Moisture damage analysis through the TSR and MIST test using water conditioning asphalt

Ana Sofía Figueroa[1, a], Fredy Alberto Reyes[2, b]

[1] *Engineering Faculty, Universidad de la Salle-Colombia, 711, Colombia*
[2] *Engineering Faculty, Javeriana University, 231, Colombia*

[a] afigueroa@unisalle.edu.co
[b] fredy.reyes@javeriana.edu.co

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.247

ABSTRACT

This paper discusses the results obtained by applying the Moisture Damage analysis to one asphalt mixture that was designed by the Superpave® method. The characterization of materials included: rheological, chemical, mechanical and performance tests using eight types of asphalt whose penetration was 80-100 (1/10mm). One of them was named original, S0, and the others seven (S3, S6, S9, S12, S15, S18, S21) were water conditioning during 21 months.

Taking in to account that moisture damage is usually determined by the Tensile Strength Ratio-TSR test, which considers a basic conditioning by temperature and humidity, this research also performed the Moisture Induced Sensitivity Test-MIST test, including the effect of water, temperature and pressure applied for the vehicles, which increase the pores pressure of the mix and could cause some kind of detachment (stripping).

The comparison between the TSR and MIST results showed how important it is to consider the dynamic loads and the temperature when we need to study Moisture Damage. In addition, it was possible to study the influence of the water on the asphalt properties and its impact on the rutting of the asphalt mixture.

Keywords: Asphalt, Best Available Technology, Indirect tension, Performance testing

1. INTRODUCTION

The majority of countries facing moisture-related problems their roads have taken measures aimed at mitigating its harmful effects, measures which run the gamut from the governmental control of construction to the application of anti-stripping agents. However, things have not always turned out favorably, which means the debate regarding the ideal solution to the problem of moisture damage rages on.

The present paper performs the following standard tests to evaluate moisture damage in asphalt: Superpave® methodology, Tensile Strength Ratio (TSR) and the more recently developed Moisture Induced Sensitivity Test (MIST).

The TSR test has achieved standardization, functioning as a sort of reference and control in a wide variety of countries (most notably after the success of studies such as that of (1). This test measures the effect of water on asphalt mixtures by looking at indirect traction; it is suited for dense mixtures made with or without an adhesive additive), which come in the form of liquids and powdered solids. Common examples of anti-stripping agents include hydrated lime or Portland cement per the specification found in INVE-725 .

For its part, the MIST test was designed to simulate stripping damage in less than three hours of treatment. Temperature levels are controlled and pore pressure is generated in the mixture, mimicking temperature, traffic and humidity field conditions. Final MIST measurement parallels that of TSR, in that both quantify the data in terms of percentage of resistance loss (to indirect traction).

Asphalt sample denotations are as follows: S0, S3, S6, S9, S12, S15, S18 and S21, with S referring to Sample and the number referring to the amount of time it was submersed in water (e.g. S6 is an asphalt sample immersed in water for six months). Results are analyzed with rutting and trapezoidal fatigue as a crucial measure of performance for the asphalt mix, especially considering its relation to TSR and MIST.

2. BACKROUND

Hot Mix Asphalt (HMA) performance is affected by the presence of water or water vapor inside the mixture. This is known as moisture damage; since the 1930s, this phenomenon has been investigated. Researchers came to realize the significance of one moisture damage's many manifestations: stripping, i.e. the detachment of the stone aggregate from the asphalt binder (2). Stripping can be defined as the loss of adhesion between the asphalt film0and aggregate surface in the asphalt mixture due to the presence of water. These effects include the breaking up the adhesive bond between the two, ultimately diminishing road functionality (3). Water also affects asphalt cement by physical and/or chemical interactions; interactions of this nature reduce cohesion, which could lead to severe reductions in mixture integrity (4).

