PERMANENT DEFORMATION EVALUATION OF MODIFIED WASTE PLASTIC-BITUMEN IN ASPHALT CONCRETE USING FUNDAMENTAL AND SIMULATIVE METHODS

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ABSTRACT: The paper discussed the fundamental and simulative method in assessing permanent deformation of modified waste plastic-bitumen in asphalt concrete. Waste plastic (HDPE) obtained from milk bottle plastic 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 waste plastic content of asphalt concrete. The optimum waste plastic content in binder was found to be 1.5% by weight of binder. The permanent deformation evaluation of asphalt concrete with and without waste HDPE was evaluated in laboratory using fundamental method (Repeated Load Axial Test) and simulative method (Wheel Tracking Test) at a range of test temperatures. The analysis data indicated that both tests fundamental and simulative test had significant correlation with each other. Both test results was consistent that the performance of asphalt concrete prepared using waste plastic were more resistance on permanent deformation over a range temperature..

Keywords: Permanent Deformation, Asphalt Concrete, Waste Plastic, Fundamental Methods, and Simulative Methods

1. INTRODUCTION

Permanent deformation is the most common mode of failure in road pavement, especially in hot climate area like in Indonesia which the maximum pavement temperature of more than 50°C throughout the year. The temperature is major influence upon the permanent deformation mode of asphalt concrete, especially when the temperature rises above 40°C or higher because the asphalt concrete tends to flow out as viscoelastic materials do at high temperatures.

There are several factors affecting the magnitude and the rate of permanent deformation (rutting) on the road pavement. 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. 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 but the polymer is categorized in expensive material in developing country such as Indonesia. For that reason, it is needed to investigate the application of new materials but low cost such as waste plastic as a modifier to anticipate those 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 a variety of methods and devices that have been used to assess the permanent deformation resistance of bituminous mixtures. Permanent deformation assessment can classified into three groups i.e. fundamental tests; empirical mix design related test and simulation test. Wheel tracking as simulative method is commonly used to assess permanent deformation of mixture because the Repeated Load Axial Test as fundamental method can be categorized in expensive apparatus at developing country like Indonesia. In this research, fundamental and simulative methods used for assessing the resistance to permanent deformation were the Repeated Load Axial Test (RLAT) and wheel-tracking test.

The objectives in this study are to investigate the effect of waste plastic (HDPE) added to bitumen on properties modified bitumen, investigate and correlation analysis the permanent deformation (rutting) characteristics of asphalt concrete from these methods.

2. MATERIALS AND PREPARATION

2.1. The Plastic Milk Cartoon-Bitumen Blend

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 was obtained from local household waste. HDPE milk cartoons 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^{o}C, 31.35 MPa, and 100%, respectively.

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^{o}C 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^{o}C, 30^{o}C, 35^{o}C and 40^{o}C) and softening point test

2.2. Aggregate

Aggregate used in this study was crushed basalt obtained from Kennedy Quarries where located in sixty miles from Belfast. The properties and gradation of aggregate can be seen in Figure 1 and 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

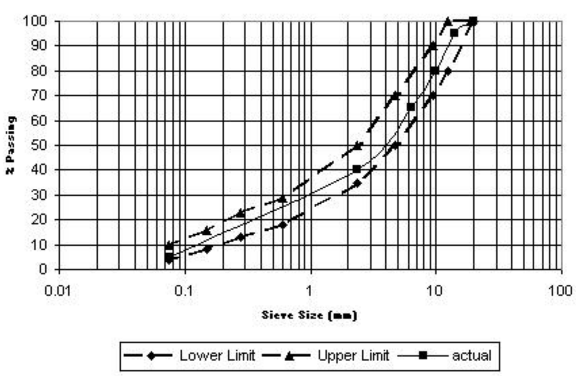


Fig. 1 The Grading Curve of Asphalt concrete [7]

Table1. Properties of Aggregate Used

Property	Basalt	
	Coarse	Fine
Physical Properties		
Apparent Particle Density	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, %	23.5	
Elongation Index, %	18.70	
Aggregate Impact Value (AIV), %	9.60	
Aggregate Crushing Value (ACV), %	13.60	
Ten Percent Fines Value (TFV), kN	289.70	
Fragmentation by LA test *)	19.00	
Resistance to Wear by Micro Deval Test*)	24.00	
Magnesium Sulphat Soundness *)	9.00	
Aggregate Abrasion Value (AAV) *)	6.3	
Polished Stone Value (PSV)*)	58	

*) Data from Whitemountain Quarries Ltd, 2003

2.3. Asphalt Concrete Specimen

The Marshall test method was used for determining the optimum bitumen content for asphalt concrete. It was found to be 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. As shown in Figure 2 that Asphalt concrete prepared using waste plastic content of 1.5% exhibited the highest of retained stability. These results agree with the previous studies that the polymer can be used as anti stripping agent. Further waste plastic content 1.5% (by weight of optimum bitumen content) was selected for more detailed in laboratory permanent deformation performance investigation.

