Rheological Investigation of Non-Foaming WMA Additives at Mid-Temperature

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ABSTRACT: In this study, the objective was to conduct a laboratory investigation of rheological properties of non-foaming WMA additives at a mid-temperature. The conventional testing procedures such as viscosity, performance grade, creep and creep recovery, and frequency sweep were performed to determine the influences of non-foaming additives on asphalt binders. The experimental design included four binders and four non-foaming WMA additives. The test results indicated that, as expected, the non-foaming WMA additive can reduce the viscosity value of asphalt binder and thus decrease the mixing and compaction temperatures of mixture. The failure temperature of binders containing non-foam additive has a slight increase compared to the virgin binder and thus, improve the rut resistance of the mixtures. In addition, creep recovery and frequency sweep tests show that the binder with Sasobit has a slightly higher complex modulus but exhibits lower creep compliance and phase angle than the binder containing other WMA additives.

INTRODUCTION

In recent years, the asphalt industry has investigated the warm asphalt technology as a means to reduce the mixing and compaction temperatures of asphalt mixes. Warm mix asphalt (WMA) is an asphalt mixture that is mixed at temperatures lower than conventional hot mix asphalt. Typically, the mixing temperatures of warm mix asphalt range from 100 to 140°C (212 to 280°F) compared to the mixing temperatures of 150 to 180°C (300 to 350 °F) for hot mix asphalt (Kristjansdottir et al. 2007; Prowell 2007; Xiao et al. 2009, 2010). Thus, warm asphalt has been gaining popularity around the world in recent years. In addition, rising energy prices, global warming, and more stringent environmental regulations have resulted in an interest in warm mix asphalt technologies as a means to decrease energy consumption and emissions associated with conventional hot mix asphalt production (Middleton and Forfylow 2009; Wasiuddin et al. 2007; Wielinski et al. 2009).

Some European countries are already using warm mix technology to produce asphalt mixes at lower temperatures without significantly affecting the quality of the mixtures. While energy savings and air quality improvements by using warm asphalt are appealing, the performance of warm asphalt in the United States is not well known. The mix designs, binder sources, equipment, climate conditions, and work practices, among many other factors, are quite different in the United States than in Europe. Warm mix asphalt requires more investigation and research before being implemented in the United States.

Two technologies have been primarily used for the production of WMA. The first technology is the use of a proprietary mineral or asphalt binder additive, such as Sasobit, Sasoflex, Aspha-Min, Rediset WMX, Cecabase, or Evotherm. The second technology consists of a physical production process known as foamed asphalt.

In this study, the objective was to conduct a laboratory investigation of rheological properties of non-foaming WMA additives at mid-temperature. The conventional testing procedures such as viscosity, performance grade, creep and creep recovery, and frequency sweep were performed to determine the influences of non-foaming additives on asphalt binders.

Experimental Process and Materials

Three PG 64-22 asphalt binders from various sources (referred to A, B, and C) and one PG 64-16 (referred to D) were used to blend with four non-foaming WMA additives (Cecabase - C, Evotherm - E, Rediset - R, and Sasobit - S) in this study. The properties of these virgin binders (V) are shown in Table 1. The percentages used (by binder weight) of non foaming WMA additives are generally based on the recommendations by the manufactures. For example, 0.3 - 0.4% Cecabase, 0.5% Evotherm, 1.5% Rediset, and 1.5% Sasobit were blended with virgin asphalt binder in this research. The chemical and physical properties of these WMA additives are shown in Table 2.

A Brookfield rotational viscometer was used to test the viscosity of the modified binders at four different temperatures (e.g. 120°C, 135°C, 150°C and 165°C) in accordance with AASHTO T316. The high temperature rheological properties of each binder were measured using a dynamic shear rheometer (DSR) according to AASHTO T315. Each binder was measured in terms of complex shear modulus (G^*) and phase angle (δ) values starting from 64ºC until failure in accordance with Superpave mix design specifications.

In addition, some tests such as creep/creep recovery and frequency sweep also were performed at 60ºC for each blended binder. For the frequency sweep tests, frequencies ranging from 0.01 to 100 Hz were run at the lowest possible strain. Typically, a frequency of 1.59 Hz simulates the shearing action corresponding to traffic speed of about 55 mph and is used for failure temperature and G*/sin δ tests.

