THE LABORATORY INVESTIGATION OF HIGH TEMPERATURE FATIGUE OF MODIFIED WASTE PLASTIC-BITUMEN IN ASPHALT CONCRETE

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Abstract
It is well known that the fatigue cracking occurs at an intermediate temperature of around 20°C and many researchers have carried out the fatigue study to generate fatigue regression at temperatures ranging only from 5°C to 30°C. The purpose of this study is to investigate the high fatigue characteristics of asphalt concrete utilizing waste plastic milk bottle (HDPE) as polymer additive over a range temperature of 20°C to 40°C. Waste plastic (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 laboratory fatigue test on asphalt concrete with and without waste plastic (HDPE) was evaluated using repeated load tests at 20°C, 30°C and 40°C under constant stress mode. Temperatures had a significant effect on fatigue performance, which the fatigue performance of asphalt concrete exhibited better at higher temperature. Test results showed that the fatigue performance in term of fatigue life of asphalt concrete using waste plastic-bitumen blend showed higher than conventional mix at a range of temperatures.

Key Words: Modified Bitumen, Waste Plastic, Fatigue Cracking, Asphalt Concrete and High Temperature

Abstrak
Telah diketahui bahwa retak lelah (fatigue cracking) umumnya terjadi pada temperature sedang yaitu di sekitar temperatur 20°C, oleh sebab itu banyak peneliti telah melakukan penelitian fatig untuk mendapatkan garis regresi fatig pada temperatur antara 5°C sampai dengan 30°C. Tujuan dari studi ini adalah untuk mengetahui sifat fatig pada aspal yang mengandung bahan tambah polimer berupa plastic dari botol susu bekas (High Density Poly Ethylene, HDPE) pada temperatur antara 20°C-40°C. HDPE digunakan untuk memodifikasi aspal pen 60/70. Pada studi ini, pengaruh HDPE pada sifat dasar aspal diuji pada variasi temperatur. Uji stabilitas Marshall dilaksanakan untuk menentukan kandungan HDPE optimum dan kadar aspal optimum pada campuran beraspal. Dari studi ini diketahui bahwa kandungan HDPE optimum adalah 1,5% terhadap berat aspal. Uji fatig campuran beraspal yang dibuat dengan dan tanpa HDPE dilakukan dengan uji beban berulang dengan tegangan konstan pada temperatur 20°C, 30°C dan 40°C. Dari pengujian ini diketahui bahwa temperature memberikan pengaruh yang siknifikan pada kinerja fatig. Pada temperatur tinggi campuran beraspal memberikan kinerja fatig yang lebih baik. Dari pengujian ini diketahui pula bahwa pada semua variasi temperatur pengujian, kinerja fatig campuran beraspal yang mengandung HDPE adalah lebih baik dibandingkan dengan aspal konvensional.

Kata kunci: Aspal Modifikasi, Plastik Bekas, Retak Lelah, Campuran, Temperatur Tinggi

1. INTRODUCTION

In developing country such as Indonesia, the traffic volumes and the percentage of heavy truck tend to increase significantly to support the development of the economy. Previous study reported that the composition rate of heavy vehicles in Indonesia, as a ratio of total traffic, is very high, reaching about 50% of the total traffic or more (Binamarga, 2002). The effects of these factors tend to toward increasing pavement deterioration, including fatigue, which it is one of the main modes of flexible pavement distress in surface layer (Brown, 1997). As a result, the road conditions are 60% in fair to good condition and 40% in poor or bad condition (Dikun, 2003).

The temperature in Indonesia as tropical country is higher than in United Kingdom and the United State of America, which pavement temperature in Indonesia is 50℃. This temperature condition contributes the bituminous mix will perform differently under different climatic condition. It is well known that fatigue cracking occurs at an intermediate temperature of around 20℃ or lower, so there is a lack of attention to high temperature of fatigue cracking characteristics of mixtures. Many researchers have conducted to generate fatigue life regression equations at temperatures ranging from 5℃ to 30℃.

