Laboratory Performance of Warm Mix Asphalt (WMA) with Chemical Based Additive

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Abstract

Warm mix asphalt (WMA) is a technology used in road construction that shows the potential of improving energy efficiency by reducing the temperature production and application on site. In general, WMA refers to the process of pavement production at temperature lower than conventional hot mix asphalt by the addition of additives. In this study, the effects of chemical based additive-liquid surfactant to the binder properties and mixture performance were evaluated. The materials used were bitumen penetration grade 80/100, aggregates of granite and chemical based additive-liquid surfactant with recommended doses of 0.4%. The experimental works included physical tests of aggregate, binder tests (dynamic shear rheometer, viscosity test, penetration and softening point) and mixture performance tests (indirect tensile strength test, moisture sensitivity test, indirect tensile stiffness modulus test and creep test). The outcomes showed that the addition of liquid surfactant had slightly changed the properties of modified binder. The modified bitumen for warm mix asphalt indicated high consistency and lower softening point than ordinary bitumen. Warm mix asphalt mixtures also showed better results in term of strength, stiffness and lower rate of permanent deformation. However, in moisture sensitivity test, the tensile strength ratio of warm mix asphalt was slightly lower than control. Tensile strength ratio value of control obtained as 88.41% compared to warm mix asphalt, 80.66%. As the conclusion, the addition of liquid surfactant had assisted the warm mix asphalt to perform as well as hot mix although it was produced at lower temperature, except for moisture resistance.

Keywords: Warm Mix Asphalt, chemical based additive, performance evaluation

1.0 Introduction

Nowadays, the environmental issue is become the most important challenges for society due to the over-exploitation, increased populations and consequently, degradation of natural sources. Energy efficient technologies are developed to response to the problems and also considered in construction phases of asphalt mixes for road construction. Over the year, Hot Mix Asphalt (HMA) is the common technique that been used in the road construction industry and produced at 160ºC [1]. The high temperature can emitted the pollution dust, particulate matter (PM), fumes and variety of gaseous to environment such as carbon monoxide, nitrogen oxides and sulphur dioxide [2-4]. These gases contribute to the global warming problems.

Instead of that, a new technology called Warm Mix Asphalt (WMA) that aiming on improving energy efficiency by reduction temperature of production and lowering emissions. According to Asphalt Institute, WMA is a modified HMA mixture that is produced, placed and compacted at a 10 – 40º C lower than the conventional HMA mixture, which is the temperature range of 140º C to 180º C [5]. As WMA is an environmental friendly technology, the benefits claimed for WMA are including less burner fuel required to heat the aggregates, lower emissions at the asphalt plant, reduction on polluting emissions, less bitumen aging during construction which contribute to the extending the life of the road and faster opening to traffic [1,6-7].

Refer to Vaitkus et.al [5], there are 3 main types technology of WMA that generally used in worldwide; foam bitumen, organic additives and chemical additives. The foam technology is whether by water or adding natural or synthetic zeolite into the asphalt mixture. Meanwhile, the additive is based on 2 types which are organic or chemical with the purpose to reduce the bitumen viscosity [2]. Most researchers used the additive such as Sasobit (organic type) and Aspha Min (foaming type). However, there are limited studies conducted on warm mix asphalt with liquid surfactant additive. This is because the manufacturer does not provide the detailed ingredient of the additive. Thus, the researcher cannot explain the reaction and the process occurred during using this additive. Therefore, the aim of this study is to investigate the characteristic of warm mix asphalt (WMA) using liquid surfactant. In specific, the objectives including evaluating the rheological properties of modified bitumen by liquid surfactant additive, to determine the moisture susceptibility and to evaluate the performance of WMA mixture in term of strength, stiffness, creep and rate of permanent deformation.

Laboratory researches have shown that liquid surfactant achieved highest stability in mixture AC 16 PD(crushed dolomite and gravel) when the amount of 0.3% by the weight of binder was used [5]. Lee and Kim [8] reported that the WMA mixture with 0.4% of Cecabase RT which is in liquid was ranking at eight out of ten products (Cecabase RT, Sasobit, Evotherm J1, Sasobit, Aspha-min powder, Aspha-min granular, Advera WMA, Rediset WMX, HMA control and WMA control) using bitumen PG 70-34. This ranking obtained regarding overall results of indirect tensile strength test, dynamic modulus and repeated load test.

