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Performance of rutting, stripping and cracking of warm mix asphalt

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Abstract. Hot Mix Asphalt (HMA) is a conventional mixtures and widely used in Malaysia. Emissions of Carbon Dioxide (CO2) during production of HMA due to high temperature give bad impact to the environment. During construction, cool weather is one of the factor that will easily influence the HMA mixtures where it will cause the reduction of temperature during compaction. This factor will affect the compaction process for the pavement which the most important part for road construction. It will reduce the density of the pavement and also the strength which cause shorter life span, rutting, cracking and stripping. Therefore, in this study, Warm Mix Asphalt (WMA) is one of the methods to overcome these issues. This study investigated the performance WMA in term of rutting, cracking and stripping incorporating different percentages of additives namely Evotherm (ET) and Evoflex (EF) with 0.3%, 0.4% and 0.5% by weight of bitumen. These additives were used to lower the mixing and compaction temperature of asphalt mixture. Asphalt mixture with nominal maximum aggregate size 14 mm (AC 14) with 5.3% optimum bitumen content were used in this study. The optimum additive content was evaluated based on the Marshall, Modified Lottman, Indirect Tensile Strength (ITS), and Asphalt Pavement Analyser (APA) tests. The results revealed that 0.4 % ET and 0.3 % EF additives were considered as optimum additive content. Both 0.4 % ET and 0.3 % EF gave better performance in stripping and rutting resistance. However, in cracking performance, 0.4 % ET was more susceptible in cracking compared with 0.3 % EF.

1. Introduction

A sustainable construction becomes main concern in highway industries due to arising global warming all over the world. In Malaysia, for road construction, Hot Mix Asphalt (HMA) is a conventional mixtures and widely used. However, HMA mixture is not considered as a sustainable element because it requires high temperature and produce carbon dioxide during production. Besides, HMA is also prone to moisture-induce damage [1]. Therefore, Warm Mix Asphalt (WMA) is seen as one of the best alternatives to replace HMA and offers numerous benefits to road industries particularly in environmental issue. It could reduce temperature during production and construction, haul the mix longer distances, lower cost, better performance and healthier environment [2-10]. It is reported by Goh et al [11] that WMA contributes for energy savings by 30% with a corresponding reduction in CO^2 emissions of also 30% as compared to conventional HMA.

WMA could reduce the temperatures of production and mixing by reducing mixture viscosity which assisted by introducing several additives such as Aspha-Min, Sasobit, Evotherm, Evoflex and Cecabase

[4,12]. These additives could enhance workability in low temperature during mixing and compaction [5, 13,14]. Evotherm was contained with recycled materials, such as reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) in the asphalt mixtures to improve their workability and reduce compaction efforts [14]. The addition of Evotherm by 0.5 % of the bitumen weight enhanced the ability of bitumen coating to aggregate as it reduces the binder viscosity thus increases the resistance to moisture susceptibility of the mixture [15]. The main contribution of Evotherm in asphalt mixture is its ability to increase the coating of binder to aggregate and at the same time acts as adhesion enhancer by the workability of bitumen [16]. Meanwhile, Evoflex which is the new product from Ingevity gives benefit by improving the low temperature during mixing of asphalt mixture. Evoflex is one of the rejuvenators that functions to restore the aged asphalt to its optimal chemical characteristics for durability, as well as to provide sufficient additional binder to coat new aggregate and to satisfy mix design requirements [11]. A good rejuvenator should not only have superior regeneration and anti-aging properties, but also should have appropriate diffusion.

Reduction of temperature in production causing moisture damage is a main concern when using WMA in terms of aggregate stripping and possibility of insufficient aggregate drying [4]. Coupled with overloading traffic, rutting and cracking issues have also become another crucial aspect for long live pavement performance [17,18]. Therefore, the performance of rutting, stripping and cracking were focused in this study by using two oil-based additives which were Evotherm and Evoflex.

2. Methodology

The investigation was conducted in UTM highway laboratory. Asphalt mixture with nominal maximum aggregate size 14 mm (AC 14) with 5.3 % optimum bitumen content (PEN 60/70) were used in this study incorporating Evotherm and Evoflex as the additives. The source of the aggregates was from Ulu Choh Quarry, Pulai, Johor. The mixture properties were analyzed by Marshall test method. Asphalt Pavement Analyzer (APA), Indirect Tensile Strength (ITS) and Modified Lottman Test were conducted to determine the performance of rutting, stripping and cracking of WMA.