The mechanisms involved in stripping can be divided into four parts: displacement, detachment, spontaneous emulsification and pore pressure. Displacement is understood as water penetration into the surface of the aggregates through a rupture in the asphalt film. As for detachment, this factor refers to the separation of asphalt film from the aggregate without a rupture in the asphalt binder's surface. Spontaneous emulsification takes place when water and asphalt combine to form an inverted emulsion; in turn, the emulsion penetrates the substrate and compromises the adhesive bond (5). Water trapped inside air voids present in the mixture are capable of generating high levels of pore pressure when exposed to traffic loads; a corollary is the mechanical erosion produced by increased pore pressure under traffic loads, another important contributor to stripping.

The laboratory protocol for moisture sensitivity in HMAs was established by (6), signaling a meaningful advance in the study of moisture damage on asphalt mixtures. Less than a decade later, his protocol was modified by (7) and became standardized as AASHTO T283 (also known as the indirect traction test for asphalt mixtures). Yet, the search for new procedures, for ever-more reliable tests to determine sensitivity to moisture damage, did not end there: the Western Research Institute (WRI) conducted a thorough investigation of asphalt chemistry and its relation to moisture damage (8). In 2005, the Mississippi Department of Transport (MDOT) carried out an investigation under the name Laboratory Accelerated Stripping Simulator for Hot Mix Asphalt (HMA). Led by (9), researchers assessed HMA coarse gradation utilizing Superpave® methodology; three anti-stripping conditions were evaluated—none, hydrated lime and a liquid anti-stripping agent—along with two asphalt binders—PG 67-22 (pure asphalt) and PG 76-22 (modified polymer asphalt). With the Superpave® gyratory compactor, HMA samples were compacted at a height of 95 mm with 7 % +/- 1 % air voids. Then, samples investigated with the MIST device. Upon completing sample conditioning, researchers proceeded to compare the traction resistance of dry and wet samples to arrive at the "Resistance of Bituminous Paving Mixtures to Stripping (Vacuum Saturation Method)" (MT-63).

For the experiment, the water's turbidity and pH readings were taken before, during and after the test. The samples were tested using the "Determination of Loss of Coating of HMA (Boiling Water Test)" (MT-59) to assess the results obtained via MIST. One of the investigation's primary conclusion reads: "The MIST shows potential in its ability to measure stripping of HMA. The data taken from the change in turbidity ratio clearly indicates that some form of stripping is occurring during the test. Further MIST research must be performed before test parameters can be selected. However, before further research is continued, several MIST modifications should be to improve its operation and stripping evaluation capability." In other words, (9) depict MIST as a tool that offers a rational method for the evaluation of HMA moisture susceptibility. Over the last decade, MIST has been deployed in various Transportation Departments across the United States, as well as in a handful of specific projects.

Other relevant studies include that of (10), which analyzed moisture damage in HMAs utilizing the Simple Performance Test (SPT) and Indirect Traction Test (IDT); the study used asphalt binders (PG 64-22) with and without an anti-stripping additive (ASA) derived from amine. Samples were treated by means of four methods: (1) a freeze-thaw (FT) cycle; (2) two FT cycles; (3) 500 pore pressure cycles with MIST; and, (4) 1,000 pore pressure cycles with MIST.

2. MATERIALS AND TEST METHODS

The current paper compares dense HMAs made with asphalt 80-100 (1/10 mm) (refinery asphalt) using Superpave®, with a maximum PG of 58°C and a fatigue temperature of 19°C. Mixtures made this asphalt are referred to as "original" or S0 (in contrast to water-treated samples). Moisture susceptibility is each type of laboratory asphalt: S0, S3, S6, S9, S12, S15, S18 and S21 and fatigue are compared for asphalt: S0, S12 and S21. As a control for moisture damage, TSR, MIST and wheel tracking testing are performed. On a side note, low asphalt temperatures are not considered by the present study, given that this issue does not pertain to tropical countries (e.g. Colombia).

2.1 Asphalt

The asphalt selected is conditioned in 2mm thicknesses on a 45cm x 45cm, and 4mm thick, glass sheet. These laminae are then immersed in different containers, all of which are fiberglass pools that eliminate water contamination risks, see Figure 1. Additionally, monthly monitoring of the water's properties helps ensure that water quality remains a constant throughout the investigation.

