Laboratory Evaluation of Warm Asphalt Emulsion Mixture

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Abstract**—**The technology of warm mix asphalt (WMA) with asphalt emulsion mixture under energy conservation, carbon reduction, and cost reducing by way of temperature control, is introduced by this study in order to change the traditional hot mix asphalt (HMA). The study used dense-graded aggregate with three nominal maximum aggregate sizes (NMAS) of 9.5mm, 12.5mm and 19mm is evaluated by stability, indirect tensile strength, moisture sensitivity and permanent deformation test. The results show that the stabilities are satisfied by the specification requirements and indirect tensile strengths of tensile strength ratios are higher than agency requirement of 80%. Based on two-way analysis of variance (ANOVA), the stability, tensile strength ratios (TSR) and permanent deformation values by different aggregate types have no significant effect. WMA with asphalt emulsion can be an alternate for pavement construction.

Keywords**—**Warm mix asphalt, Asphalt emulsion, Energy conservation

I. INTRODUCTION

Pavement uses HMA for roadway construction called flexible pavement are more than 90% around the world. The most of advantage is that flexible pavement can be used for traffic within less than 24 hours after construction. Moreover, the machinery for flexible pavement is continually developed and modified. Thus, it is no doubt that the HMA plays the mainstream of the materials for pavement used. Nevertheless, HMA mixture would cause high temperatures which depend on the grade of asphalt such as the grade of AC-10 preheating about 120°C -155°C for mixture [1]. In addition, the price of the international crude oil raised causes the price of the asphalt and ignition oil going up.

Nowadays, temperature grows up and climate changes year by year as result of global warming. One of the main reasons is the carbon dioxide emission. How to overcome global warming effect by means of energy conservation and carbon reduction is one of the important subjects and one of the government's important administrative policies. WMA, a new-type mix asphalt technology, which has the characteristics of environmental protection, energy conservation and good workability, is from Europe. Compared with HMA, the properties of the WMA are same as the HMA. WMA, a new-type mix asphalt technology which has the characteristics of environmental protection, energy conservation and good workability, is from Europe. The WMA technology developed in Europe allows a reduction in the temperatures at which asphalt mixes are produced and placed. In general, WMA produces at temperatures 20°C to 55°C lower than typical HMA in which carbon dioxide is reduced about 50% and burning fuel is saved about 1.5kg when produce one tone HMA [2]. The benefit to producing WMA is the reduction in energy consumption by burning fuels to heat traditional HMA at the production plant and also reduction in emissions from burning fuels, fumes, and odors generated at the plant and the paving site required [3-11]. The WMA technology improves workability at lower temperatures and also allows WMA to act as HMA. Moreover, WMA technologies have the potential to be beneficial during cold-weather paving or when mixtures must be hauled long distances before placement. Since WMA can be compacted at lower temperatures, more time is available for compaction.

The mechanism of these technologies is the additives which reduce the viscosity of the asphalt binder at a given temperature that is a lower temperature for fully coated aggregate than what is traditionally required in HMA production [12]. Thus, under the point of energy conservation, carbon reduction, and cost reducing by way of temperature control, the WMA with asphalt emulsion mixture was evaluated. In this study, three dense-graded aggregate of NMAS of 9.5mm, 12.5mm and 19mm is tested, and asphalt emulsion with chemical additive used as a binder is analyzed by cross-sectional scanning electron microscopy (SEM).

II. MATERIALS AND TEST METHODS

A. Aggregate, Binder and Mix Design

Crushed river stone used as aggregate was obtained from a local quarry. Three NMAS of 9.5mm, 12.5mm and 19mm, as shown in Table I, were used for specimen mixture. Cationic rapid setting (CRS-1) asphalt emulsion met the specification requirement of the ASTM D2172 with 5% dispersed chemical additive was used as a binder and 2% (the weight of aggregate) Type I Portland cement was used as mineral filler. The dispersion of asphalt emulsion was monitored by SEM observation.

The properties of crushed river stone aggregate are shown in Table II. Aggregate with 2% cement was batched in oven at temperature of 100^{o}C for one day and then mix with asphalt

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emulsion in accordance with Marshall mix design procedure with 75 blows on each side of cylindrical samples (ASTM D6926-06), optimum asphalt emulsion contents (OAEC) of WMA were determined in accordance with ASTM D6927-06.

B. Marshall Stabilities

The testing samples with the OAEC were mixture and compacted with 75 blows on each side of cylindrical samples in accordance with ASTM D6926-06. The samples allowed one day, seven days, and twenty eight days for curing. After immerged 60°C water bath for 30 minutes, the samples were processed by Marshall stability test.

