Rutting Potential of Warm Mix Asphalt and Possible Misleading Results due to Reheating

Hao Wang
Assistant Professor, Department of Civil and Environmental Engineering, Rutgers University, USA

Imad L. Al-Qadi
Founder Professor of Engineering, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign; Director, Illinois Center for Transportation, USA

Jongeun Baek
Research Professor, Sejong University, Korea

Zhen Leng
Assistant Professor, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University

ABSTRACT: The main objective of this study is to evaluate the rutting potential of warm mixes produced with various warm mix additives (Evotherm, Sasobit, and foamed asphalt). To achieve this objective, an experimental matrix was developed to determine the mechanical properties of warm mixes and the control mix. Laboratory performance testing includes evaluation of modulus, strength, and rutting potential using dynamic modulus test, indirect tensile (IDT) strength test, flow number (FN) test, and loaded wheel track (LWT) test. The test results show that the warm mix could have slightly greater or less rutting potential than the control mix depending on the type of warm mix additive and the recycled material used in the mix. In the laboratory tests, plant-produced mixes were compacted in the laboratory without and with reheating. It was found that the reheating process could significantly stiffen the mixture and the stiffening ratios varied from 1.2 to 2.0 depending on the performance characteristics and the type of mixture. In addition, the rutting test results show different levels of correlation with the dynamic modulus and the tensile strength, depending on the stress state in the performance test. This suggests that attention should be paid to the measured characteristics of each performance test based on the loading conditions.

KEY WORDS: Warm mix asphalt, rutting resistance, reheating, modulus, tensile strength.

1. INTRODUCTION

Warm Mix Asphalt (WMA) is an asphalt mixture that is mixed and compacted at temperatures lower than the required temperatures for conventional hot-mix asphalt (HMA). Typically, the mixing and compaction temperatures of WMA range from 100 to 140°C (212 to 280°F) compared to the 150 to 180°C (300 to 350°F) for HMA (Angelo 2008). It has been proven that WMA techniques can provide a number of benefits due to the lowered production and placement temperatures.

Although benefits can vary depending on the specific warm mix additive being used, the potential benefits of WMA techniques are summarized as follows (Chowdhury and Button 2008):

- Improved compaction of asphalt mix, especially stiff mixes;
- Increased use of reclaimed asphalt pavement (RAP) and roof asphalt shingles (RAS);
- Extension of paving seasons;
- Night paving and longer haul distances;
- Reduction of asphalt oxidation for prolonged pavement life;
- Less fuel consumption and energy costs;
- Reduction of heat, odor, blue smoke at the plant and paving site, thus improved working conditions for the plant/paving crews;
- Reduction of GHG emissions such as NOx, SOx, and CO_2; and
- Easier permitting for plant sites in urban areas.

In spite of the above-mentioned advantages of WMA, some concerns have been raised regarding the durability of these mixtures due to the reduced mixing and compaction temperatures used in production. Many studies have been conducted to determine the applicability of WMA techniques to paving operations and environmental conditions compared to the traditional HMA. One of the main concerns is the increased susceptibility of WMA to permanent deformation. For example, it’s possible that the asphalt binder in WMA may not harden as much at lower production temperatures and may more easily develop post-construction densification or distortion under early-age traffic.

A number of research studies have been conducted to evaluate the rutting resistance of WMA compared to HMA. Prowell et al. (2007) reported that laboratory tests conducted in the asphalt pavement analyzer indicated similar performance for the emulsion-based WMA (Evotherm) and HMA surface mixes with the PG 67-22 base asphalt. Wasiuddin et al. (2007) compared the performance of Sasobit and Aspha-Min additives in WMA and found that the Sasobit decreased the rutting potential much more significantly than the Aspha-Min additive. However, the addition of Sasobit could increase the high temperature grading of the asphalt binder.

