Permanent deformation characteristics of asphalt concrete containing reclaimed materials

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ABSTRACT: The paper discussed the laboratory investigation of permanent deformation characteristics of asphalt concrete mixes containing reclaimed materials. The reclaimed materials used in this study were reclaimed plastic (HDPE) obtained from chopped plastic milk cartons and Reclaimed Asphalt Pavement (RAP). Reclaimed 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. RAP contents of 30 and 60% were used to modify asphalt concrete mixes. The permanent deformation characteristics of asphalt concrete with and without reclaimed materials were evaluated in laboratory using Repeated Load Axial Test and Wheel Tracking Test at a range of test temperatures. The VESYS model was used to predict rutting characteristics for 10 years ahead. Test results showed that the asphalt concrete prepared using reclaimed materials such as waste plastic and Reclaimed Asphalt Pavement (RAP) were more resistance on permanent deformation over a range temperature.

1 GENERAL INSTRUCTIONS

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 is 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 at high temperatures.

Reclaimed Asphalt Pavement (RAP) as old material in flexible pavement that is removed when road pavement reach the end their usable service live. In the European countries, the use of RAP in bituminous mixes is commonly used in road construction, however the utilization of RAP in Indonesia is not a common practice in bituminous mixes because the lack of knowledge and clear guidelines about RAP. Previous studies showed that the bituminous mixtures containing RAP demonstrated similar characteristics to new hot mixtures, as long as the use RAP in mix is correctly characterized and the mix design is properly done (Pereira et al 2004), even the use RAP in mixtures is more resistant to permanent deformation and improving in mix stiffness modulus (Woodside et al, 2001).

The use of reclaimed materials is a great importance in Indonesia, particularly for reduction cost in road construction and in environmental problems. Reclaimed materials such waste plastic and RAP used in bitumen are a promising prospect for bituminous road construction industry.

The objective in this study is to investigate the permanent deformation characteristics of asphalt concrete containing reclaimed materials such as waste plastic (HDPE) as an additive and RAP.

2 MATERIALS AND PREPARATION

2.1 *The Plastic Milk Carton-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 carton, predominantly composed of High Density Polyethylene (HDPE). Waste plastic milk carton was obtained from local household waste. HDPE milk cartons 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 (Polymerweb.com, 2006).

The chopped plastic milk carton 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 Table 1 and Figure 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.

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	
3 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

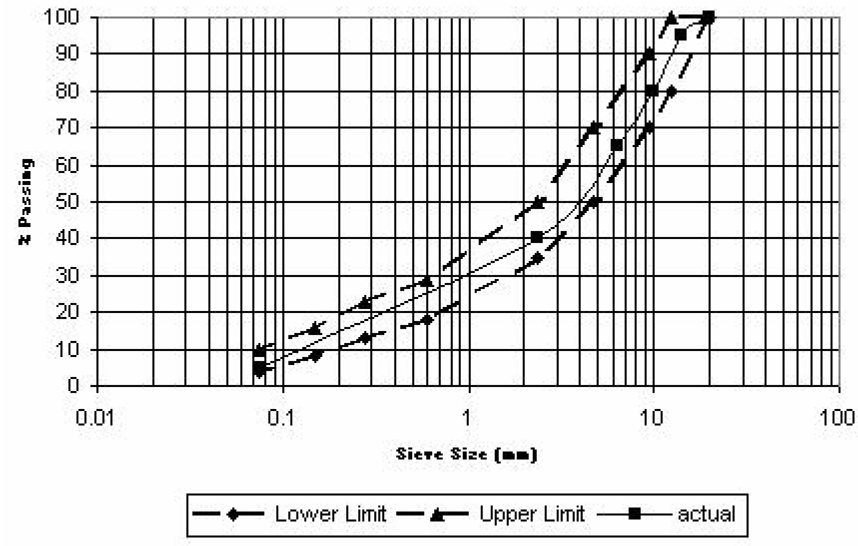


Figure 1. The Grading Curve of Asphalt concrete.