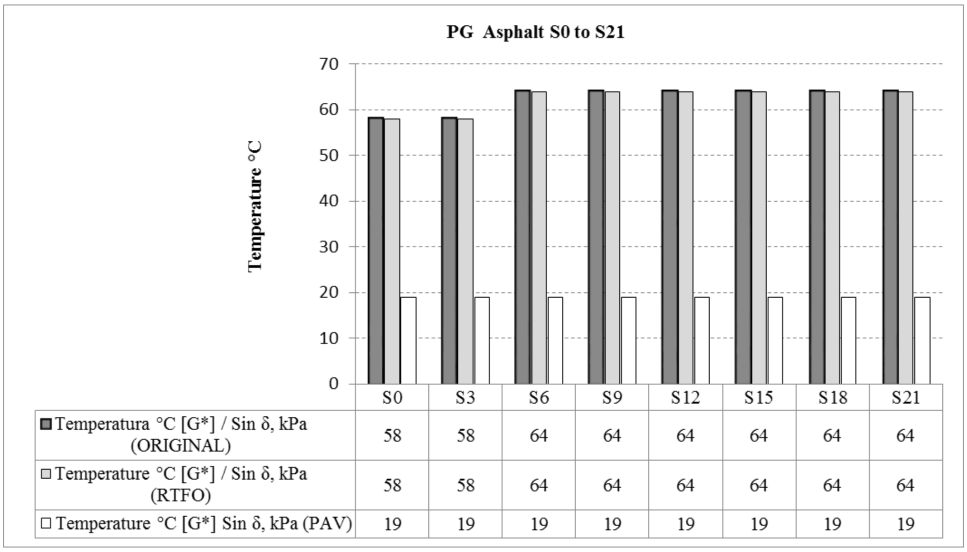
Figure 1: Arrangement of the asphalt submerged in aquaria (a); 2mm laminae on glass with lamina arrangement (b); submerged laminae

Analyses run on the samples every three months over the course of 21 months paid close attention to physical properties, such as viscosity, penetration, softening point, flash point and ductility. Readers are directed to Table 1 for these numbers.

Table 1: Asphalt characterization for each submersion period

Asphalt	TEST (average)				
	Flash Point Cleveland cup	Softening Point	Brookfield Viscosity	Penetration	Ductility
Standard	ASTM D 92	ASTM D36	ASTM D4402 06	ASTM D5	ASTM D113
S0	50,6	50,6	0,381	83,2	144,5
S3	52,0	52,0	0,452	58,7	106,8
S6	53,0	53,0	0,453	48,4	101,7
S9	53,0	53,0	0,394	43,0	93,7
S12	52,2	52,2	0,527	47,1	95,1
S15	52,7	52,7	0,564	46,6	94,2
S18	53,0	53,0	0,584	46,5	93,2
S21	53,3	53,3	0,619	46,5	92,5

PG classification entailed use a direct shear rheometer, where was measured the maximum performance temperatures for each type of asphalt, fatigue temperature in the Pressure Aging Vessel (PAV) and fatigue temperatures in PAV for submerged asphalts. As for PG classification, see Figure 2.



	S0	S3	S6	S9	S12	S15	S18	S21
■ Temperatura °C [G*] / Sin δ, kPa (ORIGINAL)	58	58	64	64	64	64	64	64
▨ Temperature °C [G*] / Sin δ, kPa (RTFO)	58	58	64	64	64	64	64	64
□ Temperature °C [G*] Sin δ, kPa (PAV)	19	19	19	19	19	19	19	19

Figure 2: PG classification for each submersion period.

2.2 Aggregates

The aggregates used for this research are of alluvial metamorphic origin; characterization is depicted in Table 2.