The binder has an important role to play in the performance of bituminous materials, particularly in the 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 of several properties such as temperature susceptibility, resistance to permanent deformation and fatigue live (Robert et.al., 1996; Tuncan et.al., 2003 and Shell, 1990) but the polymer additive is an expensive material in Indonesia. Therefore, there is a need to investigate the application of new materials but it has a low cost, such as waste plastic, to improve the asphalt concrete performance.

The objective of this paper is to investigate the effect of waste plastic milk carton added to bitumen on the properties of modified bitumen and to investigate the high temperature fatigue cracking behaviour of asphalt concrete using modified and unmodified bitumen.

2. MATERIALS USED

Bitumen collected from Lagan Bitumen has penetration grade bitumen of 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 used in this study was obtained from local household waste. HDPE milk carton 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 HDPE were 0.5 mm, 0.94 – 0.97 g/cc, 120 – 130^{o}C, 31.35 MPa, and 100%, respectively.

Aggregate used in this study was crushed basalt obtained from Kennedy Quarries, located in sixty miles from Belfast and the properties of aggregate can be seen in Table 1. The filler type used in the asphalt concrete is limestone dust.

3. PROPERTIES OF WASTE PLASTIC (HDPE)- BITUMEN BLEND

3.1 The Plastic Milk Carton-Bitumen Blend

The chopped plastic milk carton 2 x 2 mm^2 in size was blended with bitumen at low speed for about 5 minutes until all of the plastic quantity required was added. The mixture is heated constantly on 160 to170^{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 in the mixture (0.75%, 1.5% and 3% by weight of binder).

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 the softening point test.

3.2 Properties of Waste Plastic – Bitumen Blend

The results of penetration test on waste plastic-bitumen blend under various temperatures (25^{o}C, 30^{o}C, 35^{o}C and 40^{o}C) and the softening point test are shown in Table 2. The penetration values of unmodified and modified bitumen increased as the temperature increased, while the penetration values of modified bitumen at various temperatures were decreased as waste plastic content increased. The softening point of the 60/70 pen bitumen increased as the percentage of waste plastic in bitumen increased.

To determine whether waste plastic was dispersed in the bitumen or not, it can be observed using the optical micrograph.

Figure 1 represents the optical micrographs for modified bitumen and unmodified bitumen. It is shown that waste plastic was dispersed in bitumen.

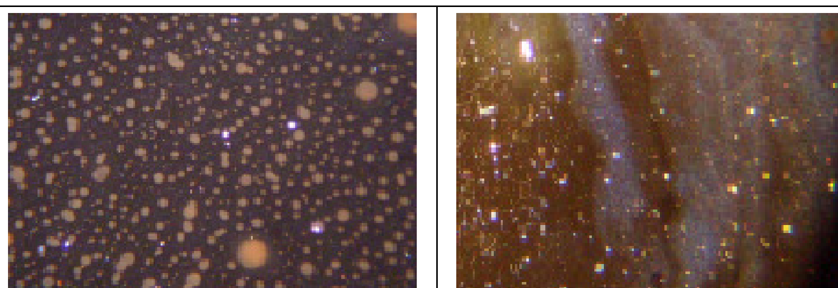
Table1. Properties of Aggregate Used

Property	Standard Method	Basalt	
		Coarse	Fine
Physical Properties			
Apparent Particle Density		2.97	2.92
Oven Dried Particle Density	BS 812 Part 2: 1995	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	

note*) Data from Whitemountain Quarries Ltd, 2003

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



a. Modified Bitumen b. Unmodified Bitumen

Figure 1. Optical Micrograph for Modified and Unmodified Bitumen

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

The Marshall test method was used to determine the optimum bitumen content for asphalt concrete. It was found the optimum bitumen content is 6% (by weight of total mix). Consequently 6% bitumen content was selected for making the specimens for assessing the fatigue cracking characteristics.