The rest of the paper is organized as follows: the next section review the materials and methodology used for experiment. Section 3 focused on the result and analysis, while section 4 is the conclusion.

2.0 Materials and Methods

2.1 Materials

The potential of warm mix asphalt technology with liquid surfactant was conducted at Highway and Transportation Laboratory, Universiti Tun Hussein Onn Malaysia. All materials (aggregate, bitumen and additive) used locally. Aggregate of granite and bitumen penetration grade 80/100 from Kemaman Bitumen Company Sdn Bhd, located at Telok Kalong Industrial Area, Kemaman, Terengganu used as the main material in producing asphalt material. Additionally, liquid surfactant was used as additive to produce the warm mix asphalt. The recommended amount of additive as much as 0.4% from binder weight that was adopted from the manufacturer. It is an oil-based proprietary formulation. The physical state of the liquid is brown color with a strong smell. The liquid was mixing with binder using mechanical stirrer at a speed of 1000 rpm for 3 minutes. The aggregate of granite was mixed according to JKR/SPJ/2008 for ACW 14. Table 1 and 2 respectively show the gradation and properties of aggregate.

Ταβλε 1: Γραδατιον λιμιτ οφ ΑΧΩ14 [9]

Sieve Size, mm	Specification
20	100
14	90-100
10	76-86
5	50-62
3.35	40-54
1.18	18-34
0.425	12-24
0.150	6-14
0.075	4-8

Ταβλε 2: Ενγινεερινγ προπερτιεσ οφ αγγρεγατε

Properties		Value
Specific Gravity	Bulk	2.71
	SSD	2.73
	Apparent	2.77
	Effective	2.76
Soundness,%	19 to 9.5mm	0.63
	9.5 to 1.5um	6.07
Sand Equivalent,%		49.62
Flakiness Index,%		12.17
Fine Aggregate Angularity,%		54.17

2.2 Asphalt Binder Characterization

The binder testing conducted in 3 conditions- unaged, short term aged and long term aged. The conditions described three critical stages during binder's life as its original state-unaged, after mixing and construction, which was stimulated using Rolling Thin Film Oven Test ASSHTO T179 [10] for short term aged and after in-service aging which stimulated using pressure aging vessel AASHTO R28 [11] for long term aged. Basic properties of binder such as penetration-ASSHTO T49 [12] and softening point-ASSHTO T53 [13] were evaluated using different amount of liquid surfactant. The viscosity also conducted in order to obtain the mixing and compaction temperature for sample preparation. The testing procedure was referred to AASHTO T316 [14].

2.3 Sample Preparation

Sample for hot mix asphalt mixture prepared by heating the aggregate for 4 hours and bitumen 80/100 was heated for 1.5 hours at the temperature in the oven. The melting bitumen was then poured into the heated aggregate in the mixer bucket. Table 3 shows the temperature used for sample preparation process. Aggregate and asphalt were mixed for 60 seconds. Warm mix asphalt also fabricated using same method like HMA except the binder. HMA used fresh bitumen meanwhile warm mix asphalt used modified binder. Liquid surfactant was added into the mixture using wet process.

Wet process is a process where the additive was mixed with heated bitumen and then, poured into the heated aggregate in the mixer bucket. All the specimens produced at same optimum bitumen content of 5.1% and compacted with the number of design gyrations is 125 for air void 4±1% and 20 gyrations for 7±1%.

Ταβλε 3: Τεμπερατυρε οφ Ματεριαλ Πρεπαρατιον φορ Μιξτυρε

Material	Type of Mixtures	
	HMA	WMA
Asphalt Temperature	145 º C	145 º C
Aggregate Temperature	155 º C	125 º C
Mixing Temperature	140-145 º C	115-125 º C
Compaction Temperature	135-145 º C	100-125 º C

2.4 Mixture Testing

Four tests were conducted in order to evaluate the performance-related characteristics of laboratory production samples. The tests included indirect tensile strength, stiffness modulus test, creep test and moisture sensitivity test. Table 4 shows the summary about the testing.

