Permanent Deformation Characteristics of Modified Waste Plastic-Bitumen in Asphalt Concrete

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Abstract

Polymer has been widely used by many researchers to modify bitumen and to improve the properties of asphalt concrete. The paper discussed the laboratory investigation of the use of waste High Density Polyethylene (HDPE) obtained from chopped plastic milk cartoons to modify the properties of asphalt concrete on the permanent characteristics. Waste HDPE was used to modify 60/70 penetration grade bitumen and Its effect on basic bitumen properties was tested over a range of test temperatures. The Marshall stability tests were carried out to determine the optimum bitumen content and optimum HDPE content of asphalt concrete. The optimum HDPE content in binder was found to be 1.5% by weight of binder. The permanent deformation behaviours of asphalt concrete with and without waste HDPE were evaluated in laboratory using wheel tracking and repeated load tests at a range of test temperatures. The VESYS model was used to predict rutting performance for 10 years ahead. Test results showed that the performance of asphalt concrete prepared using waste HDPE plastic were more resistance on permanent deformation over a range temperature.

Keywords: Permanent Deformation, Waste Plastic (HDPE), modified bitumen and Asphalt Concrete (AC).

INTRODUCTION

In recent years, traffic volumes and the percentage of heavy truck have increased significantly to support the development of the economy in Indonesia. Previous study indicated that the composition rate of heavy vehicles in Indonesia is very high, reaching about 50% of the total traffic or more. As a result, the road conditions are 60% in fair to good condition and 40% in poor or bad condition [1,2]. The most common mode of failure in Indonesia roads is the permanent deformation (rutting) especially in the wheel track, this resulted in increased traffic volume, heavy loaded and the high ambient temperature.

The binder has an important role to play in the performance of bituminous materials, particularly in asphalt concrete where the mechanical properties of binder have a major influence upon the mechanical properties of the mixtures [5,6,7,8]. The use polymer additive is one of the ways to improve the behaviour several properties such as temperature susceptibility, resistance to permanent deformation and fatigue live [6,7,8] but the polymer is categorized in expensive material in developing country such as Indonesia. Therefore, there is needed to investigate the application of new materials but low cost such as waste plastic to anticipate that problems. Development of waste plastic milk bottle as modifier in bitumen is the promising way on bituminous road construction industry in Indonesia as developing country

There are two objective in this study, the first objective is to investigate the effect of waste plastic (HDPE) added to bitumen on properties modified bitumen and the second is to investigate the permanent deformation (rutting) characteristics of asphalt concrete using modified bitumen and unmodified. The deformation characteristics of the asphalt concrete were studied using Marshal test, Wheel Tracking and Repeated Load Axial test apparatus.

MATRETIALS USED

Bitumen collected from Lagan Bitumen was penetration grade bitumen 60/70, which is widely used in Indonesia for asphalt concrete. Modifier used in this study is waste plastic milk cartoon, predominantly composed of High Density Polyethylene (HDPE). Waste plastic milk cartoon used in this study was obtained from local household waste. HDPE milk cartoon were cut into small pieces of approximately 2 x 2 mm^2 size. The thickness, density, melting point, tensile strength, and elongation at break of the material are 0.5 mm, 0.94 – 0.97 gm/cc, 120 – 130^oC, 31.35 MPa, and 100%, respectively [10].

Aggregate used in this study was crushed basalt obtained from Kennedy Quarries where located in sixty miles from Belfast and the properties of aggregate can be seen in Table 1. The filler defined in this study is the material passing through 0.075 mm sieve and the filler type used in asphalt concrete is limestone dust.

PROPERTIES OF WASTE PLASTIC (HDPE)- BITUMEN BLEND

The Plastic Milk Cartoon-Bitumen Blend

The chopped plastic milk cartoon in 2 x 2 mm^2 in size was blended with bitumen at low speed for about 5 min until all of plastic quantity required was added. The mixture is heated constantly to 160 - 170^oC and mixed at high speed for 1 hour using a mechanical stirrer. Three types of modified bitumen were prepared by varying content of waste plastic HDPE (0.75%, 1.5% and 3% by weight of binder) in the mixture.

The unmodified and modified bitumen properties have been evaluated using the penetration test at various temperatures (25^oC, 30^oC, 35^oC and 40^oC) and softening point test.