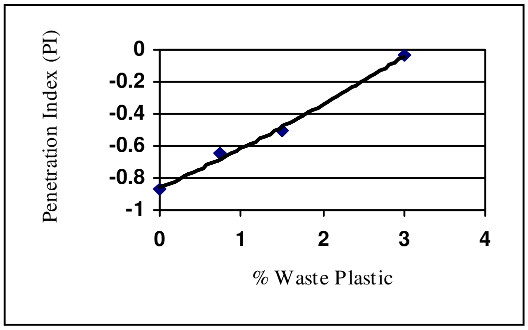


Figure 2. The Effect of Modifiers on PI of Modified Bitumen

4. ASSESSING FATIGUE CRACKING

4.1 Sample preparation

The selection of the optimum waste plastic content used in bitumen was based on the moisture susceptibility test in term of retained stability. The retained stability is the ratio of 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 minutes and not longer than 60 minutes. 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 hours. It was found that the optimum waste plastic in bitumen is 1.5%. These results agree with the previous study results (Robert et al., 1996) where the polymer can be used as anti stripping agent. Consequently waste plastic content 1.5% (by weight of optimum bitumen content) was selected for more detailed in laboratory.

4.2 Indirect Tensile Fatigue Test (ITFT)

Indirect tensile fatigue test used in this research was Nottingham Asphalt Tester (NAT). The test system was capable of imparting 0 to 4 kN through a spherical seating with a rise time between 80 to 160 ms. The deformation is measured by summing the output from two diametrically opposed linier variable displacement transducers (LVDT) resting on loading strips. All testing was carried out under controlled stress conditions with stress levels of 400 to 550 kPa; 300 to 500 kPa and 200 to 350 kPa for test temperatures of 20; 30 and 40°C respectively

Diameter and thickness of the specimens used in this research were 100 mm and 40 mm respectively. The specimens were manufactured using Marshall compaction hammer, according to BS 598 part 107 (1996).

4.3 Test Results and Discussion

Based on visual observation as shown in Table 3, all specimens failed because of excessive deformation. The failure patterns for conventional mix and modified mix appear a similar pattern to each other. An observation of the failure pattern of modified and conventional mixture showed that predominantly (80%) the ideal failure at test temperature 20°C and failure pattern becomes double split at higher test temperature (30°C and 40°C).

The fatigue analysis was performed using the relationship between strain (ε) and fatigue life (N_f) and expressed as:

$$N_f = k_1 \left(\frac{1}{\varepsilon} \right)^{k_2} \qquad (1)$$

Where N_f : Number of Load application to failure; k_1 :Constant depending on the mixture characteristics; ε : Applied strain and k_2 : Regression constant (slope of the curve).

The typical of ITFT test results were load cycles to failure versus tensile strain at range test temperatures of 20°C, 30°C and 40°C as shown in Figure 3 to 5. The Figure 3 to 5 showed that the fatigue lines for both asphalt concrete mix with and without waste plastic seem close to each other at range test temperatures.

The most important variables from the fatigue test are the intercept and the slope of the fatigue lines, k_1 and k_2 respectively. These variables represent the material properties of the fatigue characteristics of the mixture. To examine the effect of waste plastic on fatigue life, both variables k_1 and k_2 were used as input variables on prediction of fatigue life at tensile strain of 100 micro strains (100 x 10^{-6}) using Equation 1. The fatigue life in term of the number of load cycles at tensile strain of 100µ can be seen in Table 4.

It is shown that the use of waste plastic as modifier in asphalt concrete has a higher fatigue lives than a conventional mix at a certain range of test temperature.

Table 3 Fatigue Failure Patterns

Mix Compositions	**Temperature (°C)**		
	20	**30**	**40**
Modified (M)			
Unmodified (UM)			