To prepare the sample, binder by blending bitumen and additives; Evotherm and Evoflex (0.3 %, 0.4 % and 0.5 % for each additive by weight of bitumen) were prepared first. Three samples for each percentage were prepared to determine the optimum bitumen content (OBC) for AC14. The temperature used for mixed and compacted the sample were 145 °C and 130 °C respectively. For indirect tensile strength and modified Lottman test, three control samples and three samples for each percentage of additives were prepared. Three control samples and three samples for each percentage of additives for APA samples were prepared by using selected OBC for each percentage of additives for rutting test. All the data collected were analyzed in order to determine the optimum additive contents for WMA and grid analysis was used. Each mixture was scored based on respective performance test.

2.1. Marshall stability and flow test

From the Marshall stability and flow test, the performance prediction measure for the Marshall mix design method can be predicted based on ASTM D6927. The test specimen supports the maximum load at a loading rate of 50.8 mm/ minute in order to measure the stability by using the stability portion. Generally, the load is increased until it reaches a maximum then the load just begins to decrease, the loading is stopped and the maximum load is recorded. During the loading, to measure specimen's plastic flow, an attached dial gauge is used. The flow value is recorded in 0.25 mm increments and at the same time the maximum load is recorded.

2.2. Moisture susceptibility and Indirect Tensile Strength (ITS) test

Tensile Strength Ratio (TSR) is referred as the asphalt mixtures resistance to moisture susceptibility. To determine the value of TSR, Lottman modified test was conducted based on AASHTO T283. According to AASHTO specification, the compacting specimens have to achieve air void level in a range of 6.5 – 7.5 %. Six samples of different condition of asphalt binder are prepared for this test. From the Marshall Mix design, the samples of 100 mm diameter and 60-70 mm thickness were removed from the mould and they were kept at room temperature for 24 hours. In dividing the samples into their subsets, the percentage of air void was determined based on AASHTO T269. Then, the samples were divided into two subsets to make sure that the average air voids are approximately equal.

Dry condition subsets were wrapped in plastic bag and placed in conditioning cabinet at temperature 25 ºC for approximately 2 ± 10 minutes. Subsets under moisture conditioning started with vacuum saturation that contains sample was filled with water until the water level reached approximate about 1 in above the samples surface. Absolute pressure at 13-67 kPa was applied into the vacuum container for 5 to 10 minutes before the saturated, surface dry specimen is weighted in accordance to method of AASHTO T166.

Freeze-thaw cycles were conducted for specimens that achieved degree of saturation from 70-80% the samples were settled for freezing process at temperature of -18ºC for 16 ± 1 hour. The specimens next are placed in water at 60ºC for 24 hours and the water level is to make sure above 25 mm from the surface of the specimens for thawing process. The specimens were took out from the water bath to be wrapped in plastic bag and placed in conditioning cabinet at temperature 25ºC for approximately 2 ± 10 minutes. The thickness of each specimen was measured before it being tested. The specimen was placed between the bearing plates and bearing strips. Load is applied by force excretion onto the bearing plates at constant rate of 50 mm per minute.

The maximum load was recorded until the samples crack and the stability value of the specimens were obtained from the scale. From the stability value, it was converted into maximum load exerted onto the specimen through the equation, $P = (\text{stability}) \times 2.236 \times 9.81$. Indirect tensile strength was measured for all 6 samples to calculate the TSR value.

2.3. Rutting test

Asphalt Pavement Analyzer (APA) was used for rutting performance where AC14 samples were prepared. In this study, the acceptable range of air void is in between 7% ± 1%. The trial sample height was already within the air void range therefore the samples were compacted according to its required height. The number of gyration for this sample mixture 120 nos. The binder and combined aggregate were heated in an oven to the appropriate mixing temperature for the binder to be used. The required temperature was 150 °C for at least 3 hours. The amount of binder required were already weigh and were placed in the oven, then, were poured into the mix. The mixing was begun immediately as well as maintaining the temperature ranging from 130 °C - 140 °C, until the binder coated at the all edges of aggregates. The compaction mould and base plate where placed in an oven as well to preheat at the required compaction temperature for a period of 30 to 60 minutes' prior before compaction. The heated mould and the mixture were rest for a moment before compact the mixture at 120 °C - 125 °C in the gyratory compactor to the specified height rather than a fixed number of gyrations. After the compacting process end, the samples were cooled for at least 30 minutes at room temperature.