Table1. Properties of Aggregate Used

Property	Standard Method	Basalt	
		Coarse	Fine
Physical Properties			
Apparent Particle Density	BS 812 Part 2: 1995	2.97	2.92
Oven Dried Particle Density		2.87	2.79
Saturated Surface Dry Particle Density		2.91	2.84
Water Absorption, %		1.22	1.54
Flakiness Index, %	BS 812-105.1: 1989	23.5	
Elongation Index, %	BS 812-105.2: 1990	18.70	
Mechanical Properties			
Aggregate Impact Value (AIV), %	BSI 812 Part 112:1990	9.60	
Aggregate Crushing Value (ACV), %	BSI 812 Part 110:1990	13.60	
Ten Percent Fines Value (TFV), kN	BSI 812 Part 111:1990	289.70	
Fragmentation by LA test *)	BS EN 1097-2: 1998	19.00	
Resistance to Wear by Micro Deval Test*)	BS EN 1367-2: 1998	24.00	
Magnesium Sulphat Soundness *)	BS EN 1367-2: 1998	9.00	
Aggregate Abrasion Value (AAV) *)	BS EN 1097-8: 2000	6.3	
Polished Stone Value (PSV)*)	BS EN 1097-8: 2000	58	

*) Data from Whitemountain Quarries Ltd, 2003

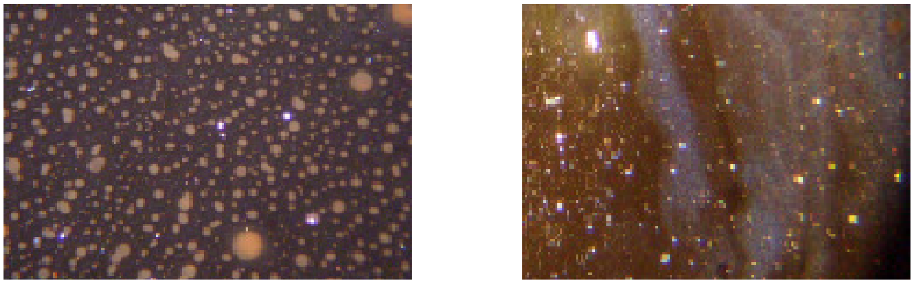
Properties of Waste Plastic – Bitumen Blend

The results of penetration test on waste plastic-bitumen blend under various temperatures (25°C, 30°C, 35°C and 40°C) and softening point test are expressed in Table 2. As presented in Table 2 that the penetration values of unmodified and modified bitumen increased as the temperature increased, while the penetration values of modified bitumen at various temperatures were found decreasing as waste plastic content increased in bitumen. The softening point of the 60/70 pen bitumen increased as the percentage of waste plastic in bitumen increased. To determine whether waste plastic dispersed in bitumen or not can be observed using optical micrograph. Figure 1 represents optical micrographs for modified bitumen and unmodified bitumen. It is clear that Figure1 showed waste plastic dispersed in bitumen.

Table 2. Summary of The Penetration Value of Waste Plastic-Bitumen Blend

Test	Waste Plastic HDPE - Bitumen Blended			
Penetration (dmm)	0%	0.75%	1.5%	3%
25°C	78	72	66	55
30°C	149	122	103	85
35°C	239	206	176	133
40°C	350	319	285	223
Softening Point (°C)	45	47	48.5	54

Temperature susceptibility of binder can be assessed using penetration index as shown in Figure 2. The temperature susceptibility for modified bitumen using waste plastic decreased as waste plastic content in bitumen increased It is clearly that modified bitumen using waste plastic can reduce temperature susceptibility. It indicates that modified bitumen using waste plastic can reduce rutting at high temperature.



Modified Bitumen Unmodified Bitumen

Fig. 1 Optical Micrograph for Modified and Unmodified Bitumen

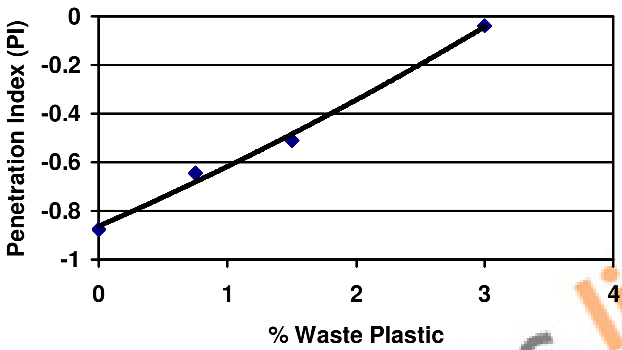


Fig. 2 The Effect of Modifiers on Penetration Index of Modified Bitumen

ASSESSING THE PERMANENT DEFORMATION

Marshall Test

The Marshall test method was used for determining the optimum bitumen content for asphalt concrete. It was found the optimum bitumen content is 6% (by weight of total mix). Further 6% bitumen content was selected for making the specimens used in assessing permanent deformation characteristics.