TABLE I
AGGREGATE GRADATION FOR MIXTURE

Sieve Size (mm)	Percent Passing		
	NMAS 19.0 (mm)	NMAS 12.5 (mm)	NMAS 9.5 (mm)
19.0	95	100	—
12.5	—	95	100
9.5	68	—	95
4.75	50	59	75
2.36	36	43	50
0.30	12	13	15
0.075	5	5	6

TABLE II
THE PROPERTIES OF CRUSHED RIVER STONE AGGREGATE

Properties	Aggregate	Specification
Bulk specific gravity, coarse	2.745	-
Bulk specific gravity, fine	2.530	-
Unit weight (kg/cm^3)	2012	-
Absorption (%)	1.45	-
L.A. abrasion (%)	20.2	<40
Sodium soundness (5 cycles) (%)	9.22	<12
Elongated (%)	0.69	>0.67
Flat (%)	0.68	>0.67

C. Indirect Tensile Strength and Moisture Sensitivity

The indirect tensile strength was determined in accordance with ASTM D 4123. The values of the tensile strength at optimum asphalt content were used for the control values for moisture sensitivity testing. The samples of each graded aggregate were tested in accordance with AASHTO T-283. According to the standard test method, two or more samples for each graded aggregate were saturated in water by a vacuum. The vacuum is required until the saturation reaches 55% to 80% or 10 minutes (if the 55% of saturation cannot be obtained). After that, the samples are placed in a 60±1°C water bath for one day and, finally, placed in 25±0.6°C water bath for twenty minutes. The control or unconditioned strength was obtained using the indirect tensile strength of the respective sample after the one-day, 7-day and 28-day curing. Thus, the tensile strength ratios (TSR) were determined by conditioned strength divided by control strength.

D. Permanent Deformation

The permanent deformation test (rutting test) determines the rut depth of samples under repeated loads. The rutting test was performed following GDT-115, developed by Georgia Department of Transportation. This testing method, utilizing the Asphalt Pavement Analyzer, determines rutting susceptibility of WMA mixtures in dry condition. The samples fabricated by the Marshall compactor were 150±0.5mm in diameter and 75±0.5mm in height. The rutting test was performed using a 3.5kg/cm^2 wheel load at a test temperature of 40±1°C for the dry conditions. The rut depth was measured at 500, 1000, 2000, 3000, 4000, 6000, and 8000 load cycles. After one-day, 7-day and 28-day curing, the samples were placed in the testing chamber for three hours, until the temperature of the samples reached 40±1°C. After the initial height of the sample measured, the test was started and the rut depth was recorded at the required numbers of cycles until 8000 cycles. The aim is to evaluate the resistant of asphalt emulsion mixture against permanent deformation in the form of rutting.

III. RESULTS AND DISCUSSION

A. Asphalt Emulsion Test Results and SEM Observation

The asphalt emulsion used as a matrix binder is the type of CRS-1as shown in Table III. The Aggregate or/and cement mix with the CRS-1 can lead to an emulsion-breaking reaction [13]. Thus, a chemical additive was added for dispersion. The chemical additive is a kind of surfactant which is the polymer reaction of olefins/cyclic olefins-maleic anhydride copolymers with methoxy polyethylene glycol amines. The mechanism is the outer edge of micro cells of asphalt drop to absorb the surfactant molecules to prevent flocculation and coalescence when moisture of emulsion from being sucked away by the aggregate and cement. The surfactant can also reduce the viscosity of asphalt emulsion and the surface tension between the interfaces of materials by which the interface energy can be degraded to enhance the stability of attaching to the material interface. Therefore, the surfactant is used as the isolation layer outside the liquid cells of CRS-1 so as to avoid the forming of stickiness resulting from emulsion-breaking effect which tends to prevent aggregate and cement with the asphalt emulsion mixture during the mixing process.

In Table III, the CRS-1 with 5% additive is within the specification requirement. The SEM observation results are shown in Fig 1. The surfactant molecules surround the outside layer of asphalt drops which repulses each other as a result of the asphalt drops dispersion homogenous as shown in Fig 1.

B. Mix Design Results

he Marshall mix design The mix design results shown in Table IV indicate that OAECs are 9.5% for the NMAS of 9.5 mm and 8.5% for the NMAS 12.5 mm and 19 mm. In Table IV, the three aggregates of stability, flow, air void (VTM), void in mineral aggregate (VMA), and void filled with asphalt (VFA) are satisfied by the specification requirements, except for the VTM of NMAS of 9.5mm which is slightly higher than the value of the specification.

C. Marshall Stabilities

The samples with OAEC mixtures were tested by different curing time. Compared the Marshall stability with curing time as shown in Fig 2, it indicates that the Marshall stability increases with an increase in curing time and the one-day average stabilities from 1032kg to 1264kg can satisfy the requirement of heavy traffic design criteria. The Marshall stability at a 28-day curing can reach 2533kg~3118kg which is more than two times of one-day curing. The Marshall stability is increased by curing time and it then can take the accumulation of traffic loading increased by time. From the stability values, the asphalt emulsion for WMA used is a candidate material substituted for HMA.