Xiao et al. (2010) evaluated the rut depth, weight loss, and gyration number of dry and conditioned specimens containing warm mix additives (Aspha-Min, Sasobit, and Evotherm). The results indicated that aggregate source affects the rutting resistance most significantly regardless of the additive and moisture content. Gandhi et al. (2010) evaluated the ageing characteristics of WMA. Results of that study indicated that the warm asphalt additives improved the moisture susceptibility of the virgin mixes. The mixes containing Sasobit exhibited less rutting and the Aspha-Min additive lowered the resilient modulus values of the mixes. On the other hand, the additives did not have any significant effect on the moisture susceptibility or the rutting resistance of the aged mixes, but significantly increased the resilient modulus values of the mixes as they aged. This indicates that the binder aging mechanism may change when warm mix additives are added into the mixture.

2. RESEARCH OBJECTIVE AND SCOPE

The objective of this study is to experimentally characterize the rutting potential of warm mixes with various additives. Specifically, three stone mastic asphalt (SMA) mixtures, prepared using different warm mix technologies (Evotherm, Sasobit, and foamed asphalt), and one conventional control SMA, were evaluated using flow number (FN) test, loaded wheel track (LWT) test, dynamic modulus test, and indirect tensile (IDT) strength test. The following research tasks were conducted:

1) Evaluate the rutting potential of the warm and control SMA mixtures using laboratory performance tests.
2) Investigate the aging effect due to mixture reheating on the rutting potential of the warm and control SMA mixtures.
3) Analyze the relationship between different performance characteristics related to the rutting potential of mixtures.

3. PREPARATION OF TESTING SPECIMEN

Three WMA techniques were used in this study to produce the warm SMA: Evotherm additive (a chemical additive), Sasobit additive (an organic additive), and foaming process. A typical SMA binder mix that has been used by Chicago area contractors on many large-scale expressway overlay projects was selected as the control mixture. As Table 1 shows, the control SMA and the Evotherm SMA had the same mixture design, which includes PG 64-22 binder with 12% ground tire rubber (GTR) and 8% fractionated recycled asphalt pavement (FRAP). PG 64-22 binder with 12% GTR was used in the foamed SMA; but the mix contained 13% FRAP. SBS-modified PG 70-22 binder, 5% FRAP, and 5% RAS were used in the SMA with Sasobit additive. The GTR is usually used to improve the high temperature properties of the virgin binder. Previous research has shown that the addition of 10% crumb rubber can increase the PG grade of the binder by at least one grade (e.g., from PG 64 to PG 70) (Putman et al. 2005). The compaction temperatures of the three warm SMA's were 15-25 ^{o}C lower than that of the control SMA.

Table 1: Composition of Asphalt Mixtures with Various Warm Mix Additives

Mix	N_{des}[a]	NMAS[b] (mm)	Binder	FRAP[c]	RAS[d]	Compaction Temp. (^{o}C)	WMA Additive
Control SMA	80	12.5	6.2% PG 64-22 with 12% GTR	8%	NA	152	NA
Evotherm SMA			6.2% PG 64-22 with 12% GTR		NA	127	0.5% of binder
Foamed SMA			6.2% PG 64-22 with 12% GTR	13%	NA	127	1.0% of binder
Sasobit SMA			6.2% PG 70-22 (SBS modified)	5%	5%	127-137	1.5% of binder

[a] N_{des} = Design number of gyrations; [b] NMAS = Nominal maximum aggregate size;
[c] FRAP = Fractionated Recycled Asphalt Pavement; and [d] RAS = Recycled Asphalt Shingles.

To accurately represent the field condition, plant-produced mixes were compacted right after sampling. In-situ compaction eliminates the concerns from reheating WMA samples in the lab. Compaction was conducted in the asphalt plant right after sampling from the truck. In addition, loose mixes collected from field were reheated and compacted in the laboratory. The same set of performance tests was conducted for the reheated specimens.