To conduct rutting test, a wheel was loaded onto a pressurized linear hose and tracked back and forth over a testing sample to simulate a wheel load. It was designed to simulate actual road conditions by rolling a concave metal wheel over a rubber hose pressurized at 689 to 827 kPa (100 to 120 psi) to generate the effect of various tire pressures. Cylindrical samples of the eight asphalt mix designs were fabricated and compacted to 7 % ± 1 % air voids with the Superpave Gyratory Compactor (SGC). The samples were tested up to 8000 cycles at 60 °C. When the test reached 8000 cycles, the APA stopped and the load wheels automatically retracted. A complete APA rutting evaluation took approximately 2 hours and 15 minutes.

3. Results and discussion

3.1. Marshall test analysis

The samples were prepared to determine the optimum percentage for both Evotherm and Evoflex additives. Stability and flow tests were conducted. Table 1 shows the Marshall test analysis. For Evotherm, only 0.5 % met all the JKR specifications [19] compared to other samples mixture. 0.5 % ET gave the highest in flow value. High flow value indicates less resistance to deform in pavement. For Evoflex, none of them were met all the specifications [19]. However, 0.3% EF recorded the better one which closed to all the requirement compared to others and attained the requirement in flow and stiffness value.

Overall, it can be concluded that 0.5 % ET and 0.3 % EF showed the best result in Marshall analysis where Evotherm additive was performed way better than Evoflex additive. It was because 0.5 % ET showed better in stability, flow, stiffness, VTM, VFA and density performance compared to 0.3 % EF.

Table 1. Marshall test result.

Marshall Parameter	JKR/SPJ/2008 Specification	Additives content						
		Control	ET			EF		
		0%	0.3%	0.4%	0.5%	0.3%	0.4%	0.5%
Stability (N)	> 8000	13873	13111	11202	12026	11988	11617	11661
Flow (mm)	2.0 – 4.0	3.9	4.5	4.3	4.0	4.0	4.8	4.6
Stiffness (N/mm)	> 2600	3575.6	2946.3	2585	3001.5	2955.2	2416.9	2536.8
VTM (%)	3.0 – 5.0	3.1	4.5	5.7	4.8	5.2	5.3	4.6
VFA (%)	70 – 80	79.7	72.3	67.5	71.2	69.2	69	72.1
Density	-	2.338	2.292	2.285	2.296	2.292	2.287	2.307

3.2. Modified Lottman test

Figure 1 illustrates the performance of TSR with different percentages of Evotherm and Evoflex additives. Based on the minimum requirement [18], value of 0.8 was the minimum. Less than that, the mixture will has high tendency of moisture damage. Control sample showed the highest TSR compared to other samples with 1.08. From all the results, obviously only 0.5% ET does not meet the minimum requirement with only 0.74. Meanwhile, 0.3 % ET and 0.5 % EF attained the highest value of TSR with 0.83 and 0.96 respectively. The higher the TSR value gave the better performance to resist moisture damage which can lead to cracking, rutting and stripping failure of the pavement.

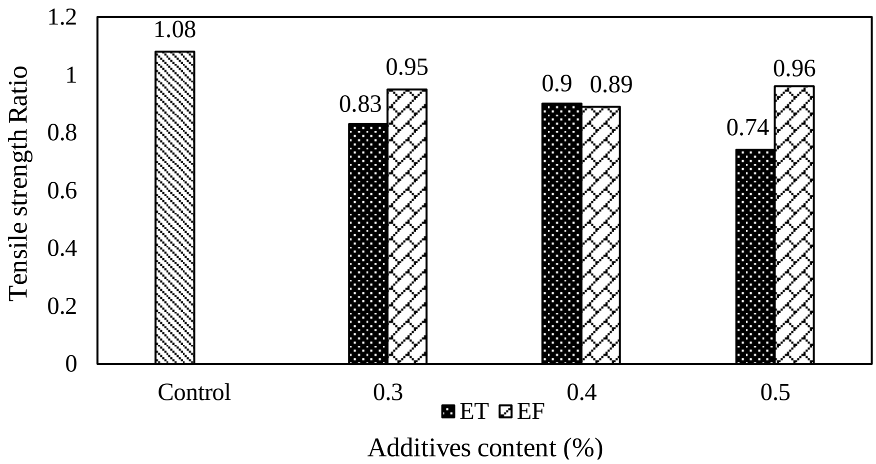

Figure 1. Comparison of TSR with various percentages of Evotherm and Evoflex additives.