Table 1 Rheological properties of binders

		No aging		RTFO aging	RTFO+PAV aging		
		Viscosity (Pa.s)	G*/sin δ	G*/sin δ	G*.sin δ	stiffness	m-value
Binder Type	**Source**	135°C	64°C	64°C	25°C	-12°C	-12°C
A (PG 64-22)	Venezuela	0.650	2127	4692	3462	144	0.349
B (PG 64-22)	Mixed	0.450	1233	3703	4438	179	0.306
C (PG 64-22)	West Texas	0.448	1274	2755	2180	139	0.299
D (PG 64-16)	California	0.492	1481	4164	3036#	165#	0.313#

Note: #: tested at 28°C and -6°C.

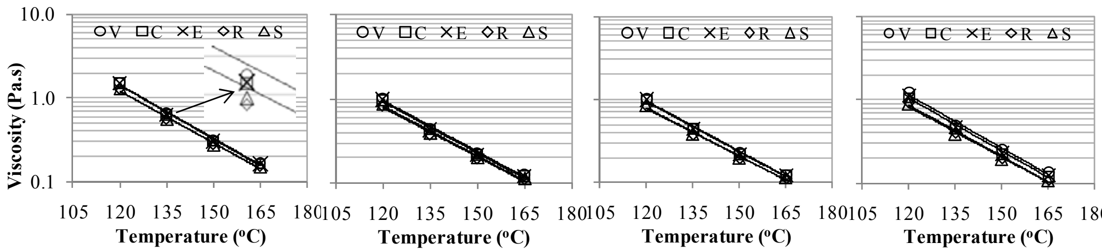
Table 2 Physical and chemical properties of WMA additives

Properties	Cecabase	Evotherm H5	Rediset WMX	Sasobit H8
Ingredients	Polymer: > 45% Fatty acid amine: <50% 1,2-Ethanediamine: >1%	Modified tall oil fatty acid polyamine condensate water	Fatty polyamines polymer Non-ionic. Component	Solid saturated hydrocarbons
Physical state	Liquid	Viscous Liquid	Solid	Pastilles, flakes
Color	Light yellow	Amber (Dark)	Brown	Off-white to pale brown
Odor	-	Fishy, Amine-like	Amine like	Practically odorless
Molecular weight	-	-	-	Approx. 1000
Specific Gravity	1	1.03-1.08	-	0.9 (25C)
Vapor density	NE	<1	-	-
Bulk density	-	1.03 g/cm^3	Not detemined	-
Ph values	NA	9~11	Not detemined	Neutral
Boiling Point	NE	>100C	Not detemined	-
Flashpoint	>100C	-	>93.3C	285C (ASTM D92)
Solubility in water	Insoluble	Water solubility	Insoluble in cold water	Insoluble

RESULTS AND DISCUSSIONS

Viscosity

The viscosity of an asphalt binder is used to determine its flow characteristics to pump and handle at the hot mixing facility; also to determine the mixing and compacting temperatures of asphalt mixtures. Fig. 1 illustrates that, as expected, the viscosity values of all asphalt binders decrease as the test temperature increases. In addition, it can be noted that the viscosity values of various PG 64-22 or PG 64-16 binders (Binders A-D) are generally different. Moreover, as shown in Fig. 1(a), virgin binder has a higher viscosity value than other binder with WMA additive; and it can be observed that the binders with Rediset and Sasobit generally have the lowest values.



(a) (b) (c) (d)

FIG. 1 Viscosity values of binders; (a)-(d) Binders A-D

Statistical analysis results shown in Table 3(a) indicate that, with respect to the effect of a non-foaming additive, there are significantly different viscosity values between any two binders with or without WMA additive except for Binders A with Cecabase and Evotherm. In addition, Table 3(b) shows that, with respect to the effect of binder type, viscosity values of binders from various sources are significantly different in terms of the WMA additive. The effect of storage duration on viscosity of WMA binder is shown in Fig. 2. It can be noted that the viscosity values of WMA binder do not obviously change as the storage duration increases.