2.3 *Reclaimed Asphalt Pavement (RAP)*

The Reclaimed Asphalt Pavement (RAP) was collected from stockpiled material at Blackmountain Quarry, Belfast belonging to the Lagan Group as shown in Figure 2 . Analysis of the RAP was carried out by LAGAN Bitumen.The bitumen content was determined in accordance with BS EN 12697-1, 2005 and found to be 5.2%.

Bitumen was recovered from the RAP in accordance with BS EN 12697-3, 2005 and assessed for penetration value at 25^{o}C and softening point by Total Bitumen. The penetration was 37 with the softening point being 56.8.

Figure 2. Sampling of stockpiled Reclaimed Asphalt Pavement.

2.4 *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 3 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 (Roberts et al. 1996, Shell, 1990). Further waste plastic content 1.5% (by weight of optimum bitumen content) was selected for more detailed in laboratory permanent deformation characteristics investigation.

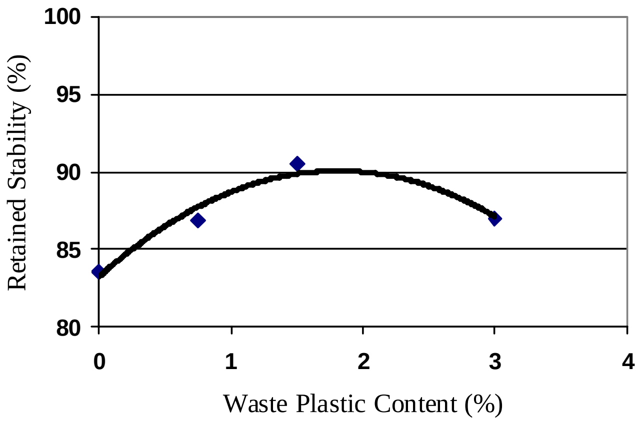


Figure 3. The Effect of Waste Plastic on Moisture Susceptibility.

The RAP content used was 30% and 60%. As recommended by the National Cooperative Highway Research Program (NCHRP report 452, 2001) RAP addition over 25% requires measurement of binder properties and aggregate gradation. The test specimens containing RAP were produced according to mix design procedure described in MS-20 (TAI, 1981).

The code ACUM was used for asphalt concrete using unmodified bitumen; ACM for asphalt concrete using modified bitumen; ACR30 and ACR60 for asphalt concrete using modified bitumen with RAP content 30% and 60% respectively.

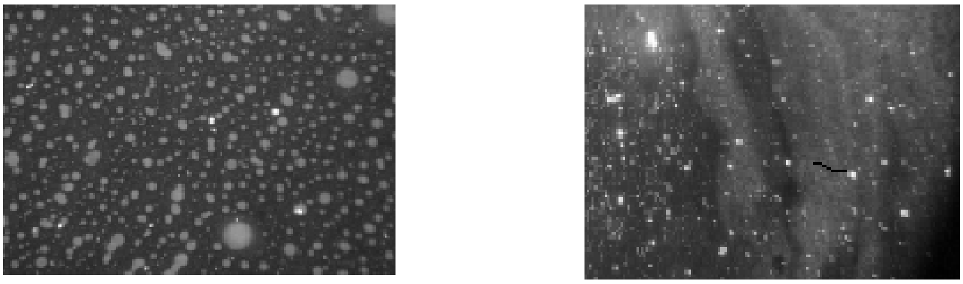
3 PROPERTIES OF WASTE PLASTIC – BITUMEN BLEND

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. The sample was placed under optical microscope to observe its morphology. The results as shown in Figure 4 represent optical micrographs for modified bitumen and unmodified bitumen. It is clear that Figure 4 showed waste plastic dispersed in bitumen.

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

Test	Waste Plastic HDPE - Bitumen Blended			
3.1.1 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 5. 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 (Roberts, 1996).



Modified Bitumen

Unmodified Bitumen

Figure 4. Optical Micrograph for Modified and Unmodified Bitumen.

