compare to unmodified asphalt. In ITFT view, the unmodified asphalt is more resistant to fatigue rather than HDPE modified asphalt except 10% of HDPE modified asphalt. The behaviour of stiffness and permanent deformation HDPE modified asphalt also has been done in Malaysia [8]. The 5% and 15% PET modified asphalt are more resistant to fatigue compare to unmodified asphalt [8]. In conclusion, the 10% HDPE modified asphalt could consider comply with all engineering properties requirement and suitable used for road pavement.

ACKNOWLEDGMENT

Some of this research reported in this paper formed part of Universiti Malaysia Pahang short grant research entitled 'Influence Utilization of Waste HDPE as Fine Aggregate Replacement and Fly Ash, Waste Glass as Filler in Hot Mix Asphalt'.

REFERENCES

[1] Waste and Resources Action Programme (WRAP),"Annual Local Authorities Plastics Collection Survey 2007," 2007.

[2] Esmaeil A, Majid Z, Rehan K, Mahrez and Ebrahim A. "Performance Evaluation Of Utilization Of Waste Polyethylene In Stone Mastic Asphalt", J. Construction and Building Material. v 36, p984-989. 2012

[3] Hínísloğlu S and Ağar E,"Use of Waste High Density Polyethylene as Bitumen Modifier in Asphalt Concrete Mix", J. Materials Letter., v58, p267-271.2004.

[4] J.Read and D.Whiteoak, "The Shell Bitumen Handbook," Thomas Telford, Fifth Edition. 2003.

[5] S.E Zoorob and L.B Suparma, "Laboratory design and investigation of the properties of continuously graded Asphaltic concrete containing recycled plastics aggregate replacement (Plastiphalt)," J. Cement & Concrete Composites, v22, p233-242. 2000.

[6] Read J M, "Fatigue Cracking Of Bituminous Paving Mixtures", PhD Thesis, University of Nottingham, UK. 1996

[7] Sunarjono Sri M.T, "The Influence Of Foamed Bitumen Characteristics On Cold-Mix Asphalt Properties", PhD Thesis, University of Nottingham,UK.2008.

[8] W M Nazmi, Achmad Fauzi and Fadzil Mat Yahaya, "Optimisation Of Recycled High Density Polyethylene Pellet As Aggregate Replacement For Road Pavement". Malaysian Technical Universities Conference on Engineering & Technology.2013