TABLE III
TEST RESULTS OF THE ASPHALT EMULSION

Properties	Specification	CRS-1	CRS-1 with 5% surfactant
Specific gravity	-	1.03	1.02
Viscosity, Saybolt Furol at 50°C	20-100	92	36
Particle charge test	Positive	Positive	Positive
Sieve test, %	0.1 max	0.08	0.03
Residue by distillation, %	60 min	65.8	62.7
Sieve Content, %	0.3 max	0.25	0.13
Penetration at 25°C (100g, 5s)	100-250	120	120
Stability (1 day)	1% max	0.43	0.26
Storage Stability (5 days)	5% max	1.06	0.72
Ductility at 25°C, cm	40 min	49.4	50.3

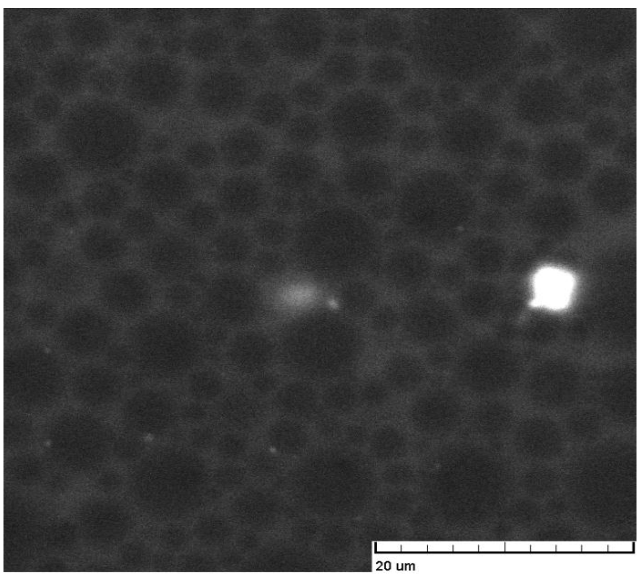

Fig. 1 SEM image for CRS-1 with 5% additive

TABLE IV
MIX DESIGN RESULTS (ONE-DAY CURING)

NMAS	OAEC*	VTM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (0.25mm)
9.5mm	9.5%	5.19	17.11	69.69	1221	9.6
	Specification	3-5	>15.0	65-75	800	8-14
12.5mm	8.5%	4.30	16.08	73.28	1264	9.4
	Specification	3-5	>14.0	65-75	800	8-14
19mm	8.5%	4.69	15.15	69.00	1274	13.5
	Specification	3-5	>14.0	65-75	800	8-14

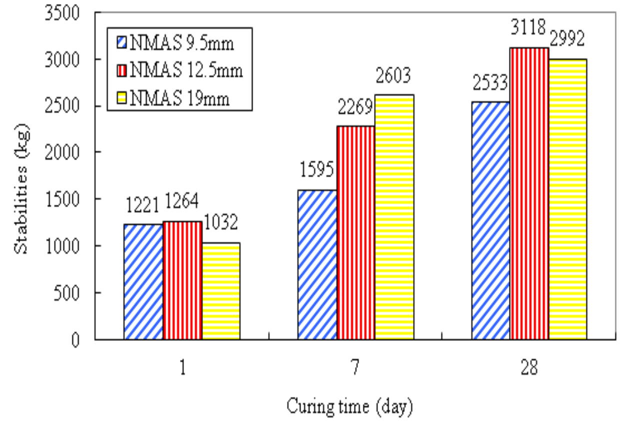

Fig. 2 Marshall Stabilities

D. Indirect Tensile Strength and Moisture Sensitivity Test Results

The results of indirect tensile strength test are displayed in Table V. As can be seen, tensile strength increases with an increase in curing time and NMAS 19 mm has the greater values than the others. TSR determined by conditioned indirect tensile strength divided by control indirect tensile strength. The typical minimum TSR value of HMA is 80% for acceptation. The TSR values presented in Fig. 3 indicate that the Portland cement enhances resistance to moisture damage and raises TSR to acceptable levels. Comparisons of the TSR of NMAS shows that the NMAS 19 mm has the maximum values and the NMAS 9.5 mm has a minimum values in different curing time.