Table 3 Statistical analysis of viscosity values

(a)

α = 0.05	WMA additive									
Binder type	V-C	V-E	V-R	V-S	C-E	C-R	C-S	E-R	E-S	R-S
A	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
B	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
C	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
D	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

(b)

α = 0.05	Binder type					
WMA additive	A-B	A-C	A-D	B-C	B-D	C-D
V	Y	Y	Y	Y	Y	Y
C	Y	Y	Y	Y	Y	Y
E	Y	Y	Y	Y	Y	Y
R	Y	Y	Y	Y	Y	Y
S	Y	Y	Y	Y	Y	Y

Note: A~D-binder t ype; V-virgin binder; C-Binder with Cecabase; E-Binder with Evotherm; R-Binder with Rediset; S-Binder with Sasobit; Y-signficant difference; N-no significant difference (α = 0.05)

Performance Grade

The grade determination feature of the DSR was used to determine the failure temperature for each binder with or without WMA additive in the original unaged state. This procedure tests the sample at a starting temperature (i.e., 64°C for PG 64-22 base binder) and increases the temperature to the next PG grade (e.g., 70°C) if the

G*/sin δ value is greater than the value required by AASHTO M320 (1.000 kPa for original binder). Two replicates were tested for each aging condition of each binder. Fig. 3 illustrates that additional WMA additive results in an increase in failure temperature, especially as Evotherm and Sasobit were added, the failure temperature rises remarkably. However, additional Cecabase generally does not increase the failure temperature of binders B and C. In general, Fig. 3(b) shows that the addition of WMA additive results in an increased temperature less than one grade (6^{o}C). Additionally, binder A generally has the highest failure temperature amongst all binders irregardless of the presence of WMA additive. Therefore, the binder source plays a key role in determining its failure temperature.

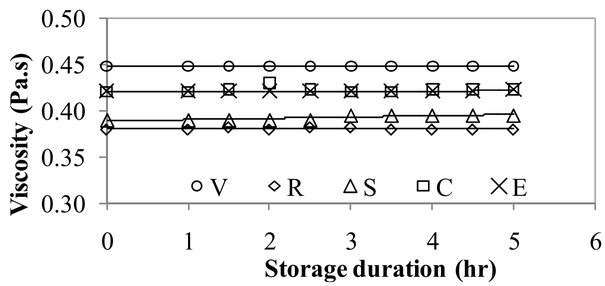


FIG. 2 Viscosity changes duration various storage durations

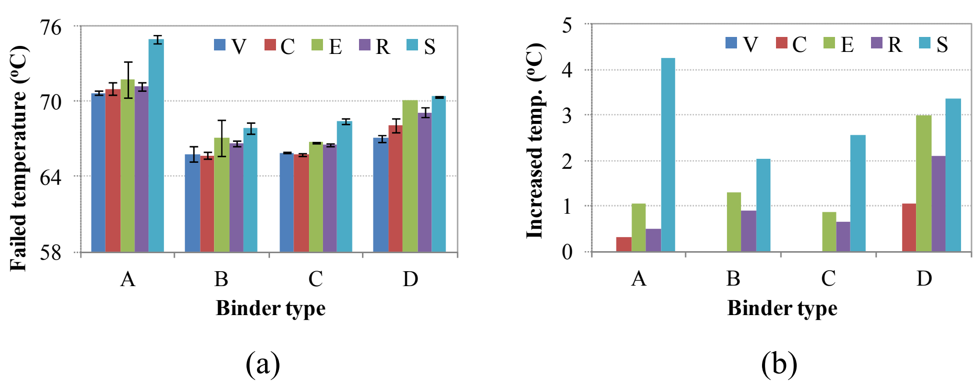


FIG. 3 Failed temperatures of binders, (a) failed temperature, (b) increased temperatures

Based on the values of complex modulus (G*) and phase angle (δ), Fig. 4 indicates that, regardless of having a starting test temperature of 64^{o}C or higher, binders containing Sasobit have the highest G*/sin δ value, while virgin binder shows the lowest one. At a higher test temperature, G*/sin δ values of various WMA binders are close since the binder generally exhibits the liquid properties. Moreover, binders B and C, with or without WMA additive, have a G*/sin δ value less than 1.000 kPa at 70^{o}C. However, G*/sin δ values of binder A (virgin or with WMA additive) and binder D with Sasobit are greater than 1.000 kPa at 76°C. As a result, one can conclude that the addition of Sasobit additive has a significant effect on PG grade of binders and contributes to an improvement of rutting resistance at a high performance temperature.