Table 2: Aggregate Characterization

Test	Standard	Samples	Average	Sandard Desviation	Coefficient of variation
LA Abrasion	ASTM C 131 – 01	3	29%	0,62%	0,02
Microdeval Abrasion	ASTM D6928 – 03	3	10,38%	0,26%	0,03
Gravel Solidity	DNER-ME 096 – 98	5	-	-	-
Fine aggregateSolidity		4	-	-	-
Methylene blue	AASHTO TP 57-01 (2004)	3	4,83	0,144	0,03
Elongation Index (IL)	UNE EN 933-3 1997	3	0,07	0,99%	0,14
Flatening Index(IA)		3	21,09%	0,69%	0,03
Flat and Elongated Particles Index (IAL)		3	2,54%	0,46%	0,18
Percentage of Fractured Faces	ASTM D 5821 – 01	3	87,68%	2,42%	0,03
Flat particles	ASTM D 4791 – 99	3	-	-	-
Flat and elongated particles		3	0,10%	0,13%	1,33
Sand Equivalency	ASTM D 2419 – 95	3	48%	9,35%	0,19
Specific Gravity (Bulk)	ASTM C 127 – 88 (Reaprobada en el 2001)	3	2,598	0,017	0,01
Specific Gravity in SSD Condition		3	2,631	0,024	0,01
Especific Gravity Bulk apparent	AASHTO T 85 – 91 (2004)	3	2,686	0,040	0,01
Absorption		3	1,25%	0,31%	0,25

2.3 Asphalt Mixture

Superpave® level 1 mix design is followed, for which 22 briquettes are developed, see Table 3.

Table 3: Asphalt mixture design

Asphalt (%)	Air Voids (%)	% VMA	%VFA
5,7	4,1	14,2	71,6

2.4 Tensile Strength Ratio-TSR

TSR measures water's effect on the asphalt mixtures by determining the indirect tension stress. In the modified version of Lottman's test, void saturation is from 70% to 80%, and temperature and load during the test are 25°C and 5.08

cm/min, respectively. Moisture susceptibility is assessed by preparing a set of laboratory-compacted specimens with voids ranging from 6% to 8%.

2.5 Moisture Induced Sensitivity Test-MIST

MIST relies on accelerated treatment to determine asphalt mixture sensitivity to water and stripping. Temperatures greater than the ambient temperature are used, and pore pressure is generated in the compacted mix to simulate what pavement faces in the form of vehicular loads. The test reproduces three factors: stress, pressure and high temperatures, all while water is present (11). Once treatment has finished, indirect tensile strength is measured. Moisture damage involves studying the relation between tension strength observed in a wet state and that observed in a dry state, see Figure 3.

Figure 3: Test MIST conditions: temperature T=60°C, Cycles N°=3000, Pressure 50 psi.

2.5 Trapezoidal Fatigue

The strain for 1’000.000 cycles for the asphalt mixture made with S0 asphalt was lower than the strain for the asphalt mixture made with S21 due to the oxidation of the asphalt during the submersion time. (Figure 4).

Figure 4: Trapezoidal fatigue test

Another explanation for the fatigue damage is the increasing of asphaltenes during the oxidation process. (Figure 5).

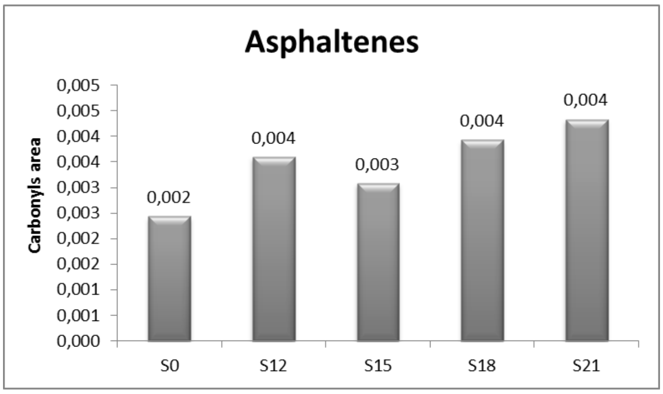


Figure 5: Increasing of asphaltenes for each period. (Infrared Spectroscopy)

Notice that for the asphalt mixture made with S12, there was a recovering of elasticity for the mixture (Figure 6), this behavior could be associated to the healing process, behavior that has been proved for different researchers, (12).