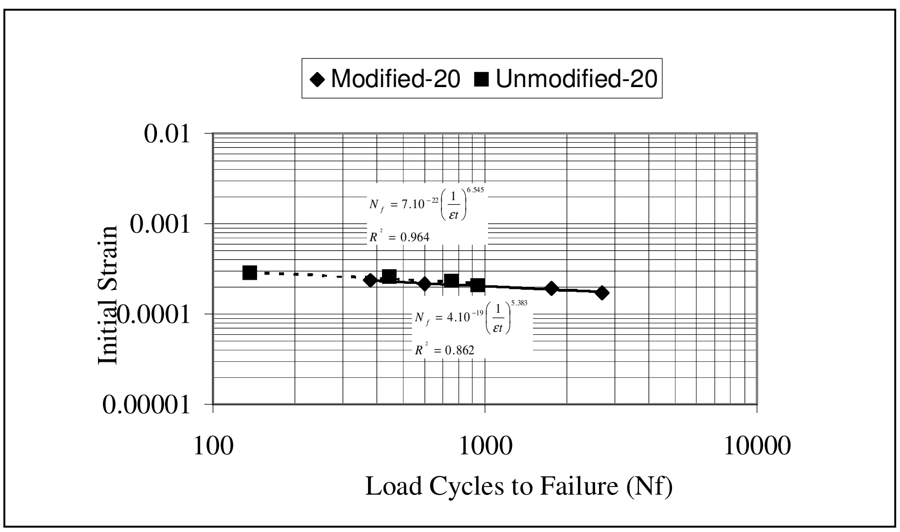


Figure 3. Fatigue Test Results for AC with and without Waste Plastic at 20°C

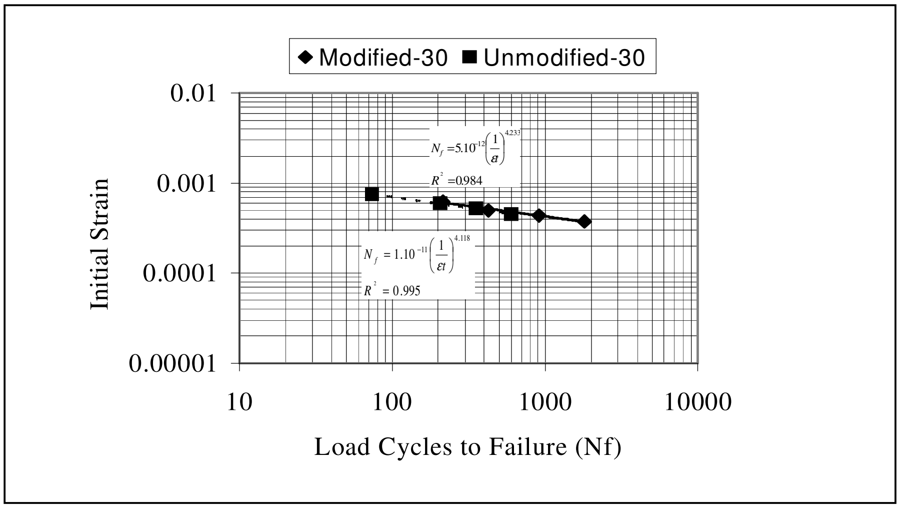


Figure 4. Fatigue Test Results for AC with and without Waste Plastic at 30^{o}C

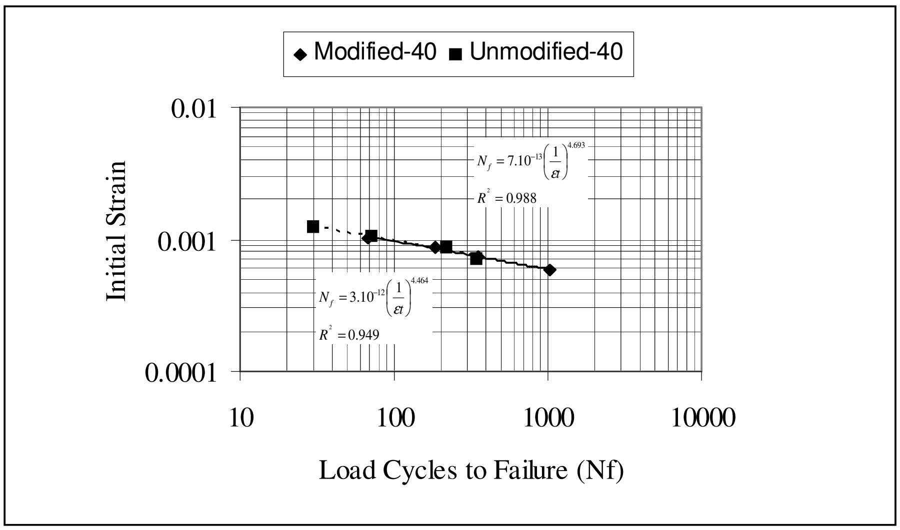


Figure 5. Fatigue Test Results for AC with and without Waste Plastic at 40^{o}C

The effect of test temperatures on fatigue life for all mix compositions is presented in Figure 6 to 7. It is shown that the number of load cycles increases with increasing temperature. The fatigue life of asphalt concrete mix prepared using waste plastic, increases considerably as the test temperature increases. The fatigue lives of plastic modified mixture are 1.17, 1.44 and 1.92 times higher than the conventional mix at test temperature of 20℃, 30℃ and 40℃ respectively. This may be due to the characteristics of bituminous mixtures at higher temperature, then the mixture becomes softer and thus causing the stiffness to decrease, the absorbing the vibration from dynamic load and resulted in delaying crack initiation.