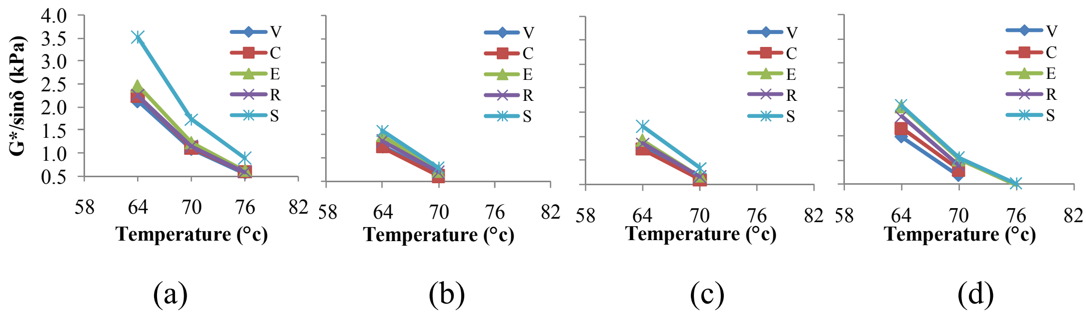


FIG. 4 G*/sin δ values of binders at various test temperatures, (a)-(d) Binders A-D

In Superpave specifications, phase angle is defined as the time lag between strain and stress under traffic loading and is highly dependent on the temperature and frequency of loading. It can be used as an indicator of binder viscosity and elasticity. As shown in Fig. 5, Virgin binder has the highest phase angle value, followed by the binder with Cecabase then Evotherm and Rediset. The binder with Sasobit has the lowest phase angle value generally.

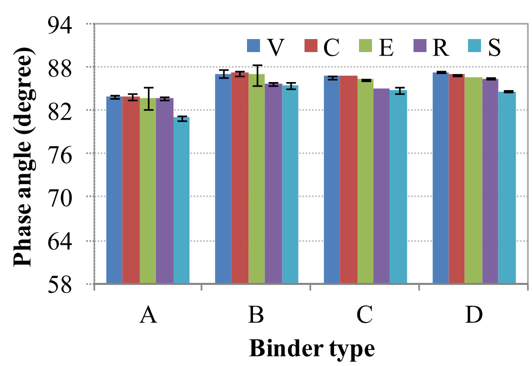


FIG. 5 Phase angles of various binders

Creep and creep recovery

Creep is defined as the slow deformation of a material measured under a constant stress. In a creep test, a fixed shear stress is applied to the sample and the resultant strain is monitored for a predetermined amount of time. This gives an idea of the permanent deformation that the binder will undergo. After a predetermined period of time, the stress is removed and the strain is further monitored. This allows the material to recover for a longer duration of time. Since the actual change of strain depends on the applied stress, compliance is used as a measure of creep rather than strain. The compliance is expressed as the ratio of strain to the applied stress. Thus, a lower value of compliance at any given stress level implies higher deformation resistance.

Fig. 6 shows the creep and creep recovery curves for binder A with various WMA additives. It can be seen that, as expected, the binder with Sasobit has the lowest creep angle and compliance values, while the virgin binder and the binder with Rediset exhibit the highest values. This result indicates that the Sasobit additive can effectively improve the deformation resistance of the asphalt binder due to the reduction of compliance value. In addition, the binders B-D exhibit similar trends as binder A.