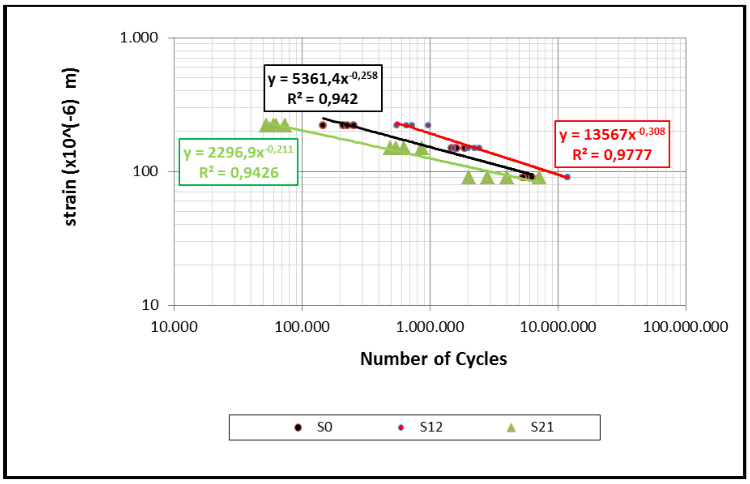
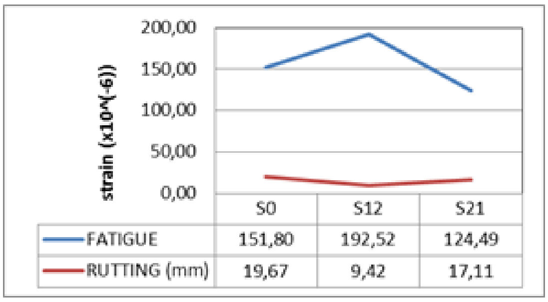


Figure 6: Fatigue low for S0, S12 and S21

2.6 Rutting

The pressure applied in the rutting test was 0.662MPa, the wheel spins at 42 r.p.m over the 300mm-long, 300mm-wide and 50mm-high briquettes at 60°C. The submerged asphalts tests took less time that the standard indicates, so it was only one hour. Notice that for the mixture made with the S21 asphalt, the rutting is lower than the mixture S0 but higher than the mixture S12 so there is a relationship with the fatigue response, when the fatigue increases the rutting decreases in the same period of time, (Figure 8). Also the behavior fluctuates during the submersion time for both types of tests.



	S0	S12	S21
FATIGUE	151,80	192,52	124,49
RUTTING (mm)	19,67	9,42	17,11

Figure 8: Comparison between rutting and fatigue behavior for the asphalt mixtures S0,S12 and S21

CONCLUSIONS

The MIST test showed a closest behavior to the real situation for the pavement taking into account that service pavement is subjected not only to temperature changes but also the effects of water, traffic and the contact pressure of these. The Figure 9, shows the results for the MIST and TSR tests.

Results proved that water also affect negatively the asphalt and the mixture is more susceptible to rutting than fatigue. However both tests have a great influence in the behavior of the asphalt mixture.

The amount of asphaltenes for each immersion period increased contributing to the oxidation process and thus fatigue damage in the asphalt mixture.

During the submersion time PG grade changed for the asphalts but the PAV aging was less significant than the WATER oxidation, which is another type of aging. On the other hand the chemical results have a significant influence in the fatigue process due to the increase of asphaltenes. This result could indicate that it is important to analyze the water effect on the asphalt in this stage of the PG classification.