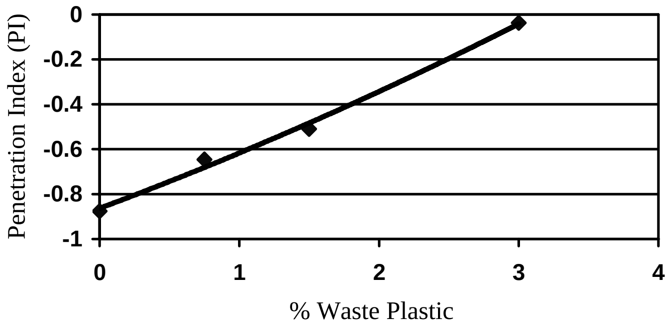


Figure 5. The Effect of Modifiers on Penetration Index of Modified Bitumen.

4 ASSESSING THE PERMANENT DEFORMATION

4.1 *Repeated Load Axial Test (RLAT)*

The specimens used in RLAT were Marshall specimens. In RLAT used in this research using Nottingham Asphalt Tester (NAT) as shown in Figure 6, 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.

Figure 6. Repeated Load Axial Test (RLAT).

4.2 *RLAT Results and Discussion*

Figure 7 showed the effect of temperatures on permanent strain of mixes. As expected, the temperature significantly affected the deformation characteristics 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%.

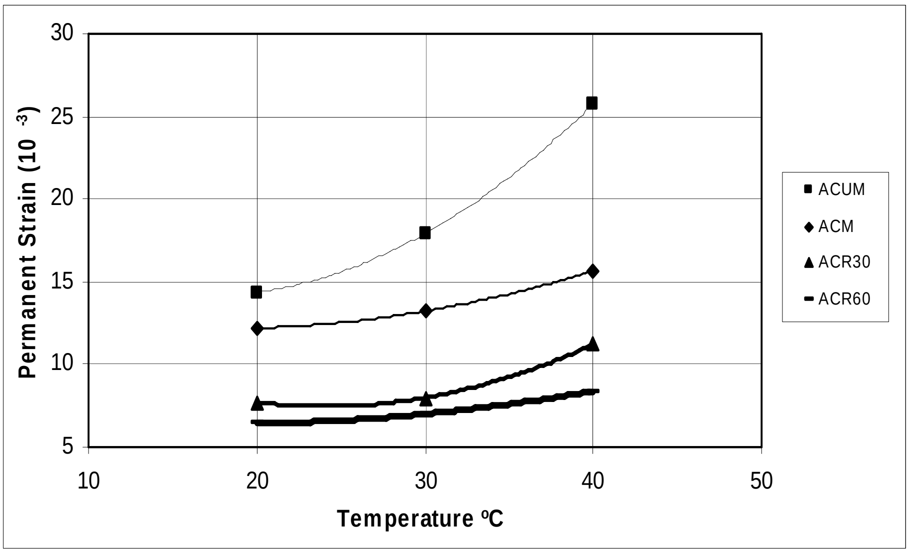


Figure 7. The effect of Temperatures on Permanent Strain for Different Compositions of Mixes Permanent Strains.

4.3 *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, 2004 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^{o}C, 40^{o}C and 60^{o}C respectively. The total wheel-track deformation every minute, in millimeters was recorded by computer, developed over the 45 min of the test.

4.4 *Wheel Tracking Test Results and Discussion*

All specimens were tested using Wessex Wheel Tracking machine under varying temperatures of 30°C, 40°C and 60°C. Examples of wheel tracking test results observed deformation patterns under 60°C for different compositions in asphalt concrete mixes are shown in Table 3

Table 3 Examples of Wheel Tracking Test at 60°C.

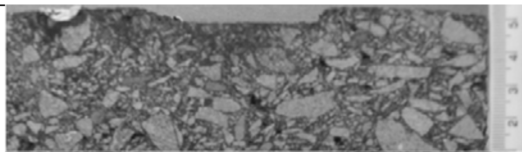
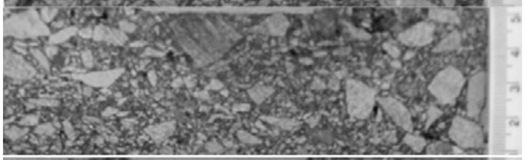
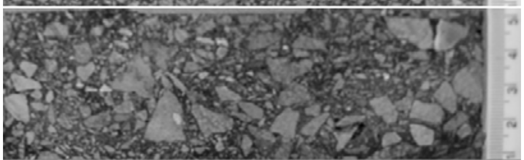
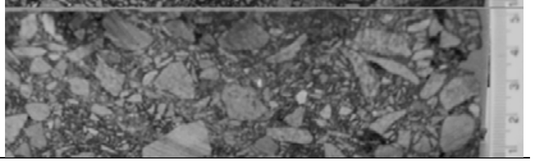
	Asphalt Concrete Mix Compositions	Rutting Profiles after Testing at 60°C
1	Virgin Material + Unmodified Bitumen	
2	Virgin Material + Modified Bitumen	
3	(Virgin Material+RAP30%) + Modified Bitumen	
4	(Virgin Material+RAP60%) + Modified Bitumen	