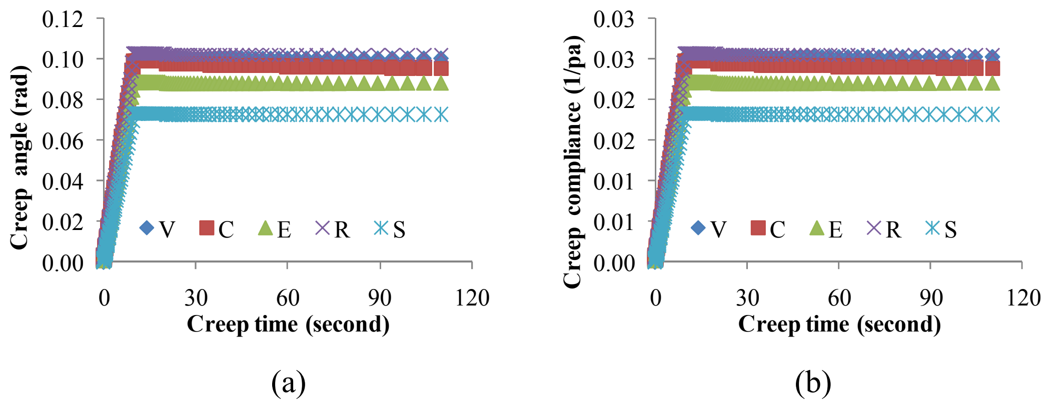


FIG. 6 Creep and Creep recovery, (a) creep angle; (b) creep compliance

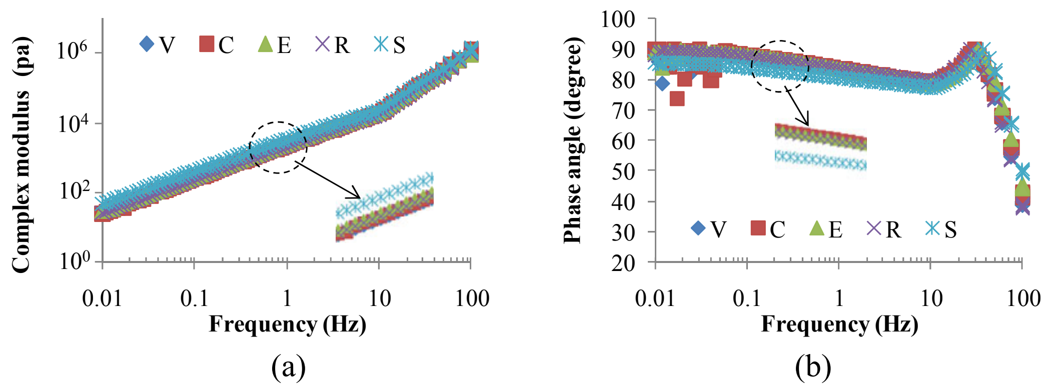


FIG. 7 (a) (b) complex modulus and phase angle values under various frequencies

Frequency sweep tests

The frequency sweep tests were performed under stress proportional to frequency. The frequencies used were between 0.01 to 100 Hz. The overall frequency sweep tests were run with the 25 mm diameter and 1 mm testing gap geometry at 60°C. Previous research papers indicated that the frequency sweep tests at various frequencies could identify the linear viscoelastic response of the binders (Anderson et al. 1994). Fig. 7 indicates that binder A with various WMA additives generally have similar viscoelastic properties. The binder with Sasobit has a slightly higher complex modulus and exhibits a slightly lower phase angle value in terms of various frequencies, thus resulting in a higher rutting resistance. Similar properties have been presented earlier as the binders were performed the G*/sin δ test at 1.59 Hz. In addition, other binders (B-D) show similar trends.

CONCLUSIONS

- The use of Cecabase, Sasobit, Evotherm, and Rediset can reduce the viscosity value of asphalt binder and thus, decrease mixing and compaction temperatures of mixture. The storage time did not significantly change the viscosity of warm asphalt binder in this study.
- The failure temperature of binders containing non-foam additive have a slight increase compared to the virgin binder and thus improving the rut resistance of the mixtures.
- The binder with Sasobit additive generally has a slightly higher failure temperature, G*/sin δ value, complex modulus and a slightly lower phase angle, creep angle, and creep compliance.

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Effectiveness of Advera® in Warm Mix Asphalt

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ABSTRACT: Benefits of warm mix asphalt (WMA) technologies in terms of energy savings and air quality improvements are highly promising. However, further investigations are needed to validate their performance as rheological and viscoelastic data are significantly lacking for material conditions in Oklahoma. To this end, effects of dosage levels of a WMA additive, Advera®, on the performance grade (PG) of a local PG 64-22 binder were evaluated. The effectiveness of a liquid anti-stripping (AS) agent, AD-here® HP Plus, on the WMA-modified binder was also studied. Based on the binder test data, the optimum dosage of Advera® was found to be 6% (by the weight of the binder), which did not alter the PG grade of the base binder. The liquid AS agent was found to be effective in increasing the fatigue fracture resistance of the WMA-modified binder. The current study is expected to enhance the inventory of rheological database and help in implementing WMA mixes in Oklahoma.