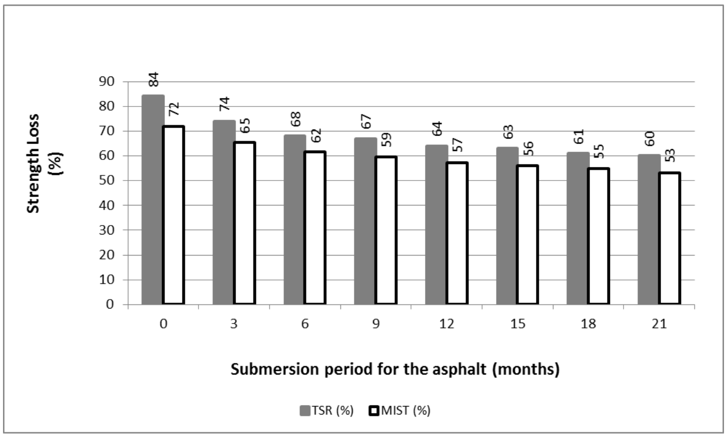


Figure 9: Results for MIST and TSR tests for all submersion periods, so from S0 TO S21

ACKNOWLEDGEMENTS

The authors would like to thank the research team INDETEC at the De La Salle University, CECATA at Javeriana University, CONCRESCOL and Dr. Nelson Gibson from FHWA Turner Fairbank Highway Research Center, the USA.

REFERENCES

1. Kennedy, T. W., Roberts, F. L., & Anagnos, J. N. (1984). Texas boiling test for evaluating moisture susceptibility of asphalt mixtures (No. FHWA-TX-85-63+ 253-5). Center for Transportation Research, Bureau of Engineering Research, University of Texas at Austin.
2. Lottman, R. P., & Johnson, D. L. (1970). Pressure-induced stripping in asphaltic concrete. Highway Research Record, (340).
3. Figueroa, A., Velasquez, R., Reyes, F., & Bahia, H. (2013). Effect of Water Conditioning for Extended Periods on the Properties of Asphalt Binders.Transportation Research Record: Journal of the Transportation Research Board, (2372), 34-45.
4. Kanitpong, K., & Bahia, H. U. (2008). Evaluation of HMA moisture damage in Wisconsin as it relates to pavement performance. International Journal of Pavement Engineering, 9(1), 9-17.
5. Solaimanian, M., Harvey, J., Tahmoressi, M., & Tandon, V. (2003). Test methods to predict moisture sensitivity of Hot-Mix asphalt pavements. Presentado en A national seminar: moisture sensitivity of asphalt pavements.
6. Lottman, R. P. (1978). “Predicting Moisture-Induced Damage to Asphaltic Concrete: Field Evaluation”. NCHRP Report 246, TRB, National Research Council, Washington, D.C.
7. Tunnicliff, D. G.; and Root, R. E. (1984). “Use of Anti-Stripping Additives in Asphaltic Concrete Mixtures”. NCHRP Report 274, Laboratory Phase, TRB, National Research Council, Washington, D.C.
8. Williams, T. M., & Miknis, F. P. (1998). The Effect of Antistrip Treatments on Asphalt-Aggregate Systems: An Environmental Scanning Electron Microscope Study. Journal of elastomers and plastics, 30(4), 282-295.
9. Buchanan, M. S., & Moore, V. M. (2005). Laboratory accelerated stripping simulator for hot mix asphalt (No. FHWA/MS-DOT-RD-04-167,).
10. Chen, X., & Huang, B. (2008). Evaluation of moisture damage in hot mix asphalt using simple performance and Superpave® indirect tensile tests.Construction and Building Materials, 22(9), 1950-1962.
11. Li, X., Gibson, N., & Azari, H. (2010). Evaluation of Instrotek Moisture Induced Sensitivity Test (m 1st) Device: Comparison and Contrast with AASHTO T 283(Draft).
12. Bahia, H. U., Zhai, H., Bonnetti, K., & Kose, S. (1999). Non-linear viscoelastic and fatigue properties of asphalt binders. Journal of the Association of Asphalt Paving Technologists, 68, 1-34.

STANDARS

Instituto Nacional de Vías –INVIAS –Normas 2007-2013.Colombia.
ASTM, A., Test, W. A., Test, C. S., & Test, A. R. (1950). American Society for Testing and Materials (ASTM).
Manual, H. S. (2010). American association of state highway and transportation officials (AASHTO). Washington, DC, 10.