Ταβλε 4: Περφορμανχε τεστ χηαραχτεριστιχσ

Test	Parameters
Moisture Sensitivity	▪ Testing temperature:25ºC ▪ Dry and wet specimens ▪ Loading rate:50mm/minute ▪ Specimen with air void 7±1%.
Indirect tensile strength	▪ Testing temperature: 25ºC ▪ Dry specimens ▪ Loading rate:50 mm/minute ▪ Specimen with air void 4±1%.
Indirect stiffness modulus	▪ Testing temperature: 25ºC ▪ Dry specimens ▪ 5 pulse ▪ Specimen with air void 4±1%.
Creep Test	▪ Testing temperature: 30ºC ▪ Dry specimens ▪ 1800 cycles ▪ Specimen with air void 4±1%.

3.0 Results and Discussion

3.1 Binder Analysis

The testing started with binder test. Binder was mixed with different dosage of additive. Table 5 shows the penetration value of liquid surfactant at 0.4% was slightly higher than without additive (control) and 0.6% for all conditions. Refer to ASSHTO T49 [12], higher values of penetration indicate softer consistency. The value in the table is the mean of three points penetration and maximum difference between highest and penetration is 4. The results show that the trend of the penetration value was decreased with the increasing percentage of liquid surfactant. The bitumen characteristic is become harder as it was aging. For softening point, control sample need the higher temperature to soften or melt compared to the modified binder.

Ταβλε 5: Βασιχ προπερτιεσ οφ βινδερ

Conditions	Additive Amounts	Testing	
		Penetration, mm	Softening Point,°C
Unaged	0%	85.27	46.5
	0.4%	95.3	41.5
	0.6%	91	37.5
Short Term Aged	0%	56.3	48
	0.4%	62	43.5
	0.6%	61	42
Long Term Aged	0%	21.3	56.5
	0.4%	30.67	52.5
	0.6%	26.67	51.5

Then, the viscosity test using Brookfield rotational viscometer equipment was used to determine the ability for pumping, coating and placing the asphalt binder [15]. Then, the important output from this test was the temperature for mixing and compaction. The mixing and compaction temperature was determined by using a plot of viscosity versus temperature. Temperature that corresponds with binder viscosities of 0.17 ± 0.02 Pa·s was selected as a mixing temperature and 0.28 ± 0.03 Pa·s as compaction temperature. This test was conducted at three temperatures; 135ºC, 150ºC and 165 ºC. The unit of viscosity is Pascal seconds (Pa.s). Table 6 shows the mixing and compaction temperature reduced as the liquid surfactant content increased. However, the reduction is not achieved the requirement needed for warm mix asphalt technology. Therefore, the temperature for mixing and compaction of warm mix asphalt was taken as lower about 30ºC than control. The mixing temperature and compaction temperature for hot mix asphalt used 165ºC and 155ºC. Meanwhile, temperature for mixing warm mix asphalt mixture used as 135ºC and compaction temperature 125ºC.

Ταβλε 6: Προδυχτιον τεμπερατυρεσ φορ διφφερεντ δοσεσ οφ λιθυιδ συρφαχταντ

Temperature,ºC	Doses of Liquid Surfactant(%)				
	0	**0.2**	**0.3**	**0.4**	**0.5**
Mixing	165	163	160	158	158
Compaction	156	154	152	151	151

3.2 Moisture Sensitivity Test

Resistance to moisture of the mixture was conducted according to AASHTO T-283 and measured by means of tensile strength ratio value (TSR). TSR is obtained from the indirect tensile strength (ITS) value of wet condition over the dry condition. Three specimens for each mixture with the saturation level about 55%-80% used for subjecting to indirect loading The sample for testing prepared for dry (unconditioned) and wet (conditioned) with air void content is 7% ± 1.The higher air void contents is due to allow the water seeps into voids and then measured how give effects to the mixture. Table 7 shows that the HMA mixtures have slightly higher value of TSR compared to WMA. It can be noted that the TSR value for both type of mixture have passed the minimum requirement value of TSR as 80% as set by Superpave. The higher value of TSR values typically indicated that the mixture will perform well respect to resistance of moisture damage. Hurley and Prowell [17] also pointed out the reduction compaction temperature may lead to the increasing potential of moisture damage.