The air voids of the compacted gyratory specimens were checked, respectively, for the specimens compacted with and without reheating. The data show that generally the air voids are within the range of 6.0±0.5%. Generally, the control mix specimens have relatively higher air voids, while the mix specimens prepared with foamed asphalt have relatively lower air voids.

3.1 Flow Number Test

The NCHRP 9-19 study on simple performance test for Superpave Mix Design (NCHRP report 465) recommends that the flow number test can be used to evaluate the permanent deformation potential of asphalt mixtures by applying repeated haversine loads and recording the cumulative deformation as a function of loading cycles. The repeated load is applied for 0.1s with a rest period of 0.9s in each one cycle. In this study, the flow number test was conducted using a uniaxial compression load without confinement at 58°C (136°F), Figure 1. A loading stress level of 200kPa (29psi) was selected to attain tertiary flow in a reasonable number of cycles. The test was conducted up to 10,000 cycles or until 5% of accumulative permanent stain was achieved.

Figure 1: Flow number test setup

The Francken model was used to fit the measured permanent strain as a function of the number of loading cycles (Krishna et al. 2007). The Francken model is a combination of power law function with an added exponential function, as shown in Equation 1. The first derivative of the Francken model is calculated as the rate of permanent strain. Then the second derivative of the Francken model is calculated to obtain the slope of the rate of permanent strain, Equation 2. The FN is calculated at the point where the slope of the rate of permanent strain changes sign (from negative to positive).

$$\varepsilon_p = AN^B + C(e^{DN} - 1) \tag{1}$$

$$\frac{\partial^2 \varepsilon_p}{\partial N^2} = A \cdot B \cdot (B-1) \cdot N^{(B-2)} + C \cdot D^2 \cdot e^{D \cdot N} \tag{2}$$

where, ε_p is accumulated permanent strain;

N is number of loading cycles; and

A, B, C, and D are fitting parameters.

3.2 Loaded Wheel Test

A Hamburg-type loaded wheel tester, manufactured by PMW, Inc., was used to assess the rutting performance of mixtures. The test was conducted in accordance with a TxDOT procedure (Tex-242-F) with the exception of being conducted in a dry condition at 30°C (86°F). The dry condition was selected to better represent the short term performance immediately after construction. The test was performed by rolling a 738N (158lb) steel wheel on the specimen surface at 50 passes/min for 20,000 total passes. This test is considered a torture test to compare rutting potential between different mixtures. Figure 2 shows a typical test setup with samples in the air conditioned chamber. The rut depth at a specified number of wheel passes or the number of passes until failure is reported.

Figure 2: Loaded wheel test setup with air condition chamber

3.3 Modulus and Indirect Tensile Strength Test

In addition to the performance test for evaluating the rutting potential of warm SMA mixtures, modulus and tensile strength tests were conducted to measure the fundamental engineering properties of warm SMA mixtures. The dynamic modulus test was performed following the AASHTO TP-62, *Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures*. In this study, dynamic modulus tests were conducted at room temperature, 25°C (77°F), and frequencies of 25, 10, 5, 1, 0.5 and 0.1Hz. The dynamic modulus tests were conducted using a controlled stress mode, which produced strains smaller than 100 microstrain. The dynamic modulus at 0.1Hz was mainly used in this study because it indicates the mixture stiffness at high temperature (low frequency).

The indirect tensile (IDT) strength test was performed in accordance with AASHTO T-322-07, *Standard Method of Test for Determining the Creep Compliance and Strength of Hot-Mix Asphalt (HMA) Using the Indirect Tensile Test Device*, on a universal testing machine manufactured by Instron, Inc. The test was conducted at room temperature 25°C (77°F) and the specimen was loaded until failure at a rate of 0.5inch/min (12.7mm/min).