3.3. Resilient modulus

For resilient modulus, the samples were conditioned at 25 °C as an indication of resistance to fatigue cracking. Figure 2 shows the resilient modulus's result for all samples. By comparing control sample

(AC14) and warm mix asphalt mixture samples with different percentage of additives content, resilient modulus for control sample had higher than all warm mix asphalt mixture samples. However, the results clearly showed 0.5 % ET and 0.3 % EF had the highest resilient modulus with 1734 Mpa and 1708 Mpa respectively. Meanwhile, both 0.4% ET and 0.4% EF recorded the lowest resilient modulus. Thus, 0.5 % ET had high resilient modulus at 25°C indicates the mixture is more susceptible to fatigue crack but less susceptible to rutting compared to 0.3 % EF.

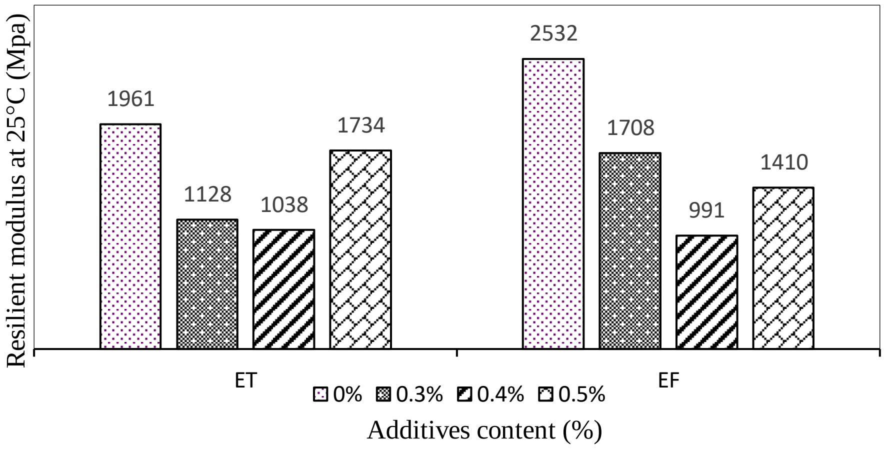

Figure 2. Comparison of Resilient modulus with various percentages of Evotherm and Evoflex additives.

3.4. *Rutting test*

Table 2 presents the results of rutting from the APA test that have been conducted. The results were analyzed based on comparison between different percentages of additives content with control sample (AC14) mixture. The air void for all samples are in acceptable range in between 7 % ± 1 %. The results show that 0.4 % ET and 0.3 % EF have the lowest percentage of rutting reduction with 13.7 % and 1.7 % respectively. Meanwhile, 0.3 % ET and 0.5 % EF gave the highest percentage of rutting reduction of 64.7 % and 43.4 % respectively. It meant, both 0.4 % ET and 0.3 % EF had the highest rutting resistance. It can be concluded, performance of Evoflex additive in rutting resistance was better compared to Exotherm additive.

Table 2. APA Test Result.

Additives content (%)		Air void (%)	Rut Depth (mm)	Rut Difference (%)
Control	0	7.18	2.40	-
ET	0.3	7.3	3.96	64.7
	0.4	7.19	3.42	13.7
	0.5	7.02	2.64	22.8
EF	0.3	7.24	2.68	1.7
	0.4	7.16	2.31	14.0
	0.5	7.36	3.31	43.4

3.5. *Selection of optimum percentage of additives based on the performance ranking*

Ranking of performance test was carried out to identify the optimum percentages of Evotherm and Evoflex additives content as shown in Table 3. 0.4 % ET was the highest ranking because of the better performance in TSR and rutting test compared to others and followed by 0.3 % and 0.5 %. Meanwhile, for EF, 0.3 % was the first ranking because of the best performance in all tests and followed by 0.5 % and 0.4 %.

In nutshell, 0.4 % ET and 0.3 % EF were the optimum percentage of additives content to be added in WMA to present better performance.

Table 3. Ranking of performance test for different percentages content of Evotherm and Evoflex additives.

Additives Content (%)	ET			EF		
	0.3	0.4	0.5	0.3	0.4	0.5
Marshall	2	3	1	1	3	2
ITS	2	3	1	1	3	2
TSR	2	1	3(failed)	2	3	1
Rutting	3	1	2	1	2	3
Ranking	2	1	3	1	3	2

4. Conclusion

Based on all the results and analysis, it can be summarized as 0.4 % ET and 0.3 % EF were the optimum percentage of additives content. 0.4 % ET had better in stripping and rutting performance but susceptible in cracking resistance compared to others mixture. Meanwhile, 0.3 % EF recorded the best performance in cracking, stripping and rutting resistance. Thus, 0.4 % of Evotherm and 0.3 % of Evoflex were recommended in WMA.

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