Ταβλε 7: Ρεσυλτσ οφ τενσιλε στρενγτη ρατιο

Condition	Tensile Strength (kPa)	
	HMA	**WMA**
Dry	247.48	244.61
Wet	218.80	197.29
Tensile Strength Ratio (%)	88.41%	80.66%

3.3 Indirect Tensile Strength

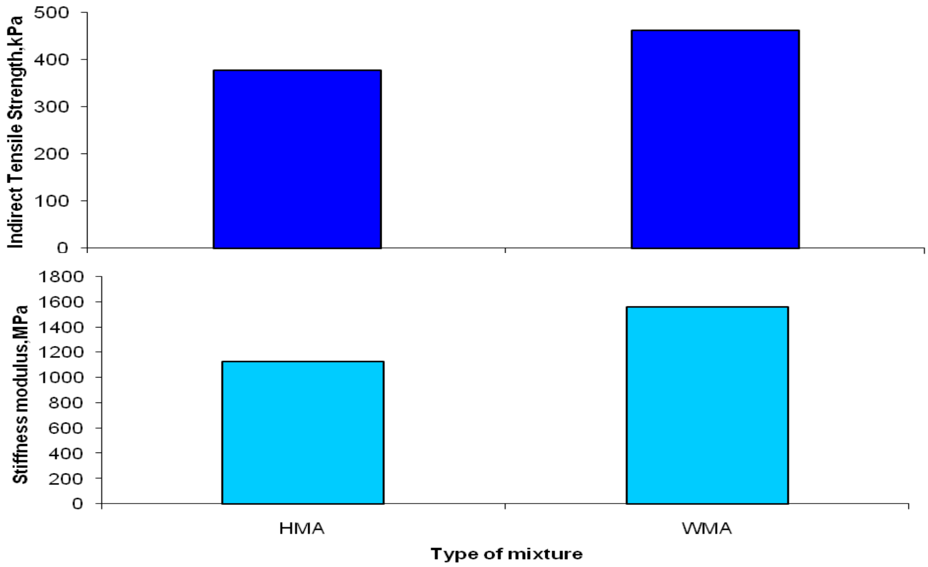
The indirect tensile strength of specimens was measured at the testing temperature of 25ºC and at the loading rate 50 mm/min by using Universal Testing Machine and it is a destructive test. This test is very useful in predicting crack in a mixture and also used to determine moisture sensitivity value. The bar chart in Figure 1(a) compares the strength for HMA and WMA. It clearly shows that the tensile strength test of warm mix asphalt sample is slightly higher than control HMA mixture. Here HMA shows 377.84 kPa and WMA shows 463.38 kPa. This result indicated that although the warm mix asphalt was produced at the temperature lower than hot mix asphalt, the liquid surfactant was improved and enhances the bonding of binder with aggregate.

3.4 Stiffness Modulus Test

Stiffness modulus was obtained by using the indirect tensile stiffness modulus (ITSM) test and it is a non-destructive test. The test was performed by Universal Testing Machine (UTM) at the temperature of 25ºC with air void content 4% ± 1. Stiffness is defined as unaxial stress divided by the corresponding strain [16]. The result of stiffness modulus as in Figure 1(b) shows that the warm mix asphalt with liquid surfactant is higher than hot mix. Stiffness for HMA recorded as 1126 MPa and WMA recorded as 1565 MPa. The liquid surfactant added in binder enhanced the compaction to the desired air void levels at lower temperature with the assistance of additive.

