Warm Mix Asphalt Surfacing Performance for Different Aggregate Gradations with Cecabase RT Additive

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Abstract. Hot mix asphalt (HMA) surface course normally consists of wearing and binder layers, with different aggregate gradations. Hot mix asphalt (HMA) mixtures are traditionally produced at relatively high temperatures of between 150°C to 180°C. Warm Mix Asphalt (WMA) offers a sustainable solution to the problem by lowering the production temperature and energy requirements. However, to be accepted as an alternative to HMA, the performance of WMA must be comparable or better than HMA. The objective of this research is to investigate the performance of WMA wearing and binder course in terms of stiffness and moisture resistance, using Cecabase RT as warm mix asphalt additive. Different concentrations of Cecabase RT were added to determine the optimum percentage Cecabase RT. Marshall method was used to produce all samples investigated and analysis as carried out on the samples. Stiffness and moisture resistance tests were carried out to measure the performance of the mixes. The stiffness modulus values obtained for WMA mixes are higher than HMA mixes, indicating better stiffness. In addition, all the mixes investigated achieved the required minimum TSR value of 80%. It can be concluded that warm mix asphalt using Cecabase RT is comparable in terms of stiffness and moisture resistance to conventional HMA and could be a sustainable alternative to the conventional HMA mix as it can be produced at lower temperatures.

1. Introduction

A typical flexible pavement structure in Malaysia consists of hot mix asphalt surface course (HMA), unbound granular base and sub-base overlying the subgrade. The HMA surface course normally consists of wearing and binder layers, with different aggregate gradations. HMA is currently produced around 160°C and compacted at temperatures of about 130°C, depending on the mix type and binder grade [1]. The high temperature is required so that the binder is sufficiently fluid for proper aggregate coating and compaction [2]. Warm Mix Asphalt (WMA) is an alternative asphalt mixture to HMA as it can be produced at much lower temperatures of about 105°C to 135°C [3], thus saving energy costs in heating, but achieving a level of performance that is similar to or better than HMA [3].

There are various categories of WMA technologies currently available for use in asphalt pavement construction including organic additive products such as Sasobit and Asphaltan B, water-bearing Zeolite products such as Aspha-Min and Advera WMA, water-based foaming process products such as WAM Foam and the lastly, emulsion-based process products such as Evotherm [4].

The application of WMA can have a significant cost savings and reduce the environmental impact on highway projects due to the lower temperature requirements [5]. It was reported that the manufacturers and materials suppliers achieved energy savings in the order of 30%, with a
corresponding reduction in CO₂ emissions of 30%. The advantages of the WMA include reduced fuel cost, reduced mixing and compaction temperature, early site opening, lower plant wear, lesser aging of binder, reduced fumes and emissions, improve workability, and extended paving window [6]. However, since warm mix asphalt is produced and compacted at temperatures lower than the conventional hot mix asphalt, there is a possibility that its performance might not be as good as HMA. For example, due to the lower production temperature, its moisture resistance might be lower than that of HMA, causing moisture-induced damage. In addition, its stiffness in terms of resilient modulus might also be affected.

Stiffness is an important parameter for flexible pavements thickness design and used in the mechanistic analysis of pavement response under dynamic traffic loads. According to Huang [7], stiffness is computed based on recoverable strain under repeated stress. Stiffness is also used to study the rutting behaviour of pavement. Stiffness test in laboratory tests usually is measured by applying a haversine waveform having the loading time (duration) of 0.1s and rest period of 0.9s.

Moisture-induced damage is defined as the weakening or eventual loss of adhesive bond, usually in the presence of moisture between the aggregate surface and the asphalt cement in the mixture [1]. The main mechanism of moisture-induced damage in asphalt pavement is the loss of cohesion (strength) and stiffness of the asphalt film, and the failure of the adhesive bond between aggregate and asphalt in conjunction with the degradation or fracture of the aggregate [8]. The objective of this study is to investigate the performance in terms of stiffness and moisture resistance of warm mix asphalt for two different aggregate gradations commonly used in Malaysia using Cecabase RT additive.