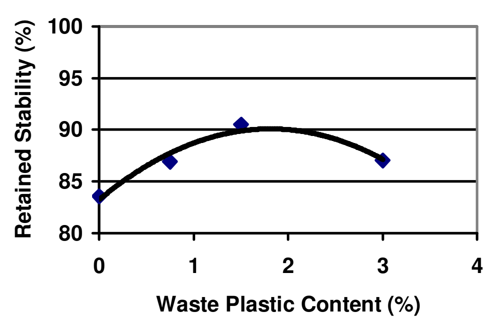


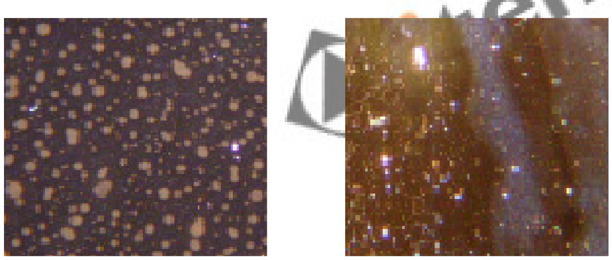
Fig. 2 The Effect of Waste Plastic on Moisture Susceptibility

3. 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 3 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			
	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
SP(°C)	45	47	48.5	54



Modified Unmodified

Fig. 3 Optical Micrograph for Modified and Unmodified Bitumen

Temperature susceptibility of binder can be assessed using penetration index as shown in Figure 4. 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, this result is in line with previous study (Tuncan et al, 2003). It indicates that modified bitumen using waste plastic can reduce rutting at high temperature.

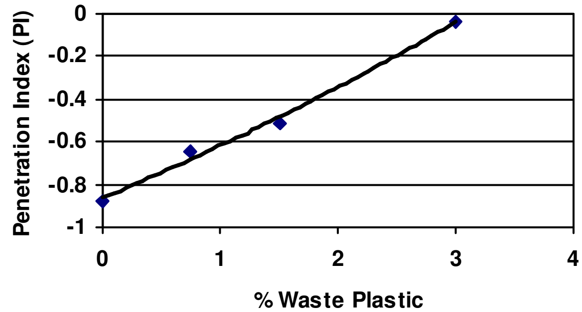


Fig. 4 The Effect of Modifiers on Penetration Index of Modified Bitumen

4. FUNDAMENTAL AND SIMULATIVE METHODS IN ASSESSING THE PERMANENT DEFORMATION

4.1. Repeated Load Axial Test (RLAT) as Fundamental Method

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 DD 226 (1996). 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.

4.2. Wheel Tracking Test as Simulative Method

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 (1998). 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.

5. RESULTS AND DISCUSSIONS

5.1. 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 5.

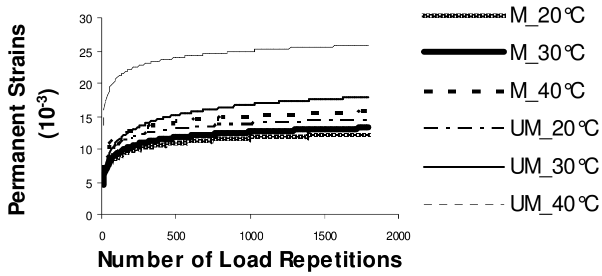


Fig. 5 Permanent Strains for Modified and Unmodified at Varying Temperature

As shown in Figure 5, 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.

Figure 6 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%.

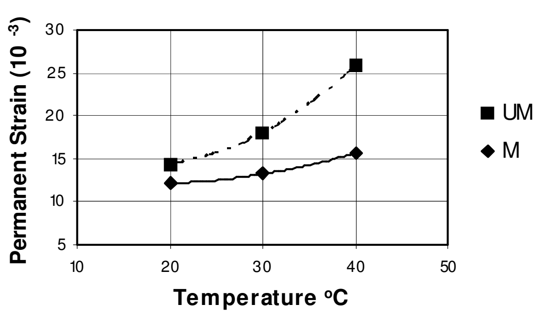


Fig. 6 The Effect of Temperature on RLAT Results

5.2. Wheel Tracking Test Results and Discussion

Figure 7 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 8 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%.