4. TEST RESULTS AND ANALYSIS

4.1 Rutting Potential of Control and Warm SMA Mixtures

The rutting potential of the control and warm SMA mixtures was evaluated using the flow number (FN) test and the loaded wheel test, respectively. Figure 3 shows the development of the permanent strain in the FN test. The cumulative permanent deformation curve is generally defined by three stages: primary, secondary, and tertiary. The permanent deformation rates decrease in the primary stage and increase again in the tertiary stage. In the tertiary stage, the permanent deformation increases rapidly. The flow number is defined as number of loading cycles until the beginning of the tertiary stage. The flow number can be viewed as the lowest point in the curve of the rate of permanent strain versus number of loading cycles.

As shown in Equation 1, the measured permanent strain is characterized with Francken model, which is a composite model that considers all stages of permanent deformation. It combines both the power model that characterizes the primary and secondary stages and the exponential model that fits the tertiary stage. Therefore, the power model coefficient (B) and the exponential model coefficient (D) were used in the analysis along with the flow number.

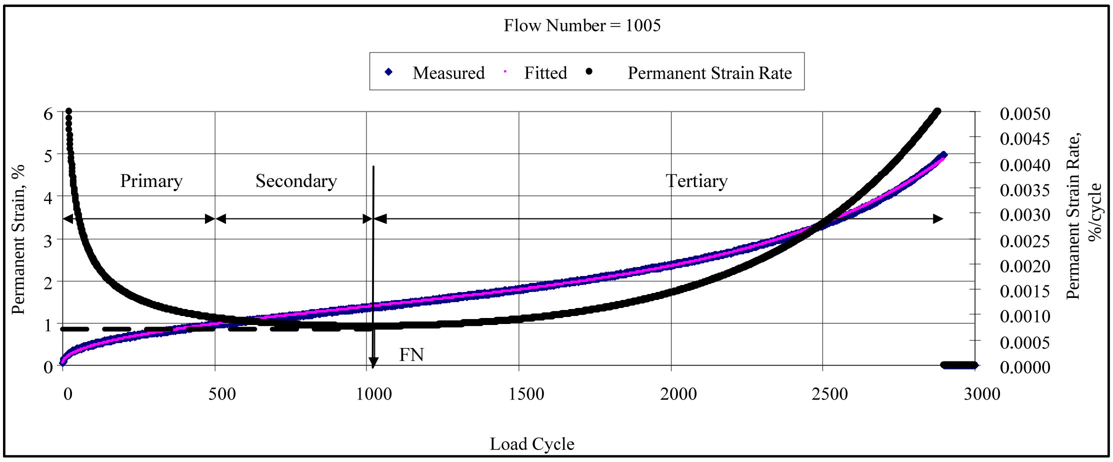

Figure 3: Illustration of permanent strain development and flow number

Table 1 shows the rutting parameters measured from FN test for each different mixture. The results indicate that adding Evotherm to the control mixture results in slightly higher rutting potential. This could be due to the effect of the less aged binder; these two mixtures have the same mixture components except the Evotherm additive.

Compared to the control mixture, the mixtures containing Sasobit and foamed asphalt show superior performance in reducing rutting potential. This could be due to the combined effects of warm mix additives and recycled materials. The control mixture has 8% FRAP. However, the mixture containing foamed asphalt has 13% FRAP, while the mixture containing Sasobit has 5% FRAP and 5% RAS. As expected, higher RAP contents can increase the mixture stiffness and reduce rutting potential. Previous research has also shown that the use of asphalt shingles results in the increase of modulus and the decrease of rutting potential due to use of higher viscosity asphalt in the shingles along with the reinforcing effect of the fiber (Sengoz and Topal 2005).

Table 1: Rutting Parameters Measured from Flow Number Test

Rutting parameters	SMA Mixture			
	Control	Evotherm	Foam	Sasobit
Flow number (FN)	3229	2568	5267	8047
Power model coefficient (B)	0.35	0.44	0.25	0.29
Exponential model coefficient (D)	0.00043	0.00085	0.00022	0.00018

Figure 4 shows the rutting development under the repeated load wheel testing. The development trend of rutting depth is similar to the development trend of the permanent strain in the FN test. The measured rutting depth at 5000 passes and 20,000 passes were used in the analysis as the indication of rutting at different stages.