The selection of the optimum waste plastic content used in bitumen was based on moisture susceptibility test in term of retained stability. The retained stability is ratio Marshall stability of conditioned specimen over unconditioned specimen. Unconditioned specimen is the specimen placed in a water bath at 60°C (140°F) for at least 40 min and not longer than 60 min, after that the Marshall stability of the samples is determined. Conditioned specimen is the specimen placed in a water bath at 60°C (140°F) for 24. As shown in Figure 3 that Asphalt concrete prepared using waste plastic content of 1.5% exhibited the highest of retained stability. These results agree with the previous study results that the polymer can be used as anti stripping agent [8,9]. Further waste plastic content 1.5% (by weight of optimum bitumen content) was selected for more detailed in laboratory permanent deformation performance investigation.

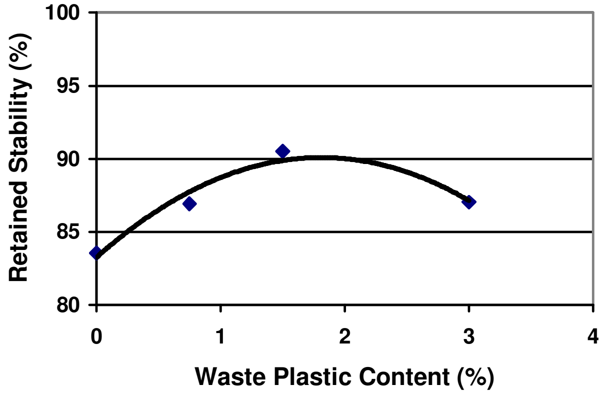


Fig. 3 The Effect of Waste Plastic on Moisture Susceptibility

Repeated Load Axial Test (RLAT)

The specimens used in RLAT were Marshall specimens. In RLAT used in this research using Nottingham Asphalt Tester (NAT), which an axial stress of 100 kPa is repeatedly applied once every two seconds to a specimen at a specified temperature. The resultant axial strain is measured at intervals until the required number of load pulses (1800 load cycles) has been applied. The deformation is measured by summing the output from two diametrically opposed linier variable displacement transducers (LVDT) resting on the upper platen. This test is carried out according to BS 598-111:1995.The repeated load axial test was carried out to asphalt concrete with and without waste plastic under varying temperature of 20°C, 30°C and 40°C respectively.

RLAT Results and Discussion

The result of the permanent strains versus number of load repetitions on asphalt concrete using modified and unmodified bitumen under varying temperatures of 20°C, 30°C and 40°C respectively is demonstrated in Figure 4. As shown in Figure 8, the permanent strains of asphalt concrete using modified bitumen is smaller than unmodified bitumen, which mean the mixture with modified bitumen has more resistance to permanent deformation than unmodified bitumen. This indicated that modified bitumen using waste plastic gave improvement in deformation performance of asphalt concrete.

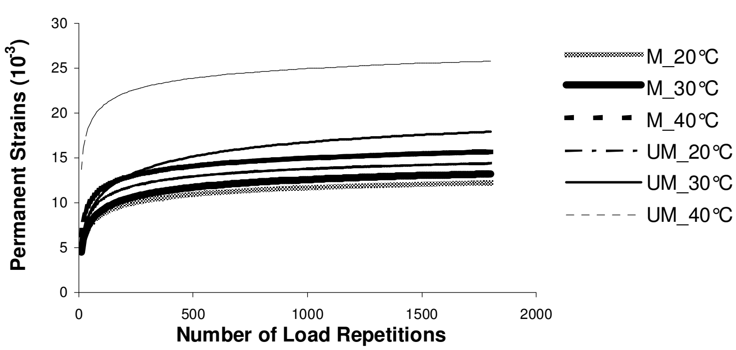


Fig. 4 Permanent Strains for Modified and Unmodified at Varying Temperature

Figure 5 showed the effect of temperatures on permanent strain of mixes. As expected, the temperature significantly affected the deformation performance of mixes, which permanent strain exhibits higher at the higher temperatures. It showed clearly that modified bitumen could reduce significantly susceptible to temperature as indicated by the slope of permanent strain versus temperatures. Compared to conventional mixed, asphalt concrete using modified bitumen at the highest temperature testing (40°C) showed an improvement in decreasing permanent deformation about 40%.