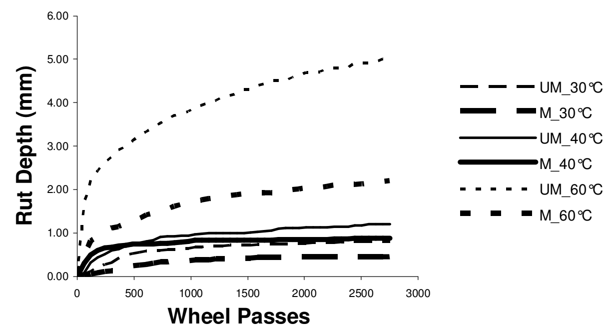


Fig. 7 Rut Depth for Modified and Unmodified at Varying Temperatures

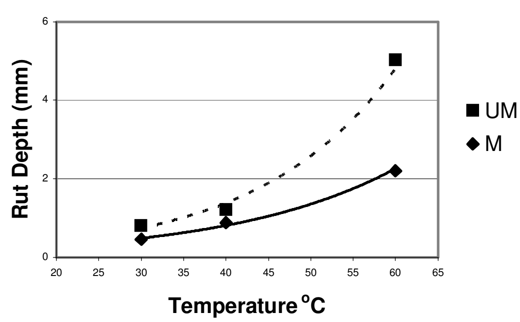


Fig. 8 The Effect of Temperature on Wheel Tracking Test Results

5.3. The comparison of test methods

The comparison of both fundamental test and simulative test in assessing the permanent deformation performance were quantified by ultimate rut depth or permanent strain and the rate of deformation at the linier phase under same temperatures testing. The rate of rut from wheel tracking test was calculated by using Equation in accordance with BS 598-110 (1998) and rate of strain from RLAT was determined by average of strain rate at linier phase. A correlation analysis was conducted to evaluate the relationship between wheel tracking test and RLAT results in terms of ultimate rut and the rate of rut as shown in Figure 9 and 10. A summary results is presented in correlation matrix for both tests as shown in Table 3. As shown in Table 3 that a strong correlation was found, with correlation coefficient of 0.903 when the rate of strain and rate of rut are compared. This result agrees with previous study conducted by Zang et. al. This also indicates that both tests RLAT as fundamental test and wheel tracking as simulative test are tending to rank the material tested in a similar order as shown in Table 4. The results in Table 4 clearly show that bituminous mixes using modified exhibit superior rutting resistance as demonstrated by lower values of ultimate deformation and deformation rate compared to conventional mix.

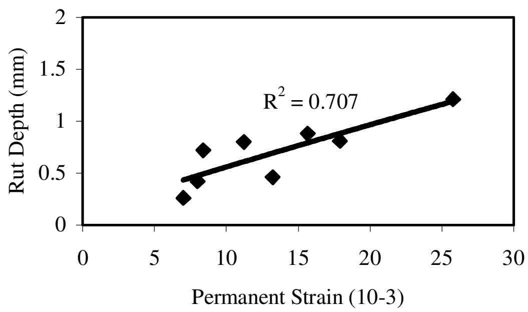


Fig. 9 The Relationship of Rut Measurement between RLAT Results and Wheel Tracking Test Results

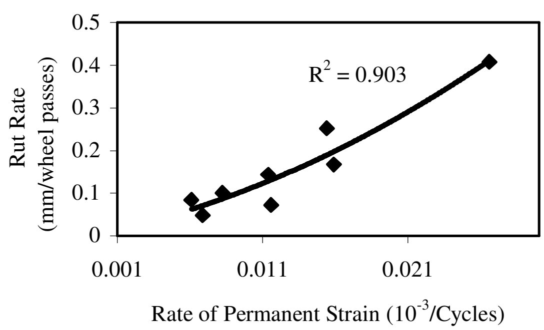


Fig. 10 The Relationship of Rut Rate Measurement between RLAT Results and Wheel Tracking Test Results

Table 3 Correlation Matrix

Test	*RLAT*	*Wheel Tracking*
RLAT		
Ultimate Permanent Strain	1	0.707
Permanent Strain Rate	1	0.903
Wheel Tracking		
Rut Depth	0.707	1
Rut Rate	0.903	1

Table 4 Ranking of Permanent Deformation Performance

Temp (°C)	Mix Comp	RLAT		Rank	WT		Rank
		Permanent Strain	Strain Rate		Rut Depth	Rut Rate	
20	UM	14.374	0.011	2	-	-	-
	M	12.197	0.010	1	-	-	-
30	UM	17.920	0.015	2	0.81	0.252	2
	M	13.223	0.012	1	0.46	0.072	1
40	UM	25.776	0.027	2	1.21	0.408	2
	M	15.650	0.016	1	0.88	0.168	1
60	UM	-	-	-	5.03	2.148	2
	M	-	-	-	2.2	0.852	1

6. CONCLUSIONS

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. Good relationship was found between fundamental test (RLAT) and simulative test (wheel tracking test) in assessing the permanent deformation performance.
5. Both tests RLAT as fundamental test and wheel tracking as simulative test are consistent and have a similar rank.
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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