Figure 8 showed the rut depth of asphalt concrete using reclaimed materials 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 reclaimed materials.

Figure 8 also showed clearly that modified asphalt concrete using reclaimed materials gave improvement in reducing susceptible to temperature as indicated by the slope of rut depth versus temperatures. Compared to conventional mixed, bituminous mixes with composition ACM, ACR30 and ACR60 at the highest temperature (60°C) showed an improvement in decreasing rut depth about 55%, 75% and 80% respectively.

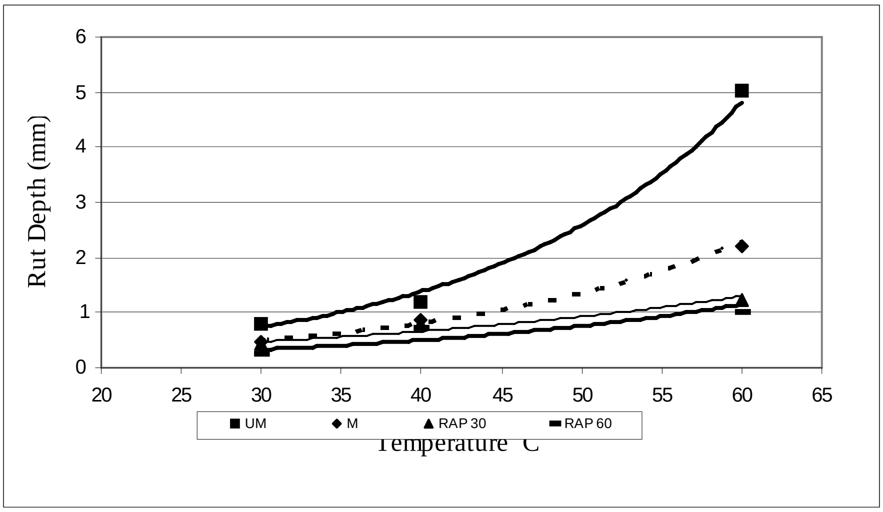


Figure 8. The Effect of Temperature on Wheel Tracking Test Results.

5 THE EVALUATION OF PERMANENT DEFORMATION CHARACTERISTICS USING VESYS

VESYS model was used to evaluate the permanent deformation characteristics on asphalt concrete with and without reclaimed materials. The VESYS 5 computer model is used to predict the structural responses and the integrity of flexible pavement, which developed by Kenis et al. Full details of the VESYS 5 computer model are described in user manual of VESYS 5 (FHWA, 2003).

The two main input parameters in the VESYS 5 rutting model are ALPHA (α) and GNU (μ). These parameters are obtained from the linear regression line when permanent strain and number of load repetitions is plotted on a log-log scale as shown in Figure 9.

The α and μ parameters are determined as follows:

$$\mu = a.b/\varepsilon_r \quad (1)$$

$$\alpha = 1- b \quad (2)$$

where a: Intercept with permanent strain axis; b: Slope of linear regression line and ε_r Resilient strain.