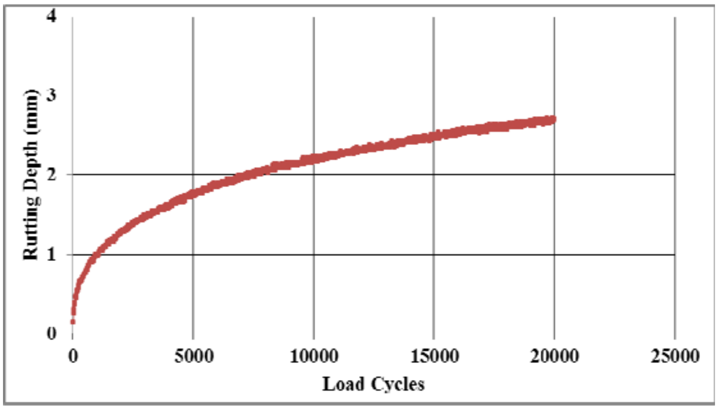

Figure 4: Illustration of rutting depth development in loaded wheel test

Table 2 shows the rutting depth from loaded wheel test for each mixture. The results suggest that the SMA mixture with Evotherm has the highest rut depth while the SMA mixture with Sasobit has the smallest rut depth, when compared at the same number of passes. In general, the findings are similar with the results from the FN test for the comparison of rutting potential between different SMA mixtures.

Table 2: Rutting Depth Measured from Loaded Wheel Test

Rutting parameters	SMA Mixture			
	Control	Evotherm	Foam	Sasobit
Rut depth at 5000 passes (mm)	2.52	2.60	1.50	1.19
Rut depth at 20,000 passes (mm)	3.62	3.94	2.71	1.95

4.2 Effect of Aging on Rutting Potential

An aging ratio was used to quantify the extent of the binder hardening effect on mixture properties due to reheating. The aging ratio was calculated as the ratio of the flow number tested using the reheated specimens with respect to the flow number tested using the specimens without reheating (vice versa for rut depth).

Table 3 compares the aging ratios due to reheating for various SMA mixtures. The results show that the reheating process causes asphalt mixtures having less rutting potential. This is expected because the viscosity of binder could increase significantly during the reheating process and the binder becomes stiffer. The aging ratio ranges from 1.2 to 2.0 depending on the performance characteristics and the type of SMA mixture.

Table 3: Aging Ratio due to Reheating for Control and Warm SMA Mixtures

Aging Ratio for	SMA Mixture			
	Control	Evotherm	Foam	Sasobit
Flow Number	2.03	1.23	1.28	1.41
Rut depth at 5000 passes	1.76	1.83	1.56	NA
Rut depth at 20,000 passes	1.91	1.97	2.09	NA

4.2 Relationship between Different Performance Characteristics

Linear regression analysis was performed to evaluate the relationship between the flow number and the rut depths at 5000 and 20,000 passes from the loaded wheel test, as shown in Figure 5. As expected, the general trend is that the mixtures with the higher flow number have the smaller rut depth. However, the R-square values in the regression model are not high. This is probably because that the mixtures may fail in different ways in the two performance tests: pure compression in the flow number test; but compression and shear in the loaded wheel test. Hence, general trend may be obtained; but test results of one test may not be used to predict may not be determined.