Therefore it could be concluded that the use of modified bitumen using waste plastic in bituminous mixes gave a significant improvement in fatigue life at higher temperature.

Table 4. The Number of Load Cycles at Tensile Strain 100 μ

Temp. (°C)	N_f at ε_t =100 microstrains		Percentage Increase in Fatigue Life Compared to ACUM
	ACUM[1)]	**ACM[2)]**	
20	89797	105462	17
30	296483	427533	44
40	2157353	4137119	92

note: [1)] ACUM = Asphalt Concrete with Unmodified Bitumen
[2)] ACM = Asphalt Concrete with Modified Bitumen

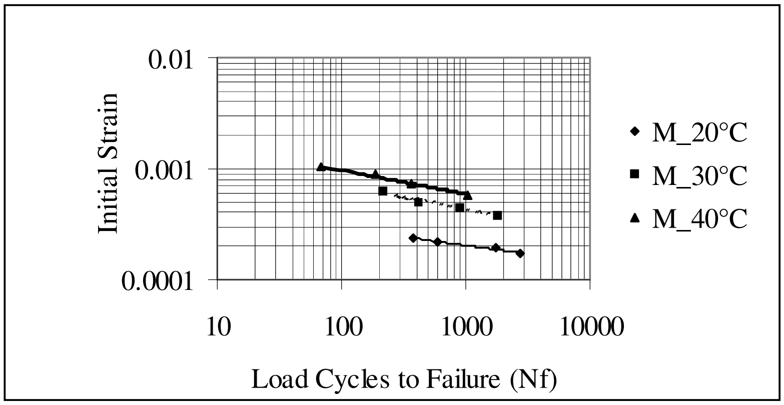


Figure 6. Fatigue Characteristics of Modified AC at Varying Temperatures

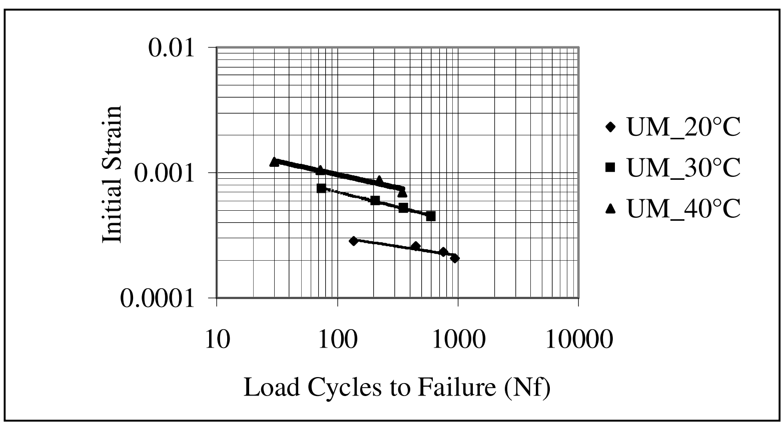


Figure 7. Fatigue Characteristics of Conventional AC at Varying Temperatures

5. CONCLUSIONS

Based on the results of the experimental research, the following conclusions have been drawn:

- The penetration values of modified bitumen were found lower than virgin bitumen but the softening values showed higher than the virgin bitumen.
- The addition of waste plastic in binder can increase the Penetration Index values, means that it can reduce temperature susceptibility.
- The addition of waste plastic in the binder for asphalt concrete could give significantly improvement in fatigue lives when tested at higher temperature.
- It is found that the effect of test temperature gave significantly different form of fatigue behaviour of asphalt concrete.
- In general the fatigue cracking performances of asphalt concrete mixes prepared using waste plastic were better than the conventional mixes at service temperature.

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