TABLE V
INDIRECT TENSILE STRENGTH TEST RESULTS

NMAS	1-day curing		7-day curing		28-day curing	
	Control Strength (kg/cm^2)	Conditioned Strength (kg/cm^2)	Control Strength (kg/cm^2)	Conditioned Strength (kg/cm^2)	Control Strength (kg/cm^2)	Conditioned Strength (kg/cm^2)
9.5mm	1.98	1.65	3.76	3.26	7.52	6.11
12.5mm	3.68	3.43	4.26	3.72	7.65	7.37
19mm	3.67	3.45	4.32	3.95	8.09	7.86

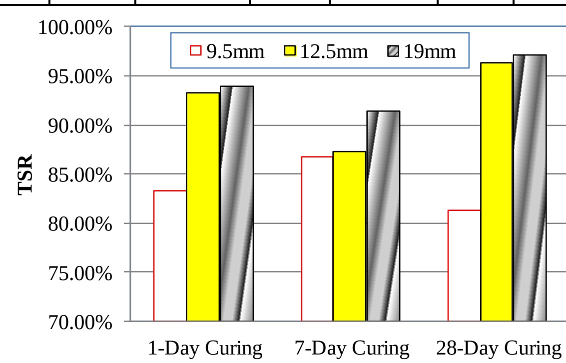

Fig. 3 TSR values for NMAS and curing Time

E. Permanent Deformation Test Results

The results of the average deformation of each sample at 8000 load cycles are shown in Fig. 4. As can be seen, the samples with 1-day curing have the highest rut depths and samples run in 28-day curing have lower rut depths than those in the other. In general, the internal friction between aggregate particles providing the ability of deformation resistance, plastic flow can be minimized by using large size aggregate, angular and rough textured coarse and fine aggregates. The value of permanent deformation is depended on the mixture composition and its component materials. Due to Portland cement used as mineral filler, the stiffness of WMA is increased as rut depth decreased. Therefore, the curing time is important factor for resistant deformation.

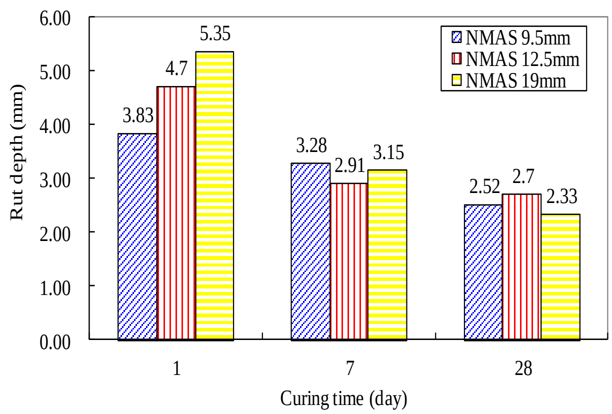

Fig. 4 Permanent deformation test results

F. Two-way ANOVA Results

To determine the statistical significances on the effect of stabilities, TSR and permanent deformation at different NMAS, a ANOVA test was performed, which was done to determine if the treatments were significant at a certain confidence limit by the F-test. The F-test is used to determine if the regression relationship between the variances obtained from test is statistically significant. In the same manner, the p-value is used to test if the relationship between the variances obtained from test is linear at a level of significance of 0.05. In general, the p-value is the smallest level of significance that would lead to the rejection of the null hypothesis. Therefore, for p-values less than the level of significance of 0.05, the null hypothesis is rejected; thus, the relationship is significant.

The ANOVA results shown in Table VI indicate that the stability, TSR and permanent deformation values by different aggregate types have no significant effect at a confidence limit of 95% (F > F0.05 and p-value > 0.05). However, the stability and permanent deformation have significant effect at different curing time.

TABLE VI
TWO-WAY ANOVA TEST RESULTS

Source of variation	Stability		TSR		Permanent deformation		$F_{0.05}$
	F	*p*-value	*F*	*p*-value	*F*	*p*-value	
Aggregate types	1.958	0.255	6.276	0.0584	0.455	0.663	6.944
Curing time	23.385	0.006	0.488	0.646	13.383	0.017	6.944

IV. CONCLUSION

The test results indicate that the WMA presents an opportunity for the asphalt industry to improve its product performance, construction efficiency, and environmental protection of energy conservation and carbon reduction. Based on the results from the laboratory testing using emulsion asphalt with Portland cement as mineral filler, the following conclusions are made:

- The mix design is satisfied by the specification requirements, except the VTM of NMAS of 9.5mm which is slightly higher than the value of the specification.
- The Marshall stability increases with an increase in curing time and the one-day stability can satisfy the requirement of heavy traffic design criteria. It then can take the accumulation of traffic loading increased by time.
- The indirect tensile strengths of TSR are higher than agency requirement of 80%. The results indicate that the 2% Portland cement enhances resistance to moisture damage and raises TSR to acceptable levels.
- The results of the average deformation show that the samples with 1-day curing have the highest rut depths and samples run in 28-day curing have lower rut depths than those in the other.
- The stability, TSR and permanent deformation values by different aggregate types have no significant effect. However, curing time has significant effect the stability and permanent deformation values.
- WMA with asphalt emulsion can be an alternate for pavement construction.

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