INTRODUCTION

WMA technologies are relatively new processes and products. These technologies use various mechanical and chemical means to reduce the shear resistance of the mix at relatively low production temperatures, while reportedly maintaining or improving the pavement performance. These technologies can reduce the production temperature of the hot mix asphalt (HMA) by 16°C to over 55°C (Newcomb, 2010). The lower production temperatures lead to reduced emissions (i.e., volatile hydrocarbons and CO_2), dusts and production costs (Goh et al., 2007). It also extends the paving season in certain locations where the HMA construction is restricted to warmer months. However, experimental data are significantly lacking in terms of rheological and viscoselastic properties of modified binders as well as strength and performance-related properties of the mix.

A commonly used water-bearing WMA additive named Advera® was selected for evaluation in this study. Advera® is a finely powdered synthetic zeolite (sodium aluminum silicate hydrate) that is hydro-thermally crystallized, and it holds from 18 to 22% (by mass) of water. Theoretically, the zeolite releases water which creates foam that reduces the viscosity and increases the workability. It facilitates better coatings of the asphalt binder on aggregates. Once the binder is cooled off, the water condenses and, ideally, is reabsorbed by the zeolite, thus leaving no significant effect on the rheology thereafter. The recommended dosage of Advera® is 0.25% (by the weight of the mix), which can be introduced into the plant using a feeder, with minor modification to the plant (PQ Corporation, 2010).

In practice, many agencies simply allow the addition of a WMA additive to an approved PG binder without accounting for possible grade change to the base binder (Austerman et al., 2009). As the modified binder needs to meet the Superpave specifications, it is important to examine the impacts of the additive on the PG grading of the binder. Previous WMA studies (e.g., Hurley and Prowell, 2005; Sneed, 2008; Austerman et al., 2009; Carter et al., 2010) demonstrated significant changes in both the high PG and the low PG temperatures of the base binders. The extent of changes in PG temperatures depends on the amount of additive being added to the binder. Therefore, performance factors (rutting, fatigue fracture and thermal cracking factors) of the Advera®-modified binder need to be evaluated. For instance, the reduced aging of asphalt binder can lead to excessive rutting during the early age of the pavement. Another common concern for the WMA stems from the argument that the low production temperature would leave behind more moisture within the mix during the construction process. Additionally, if the moisture contained in Advera® does not completely evaporate during the production process or become reabsorbed, it may further worsen the situation. The moisture damage potential of a mix is generally evaluated through the determination of tensile strength ratio (TSR), in accordance with AASHTO T 283 (Cross et al., 2000; Hurley and Prowell, 2005). It can also be determined through the observation of the point of inflection in Hamburg-wheel tracking (HWT) tests (Hurley and Prowell, 2005).

The working mechanism of Advera® is similar to that of another water-bearing WMA additive named Aspha-Min® zeolite. Hurley and Prowell (2005) studied the viability of Aspha-Min® at different production temperatures ranging from 149°C down to 88°C. These researchers evaluated two binders (PG 58-28 and PG 64-22) and reported that the zeolite (0.3% by the weight of the mix) did not contribute to the increased Asphalt Pavement Analyzer (APA) rut depth. Rather, the increased rut depth was associated with the reduced mixing and compaction temperatures. These researchers also suspected significant increase in moisture susceptibility of the zeolite-modified mix, which seemed to be mitigated with hydrated lime.

The Montana Department of Transportation (MDT) studied the rutting potential of loose mix samples collected from an Advera®-modified WMA section in Yellowstone National Park (YNP) (Perkins, 2009). The production temperature for the WMA section was 121°C, and the dosage level of Advera® was maintained as 0.25% (by the weight of the mix). HWT data from laboratory prepared slabs showed the Advera® mix rutted much faster than the control mix to the point that the former did not pass the MDT specifications (maximum 13 mm rut depth 20,000 cycles). Based on the field experience with the YNP project, the MDT conducted a laboratory study on several