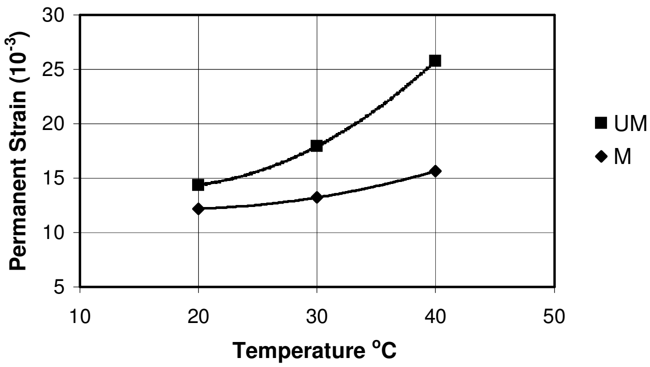


Fig. 5 The Effect of Temperature on RLAT Results

Wheel Tracking Test

Diameter and thickness of specimens used in this research were 150 mm and 50 mm respectively. The specimens were manufactured using gyratory compactor in accordance with BS EN 12697-31 with trial and error to obtain the same density with previous Marshall samples. The average number of gyration required to obtain the similar density as the Marshall specimens was approximately 48 gyrations. In this study used Wessex Wheel Tracking machine is designed to carry out tests on asphalt concrete in accordance with BS 598-110. This machine is operated by computer program to measure and record plastic deformation or rut depth under various temperatures and pressures similar to those experienced under road use by computer program.

The samples of asphalt concrete with waste plastic and without plastic were tested using Wheel Tracking machine under varying temperature of 30°C, 40°C and 60°C respectively. The total wheel-track deformation every minute, in millimeters was recorded by computer, developed over the 45 min of the test.

Wheel Tracking Test Results and Discussion

Figure 6 showed the rut depth of asphalt concrete using modified bitumen at varying temperatures exhibited lower than conventional mixes. It can be clearly seen that the significant improvement in rutting resistance can be achieved by adding waste plastic in bitumen.

Figure 7 also showed clearly that waste plastic addition in bitumen gave improvement in reducing susceptible to temperature as indicated by the slope of rut depth versus temperatures. Compared to conventional mixed, asphalt concrete with waste plastic at the highest temperature (60°C) showed an improvement in decreasing rut depth about 55%.

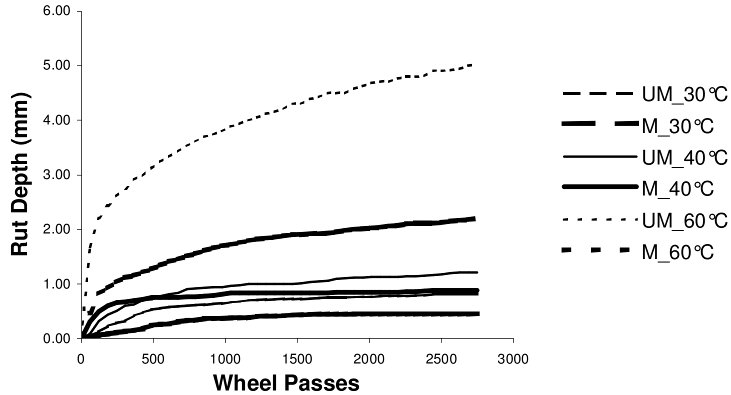


Fig. 6 Rut Depth for Modified and Unmodified at Varying Temperatures

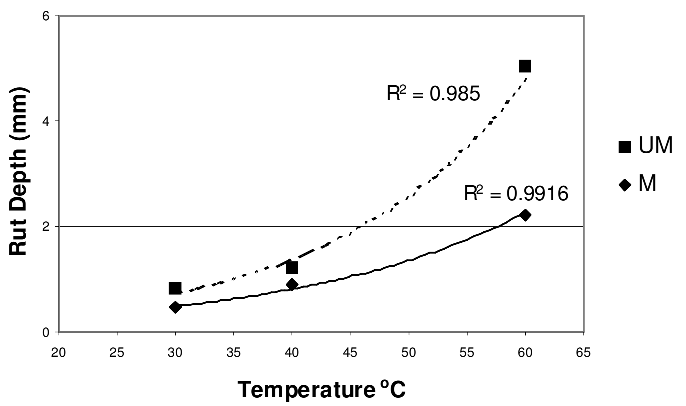


Fig. 7 The Effect of Temperature on Wheel Tracking Test Results

THE PERMANENT DEFORMATION PERFORMANCE

VESYS performance model was used to evaluate the permanent deformation performance on asphalt concrete with and without waste plastic. The VESYS 5 computer model is used to predict the structural responses and the integrity of flexible pavement, which developed by Kenis et al [4]. Full details of the VESYS 5 computer model are described in user manual of VESYS 5 [3]