(a)

(b)



Φιγυρε 1: Ρεσυλτσ οφ ινδιρεχτ τενσιλε στρενγτη ανδ ινδιρεχτ τενσιλε στιφφνεσσ μοδυλυσ

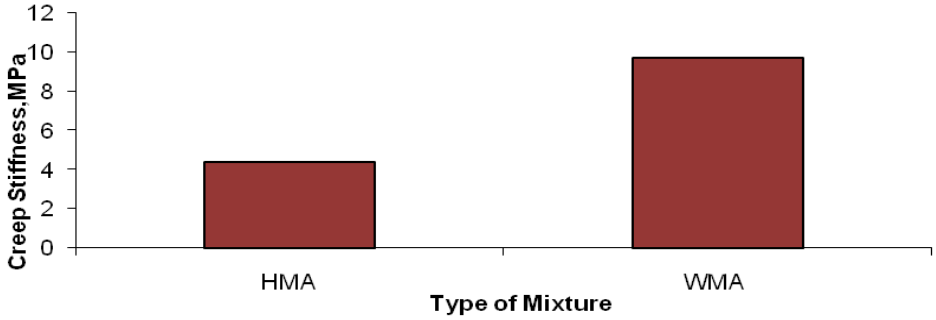
3.5 Creep Stiffness

The deformation resulting from repeated loading can be simulated in the laboratory using creep test. In this study, dynamic creep test was used and it can measure the rate of permanent deformation and creep stiffness of both types of asphalt mixture. Dynamic creep test by using UTM machine involved the total of 1800 cycles. Higher value of creep stiffness indicated better rutting resistance. The result in Figure 2(c) clearly shows that the mixture of warm mix asphalt has the better rutting resistance. HMA recorded as 4.37 MPa and WMA recorded as 9.7MPa.

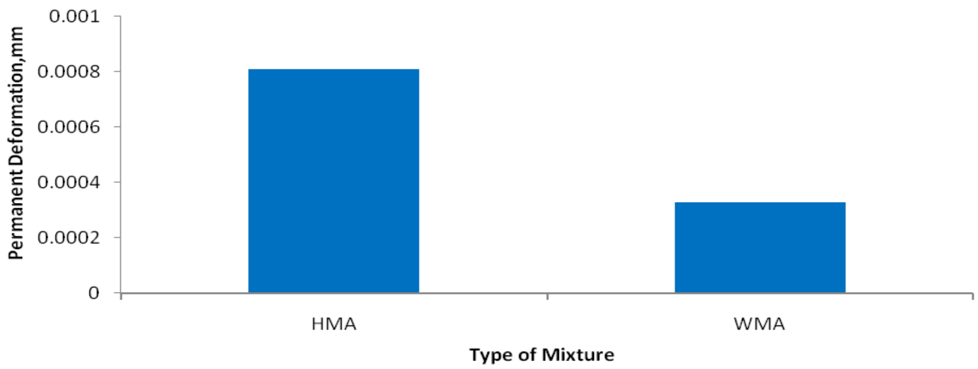
3.6 Rate of Permanent Deformation

The prominent feature of creep test is it can used to predict the rate of permanent deformation. The accumulation of repeated load results the increasing of permanent deformations [15]. Warm mix asphalt mixture shows the lower rate of permanent deformation which is 0.00033 mm per cycle compared to hot mix asphalt with the rate as much as 0.00081 mm per cycle as shown in Figure 2(d).

(c)



(d)



Φιγυρε 2: Ρεσυλτσ οφ χρεεπ στιφφνεσσ ανδ ρατε περμανεντ δεφορματιον

4.0 Conclusions

Generally, in this limited study it was found that the using of liquid surfactant can improve the performance of the warm mix asphalt although it was produced at the lower temperature than conventional. However, these data is the preliminary results and need the extensive investigation. The evaluation of modified binder showed that penetration was slightly higher and thus, the softening point is lower or softer than control binder. The viscosity of modified binder showed only slightly reduction and higher failure temperatures than control. In the moisture susceptibility test, the WMA shows the lower tensile strength ratio compared to control. The main reason is due to the reduction temperature during compaction. Meanwhile, in other performance test, WMA exhibited the good results. Thus, these findings can conclude that liquid surfactant can improve the performance of the warm mix asphalt despite its lower temperature production except for the moisture resistance. In process to validate the research finding herein, additional research needed with various gradation and different bitumen types. Additionally, the performance testing such as rut depths, fatigue test or dynamic modulus can be conducted as to collect the detailed data testing for chemical based additive of liquid surfactant.

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