2. Methodology

Laboratory work was carried out to evaluate the stiffness performance and moisture susceptibility for warm-mix asphalt (WMA) using binder of penetration grade 60/70 with Cecabase RT additive at mixing temperature of 135°C. Cecabase RT is a surfactant type, water-free additive used to produce WMA [9]. AC14 and AC28 gradations using granite aggregates as shown in Table 1 and bitumen of penetration type 60/70 were used for this study based on the Public Works Department of Malaysia’s Standard Specification for Road Works. Marshall mix design method in accordance with ASTM D1559 was used to prepare the samples and to determine the optimum binder content of the AC14 and AC28 mixes [10].

| Mix Designation | AC14 | AC28 |
|-----------------|------|------|
| B.S Sieve       | % Passing By Weight | % Passing By Weight |
| 28.0 mm         | -    | 100  |
| 20.0 mm         | 100  | 72 - 90 |
| 14.0 mm         | 90 – 100 | 58 – 76 |
| 10.0 mm         | 76 – 86 | 48 – 64 |
| 5.0 mm          | 50 – 62 | 30 – 46 |
| 3.35 mm         | 40 – 54 | 24 – 40 |
| 1.18 mm         | 18 – 34 | 14 – 28 |
| 425 µm          | 12 – 24 | 8 – 20 |
| 150 µm          | 6 – 14  | 4 – 10  |
| 75 µm           | 4 – 8   | 3 - 7   |

Bitumen modification was carried out by adding Cecabase RT at percentages of 1% to 3% at increments of 0.5% by weight of bitumen using a mechanical stirrer to ensure adequate blending between the bitumen and Cecabase RT with the temperature controlled at 135°C (the stirrer was provided with a temperature control system). After the modification of the bitumen, the bitumen and aggregates were mixed and compacted at a temperature of 120°C.

Moisture resistance test was carried out to ensure that the asphalt mix achieved adequate resistance to moisture damage for use as a pavement surfacing. The resistance to moisture damage is determined from the Modified Lottman test using the indirect tensile strength (ITS) Test based on AASTHO T283. Three compacted specimens from each mixture (HMA and WMA) were conditioned in air at 25°C for 24 hours prior to testing the ITS (ITSₜₐ) and another three specimens were submerged in 60°C water
for 24 hours followed by 2 hours in 25°C water before testing the ITS (ITS<sub>wet</sub>). The samples were then placed between the steel loading strips by loading the samples at constant head rate (50 mm/minute vertical deformation at 25°C) and maximum compressive force required to break the specimens were recorded. The potential for moisture-induced damage was determined based on the Tensile Strength Ratio (TSR). The TSR was calculated as the ratio of the ITS<sub>wet</sub> to the ITS<sub>dry</sub>.

The stiffness was determined using the indirect tensile repeated load test. The test used the UTM-5P machine. The stiffness test was conducted to measure the modulus of the design asphalt mixtures. All samples were conditioned for 3 hours at a temperature of 25°C. The test was performed in accordance with ASTM D 4132. Three pulse repetition periods was applied, 1000 ms indicates low traffic volume road (high speed), 2000 ms for medium traffic volume road while 3000 ms is high traffic volume road (slow speed). The compacted Marshall samples for the different types of asphalt gradation was subjected to diametrical repeated loading of 900 N and two points was taken on different axis at each sample.

Evaluation and analysis of the above test results will lead to the understanding of the effect of WMA with the additive (Cecabase RT) on the stiffness and moisture resistance performance of the WMA. This can be carried out by comparing the properties of the WMA with properties of the conventional HMA (control sample).

3. Results and Discussions

3.1. Marshall Test Results

The purpose of Marshall mix design is to determine the optimum bitumen content (OBC) for AC14 and AC28. The samples were compacted using 75 blows of the Marshall hammer. Data from the Marshall test were used to plot five parameters that are Stability, Flow, Bulk Density, Voids Filled with Bitumen (VFB) and Air Voids in Mix (VIM) versus the bitumen content. The optimum bitumen content and cecabase content was then determined.

3.1.1. Optimum Bitumen Content (OBC)

Determination of OBC for this study was obtained by referring to PWD Malaysia’s method. Table 2 shows the OBC results that have been obtained from Marshall test results graph by averaging the five parameters. The OBC obtained for AC 14 and AC 28 was 4.9% and 4.3% of bitumen content respectively. The values at OBC were checked for Stability, Flow, Bulk Density, Voids Filled with Bitumen (VFB) and Air Voids in Mix (VIM) for compliance with the PWD Malaysia’s requirements.

| Parameter                        | OBC for AC 14 | OBC for AC 28 |
|----------------------------------|---------------|---------------|
| Peak of stability curve          | 4.25          | 4.50          |
| Peak of bulk density curve       | 5.6           | 4.60          |
| Flow equals to 3 mm              | 4.4           | 3.70          |
| VFB equals to 75% (AC14), 70% (AC28) | 5.5         | 4.50          |
| VIM equals to 4.0% (AC14), 5% (AC28) | 4.75        | 4.5           |
| Average                          | 4.9           | 4.3           |