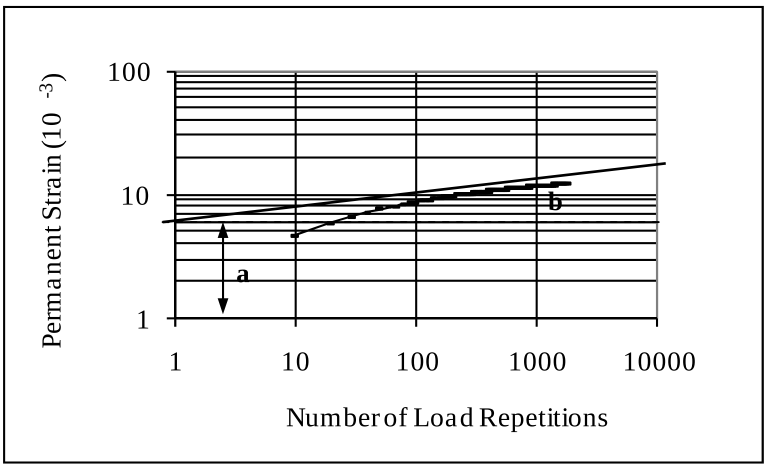


Figure 9. Determination of Linear Regression Constants a and b.

The geometry of pavement layer was selected to evaluate the effectiveness of the effect of reclaimed materials added in mixes for reducing rut depth in surface course under a range temperatures of 20°C, 30°C and 40°C, the thickness used in this case is the cross section of each consisted of a 4 inches (100 mm) bituminous 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 characteristics of asphalt concrete using VESYS 5 model analysis for modified and unmodified asphalt concrete varying temperatures can be seen in Figure 10. As expected, modified asphalt concrete prepared using reclaimed materials have 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. Furthermore, Figure 10 also shows that the large difference in rut depth occurred starting from temperature 30°C and higher temperature.

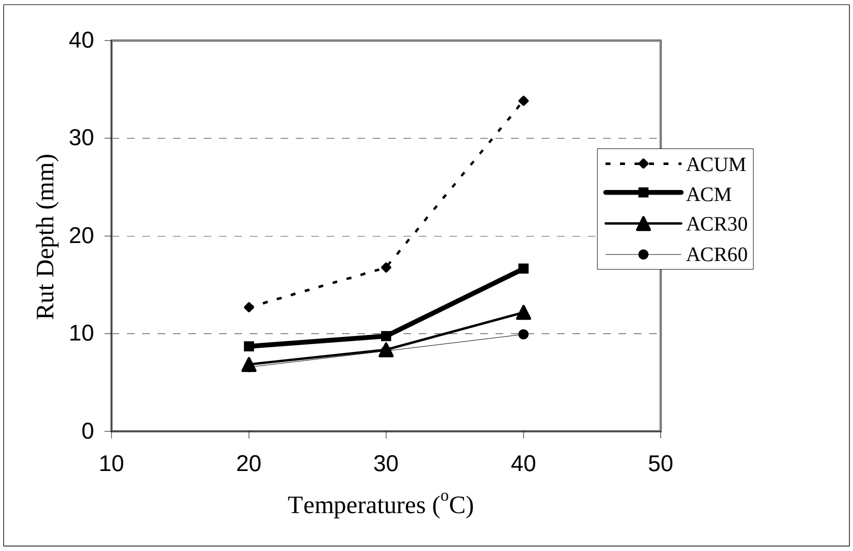


Figure 10. Prediction of Rut Depth Using VESYS 5 at 10th Year Under Varying Temperatures.

Compared to conventional mix, asphalt concrete mixes with composition ACM, ACR30 and ACR60 over the service live 10 years at the maximum temperature testing (40°C) showed an improvement in reducing rut depth about 51%, 64% and 71% respectively.

6 CONCLUSIONS

Based on the results of the experimental investigations conducted on conventional and modified asphalt concrete using reclaimed materials, the following summaries have been drawn:

- The penetration values of modified bitumen were found lower than virgin bitumen but the softening values showed higher than virgin bitumen.
- The addition of waste plastic in binder can increase penetration index values, which mean it can reduce temperature susceptibility.
- The addition reclaimed materials such as waste plastic in binder and Reclaimed Asphalt Pavement (RAP) for asphalt concrete can reduce significantly permanent deformation when tested at higher temperature.
- It is found the same trend of deformation curve between predicted rutting from VESYS analysis and repeated load axial test results.
- The predicted rutting resistances of asphalt concrete using reclaimed materials were significantly superior to resist deformation under varying temperature.

– In general the deformation characteristics of asphalt concrete mixes prepared using reclaimed materials were better than conventional mixes at a range service temperature.

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