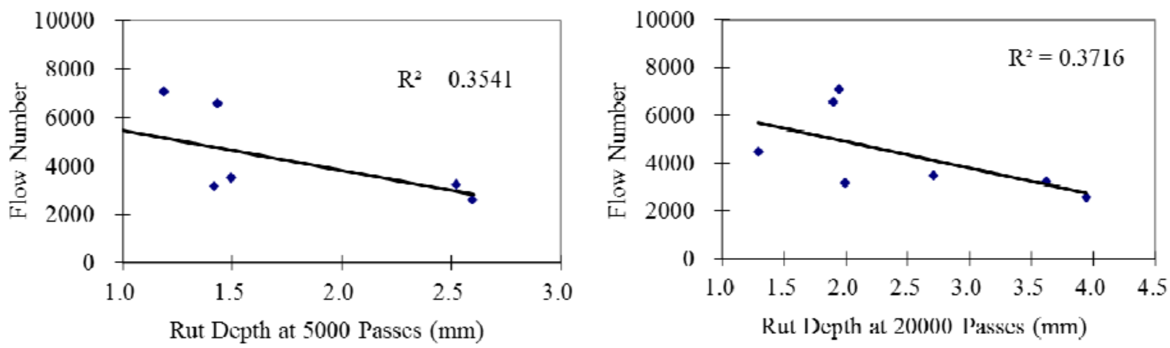

Figure 5: Linear regression relationships between flow number and (a) rut depth at 5000 passes; and (b) rut depth at 20,000 passes

The linear regression relationship between the rutting parameters and the stiffness and modulus were also investigated, as shown in Figure 6. Good correlations were found between the flow number and the dynamic modulus at 0.1Hz, and between the rut depth and the IDT tensile strength, respectively. The mixture with the higher dynamic modulus test is stiffer to resist permanence deformation under compression; while the mixture with the higher tensile strength is stronger to resist the torture failure in the loaded wheel test. This indicates that the performance characteristics at similar stress states have better correlations between each other.

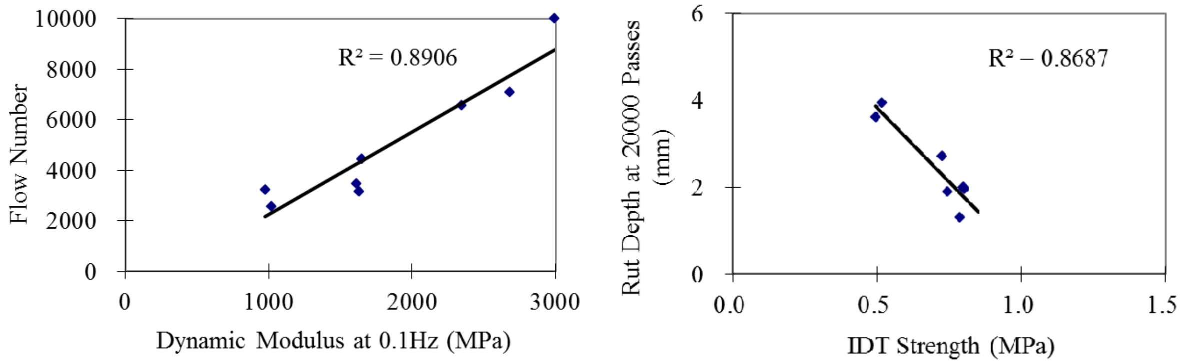

Figure 6: Linear regression relationships (a) between flow number and dynamic modulus at 0.1Hz; and (b) between rut depth and tensile strength

5. SUMMARY

This study characterized the rutting potential of warm mixes using laboratory performance tests, including flow number test, loaded wheel track test, dynamic modulus test, and IDT strength test. The test results show that the warm mix could have slightly greater or less rutting potential than the control mix, depending on the type of warm mix additive and the recycled material used in the mix. In the laboratory tests, plant-produced mixes were compacted in the laboratory without and with reheating. It was found that the reheating process could significantly stiffen the mixture and the stiffening ratios varied from 1.2 to 2.0 depending on the performance characteristics and the type of mixture. In addition, the rutting test results show different levels of correlation with the dynamic modulus and the tensile strength, depending on the stress state in the performance test.

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