The geometry of pavement layer was selected to evaluate the effectiveness of the effect of waste plastic added in mixes for reducing rut depth in surface course under a range temperatures of 20℃, 30℃ and 40℃, the thickness used in this case is the cross section of each consisted of a 4 inches (100 mm) bituminous concrete layer over 10 inches base course layer. The composition rate of heavy vehicles as a ratio of total traffic used in this case is 50% of the total traffic. The average traffic of 150 ESAL per day and an analysis period of 10 years were used in this analysis.

The results of rutting performance of asphalt concrete using VESYS 5 model analysis for modified and unmodified bitumen varying temperatures can be seen in Figure 8 and 9. As expected, asphalt concrete prepared using modified bitumen has higher ability to resist permanent deformation (rutting) and lower temperature susceptibility than conventional mix. Those results are consistent with the laboratory test results such as wheel tracking test and RLAT.

Compared to conventional mix, asphalt concrete with waste plastic over the service live 5 years at the maximum temperature testing (40℃) showed an improvement in reducing rut depth about 52% while improvement in ability resist to deformation about 51% for over the service live 10 years.

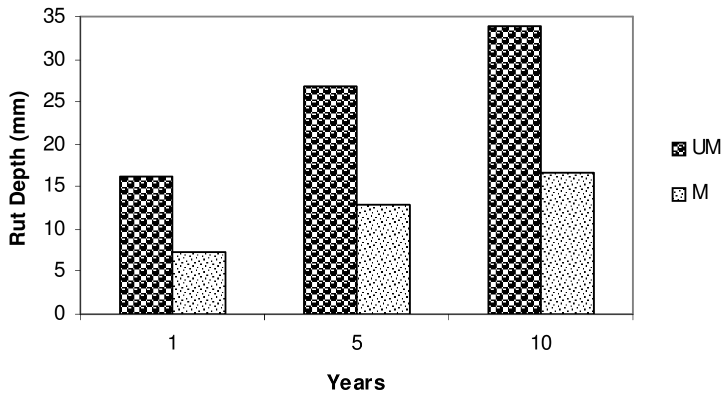


Fig. 8 The Effect of Waste Plastic on Permanent Deformation Performance

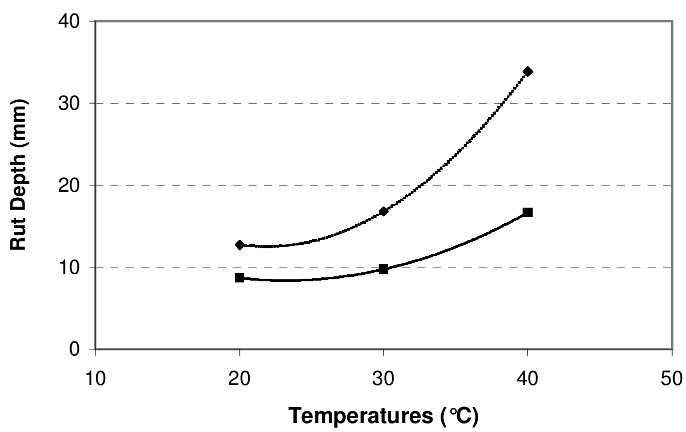


Fig.9 The Effect of Temperature on Permanent Deformation Performance

CONCLUSIONS

Based on the results of the experimental investigations conducted on normal and modified bitumen using waste materials in asphalt concrete mixes, the following summaries have been drawn:

1. The penetration values of modified bitumen were found lower than virgin bitumen but the softening values showed higher than virgin bitumen.
2. The addition of waste plastic in binder can increase penetration index values, which mean it can reduce temperature susceptibility.
3. The addition waste plastic in binder for asphalt concrete can reduce significantly permanent deformation when tested at higher temperature.
4. It is found the same trend of deformation curve between predicted rutting from VESYS analysis and repeated load axial test results.
5. The predicted rutting resistances of asphalt concrete using waste plastic were significantly superior to resist deformation under varying temperature.
6. In general the deformation performances of asphalt concrete mixes prepared using waste plastic were better than conventional mixes at a range service temperature.

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