3.1.2. Optimum Cecabase Content

Using the OBC obtained from AC14 and AC28, WMA14 and WMA28 specimens that contain Cecabase RT was prepared. The amount of Cecabase RT to be added was determined by varying the amount of Cecabase RT used at the optimum bitumen content. The amount of Cecabase RT used was 0.2%, 0.25%, 0.3%, 0.35% and 0.4%. The optimum amount of Cecabase RT to be used was determined at 0.3% for AC14 and 0.26% for AC28 by weight of bitumen based on the amount that complied with PWD Malaysia’s specification requirements on the volumetric properties of HMA. The result is tabulated in Table 3. The Marshall stability, flow, VFB and VIM for WMA14 and WMA28 as shown in Table 4 complied with the PWD Malaysia’s specification requirement.
Table 3. Determination of additive content

| Parameters                           | AC14 Optimum Cecabase Content (%) | AC28 Optimum Cecabase Content (%) |
|--------------------------------------|-----------------------------------|-----------------------------------|
| Peak of stability curve              | 0.32                              | 0.24                              |
| Peak of unit weight curve            | 0.29                              | 0.23                              |
| Flow equals to 3mm                   | 0.225                             | 0.23                              |
| VIM equals to 4.0% for wearing       | 0.24                              | 0.23                              |
| VFB equals to 75% (AC14), 70% (AC28)| 0.39                              | 0.35                              |
| Average                              | 0.3                               | 0.26                              |

Table 4. Comparison of specification requirement for WMA at 0.3% Cecabase content

| Parameters            | PWD Malaysia's specification | WMA14 | WMA28 |
|-----------------------|-----------------------------|-------|-------|
| Marshall stability    | >8000N                      | 15100 | 25000 |
| Flow                  | 2-4 mm                      | 3.6 mm| 3.6 mm|
| VFB                   | 70-80% (AC14)               | 74    | 65.2  |
|                       | 65-75% (AC28)               |       |       |
| Air void (VIM)        | 3-5% (AC14)                 | 3%    | 3.9%  |
|                       | 3-7% (AC28)                 |       |       |

3.2. Stiffness Performance Results

Figure 1 shows the stiffness graph for pulse repetitive periods of 1000 ms, 2000 ms and 3000 ms. The WMA28 and AC28 mixes have the highest modulus value for all pulse repetition periods compared to WMA 14 and AC14 mixes. For the pulse repetitive period, for all mixes, the modulus values for each mix for the 1000 ms pulse period is always higher than pulse periods of 2000 ms and 3000 ms. This indicates that higher volume, faster moving vehicles produce higher resilient modulus, compared to lower volume, slower moving vehicles that decreased the modulus value. The results showed that the addition of Cecabase can improve the stiffness of asphaltic concrete mixes as indicated with the higher modulus values for the both WMA 14 and WMA 28 mixes.

![Figure 1. Comparison of Stiffness values for HMA and WMA](image)

3.3. Moisture Susceptibility Results

Indirect tensile strength test was carried out to evaluate the moisture resistance of the mixes. Figure 2 shows the result of ITS obtained for HMA and WMA samples. The results shows that the ITS values
decreased after moisture conditioning. It could be seen that both HMA samples (AC14 and AC28) have higher values than WMA (WMA14 and WMA28) for both dry and wet condition. In addition, the larger gradation (AC28 and WMA28) has higher ITS values for both dry and wet samples.

**Figure 2.** Results for ITS for HMA and WMA

Figure 3 shows that the TSR value for both HMA and WMA mixes. The HMA has a higher TSR value compared to WMA for both types of aggregate gradation. The highest TSR value is achieved by AC28, followed by AC14, WMA28 and WMA14. According to PWD in Malaysia specification, the minimum requirement for TSR value of 80%. Therefore, as the values for TSR for all mixes are above 80%, these mixes are acceptable as the minimum value was attained. The results indicate that HMA is less susceptible to moisture-induced damage compared to WMA. However, WMA still have the ability to resist moisture-induced damage since the value of TSR obtained is more than 80%.

**Figure 3.** Comparison of TSR values for HMA and WMA
4. Conclusion
This study has shown that the use of Cecabase additive can produce WMA that met the requirements for Marshall properties of conventional HMA based on PWD Malaysia’s Specification for Road Works. This shows that WMA is suitable to be used as pavement surfacing, equivalent to that of the conventional HMA. The WMA mixes also attained higher resilient modulus values, indicating better stiffness for the pavement structure. The TSR value for WMA met the minimum requirements of AASTHO T283, indicating that the design WMA mix with Cecabase used in this study is able resist to moisture-induced damage. It can be concluded that the use of Cecabase additive have the advantages of reducing the mixing temperature, thus producing a more energy efficient mix without compromising the performance of the mix for pavement surfacing.

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