WATER EFFECT ON DETERIORATIONS OF ASPHALT PAVEMENTS

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Abstract: Water has lots of adverse effects on pavement performance. In fact, moisture damage in asphalt pavements is global concern. Moisture damage can be defined as the loss of strength and durability in asphalt mixtures caused by the presence of water. Hence, it's the need to correctly identify the problem and isolate issues of contributing factors like material variability and construction practices for a better understanding of water effect on pavement deterioration. This study has discussed some of major failure mechanisms associated with the presence of water. In addition this study has also summarized some of the widely used methodology for the evaluation of water susceptibility. It was found that the empirical nature of test methods and the inherent variability of the results are the two primary challenges that impede the reliable characterization and assessment of water effect on pavement deterioration.

Keywords : Asphalt pavements, water effect, pavement deteriorations, stripping

INTRODUCTION

Moisture damage can be defined as the loss of strength and durability in asphalt mixtures caused by the presence of water. Moisture damage is induced by the loss of bond between the asphalt cement or the mastic (asphalt cement, the mineral filler and small aggregates) and the fine and coarse aggregate. Moisture damage accelerates as moisture permeates and weakens the mastic, making it more susceptible to moisture during cyclic loading. Finally, moisture damage mechanisms results in the following distresses.

- Stripping: Debonding of aggregates and binder at the bottom of HMA layer.
- Bleeding: Formation of asphalt binder film on the pavement.
- Rutting: Surface depression along wheel path.
- Corrugation and Shoving: Plastic movement typified by ripples or an abrupt wave across the pavement surface.
- Cracking, Water Bleeding and Pumping.
- Raveling: Progressive disintegration of HMA layer.
- Localized failures: Progressive loss of adhesion between binder and aggregates or progressive loss of cohesion in aggregates and in binder.

Historically, six contributing mechanisms have been identified associated with moisture damage: detachment, displacement, spontaneous emulsification, pore pressure induced damage, hydraulic scour, and the effects of the environment on the aggregate–asphalt system. However, it is to be mentioned that moisture damage is not limited to a single mechanism but is the outcome of a combination of these mechanisms (Little and Jones, 2003). Santucci and Aschenbrener (2003) have identified the following factors that contribute to adverse effects of water in asphalt pavement.

Table 1: Factors Contributing Water Induced Distresses (after Santucci and Aschenbrener, 2003)

Mix Design	• Binder and aggregate chemistry • Binder content • Air voids • Additives
Production	• Percent aggregate coating and quality of passing the No. 200 sieve • Temperature at plant • Excess aggregate moisture content • Presence of clay
Construction	• Compaction—high in-place air voids • Permeability—high values • Mix segregation • Changes from mix design to field production (field variability)
Climate	• High-rainfall areas • Freeze–thaw cycles

	• Desert issues (steam stripping)
Other Factors	• Surface drainage • Subsurface drainage • Rehab strategies—chip seals over marginal HMA materials • High truck ADTs.

Identification of the Problem

For a better understanding of water effect on pavement deterioration, it's the need to correctly identify the problem and isolate issues of contributing factors like material variability and construction practices. To this end, current study is intended to discuss the mechanisms associated with water induced damages in pavement. In order to fulfill this objective, this paper addresses following issues:

- Identification of the problem.
- Fundamental concepts- binder and aggregate interaction and representative failure mechanisms.
- Test methods to characterize moisture sensitivity.

FUNDAMENTAL CONCEPTS

Before delving deeper in the mechanisms of water induced distresses, sources of water ingress and egress should be identified. Current engineering practice is predicated on the fact that water enters the pavement despite the efforts to prevent it. The presence of water in the pavement is mainly due to infiltration through the pavement surfaces and shoulders, melting of ice during freezing/thawing cycles, capillary action, and seasonal changes in the water table. The significance of the respective routes depends on the materials, climate, and topography. Elsayed and Lindly (1996) noted that prior to the study by Ridgeway (1982), high water table and capillary water were thought to be the primary causes of excess water in pavements. However, crack and shoulder infiltration, and to some extent subgrade capillary action, are also considered to be the major routes of water entry to the pavement (Dawson and Hill, 1998). A simplified schematic for routes of ingress and egress of water is provided in Figure 1.

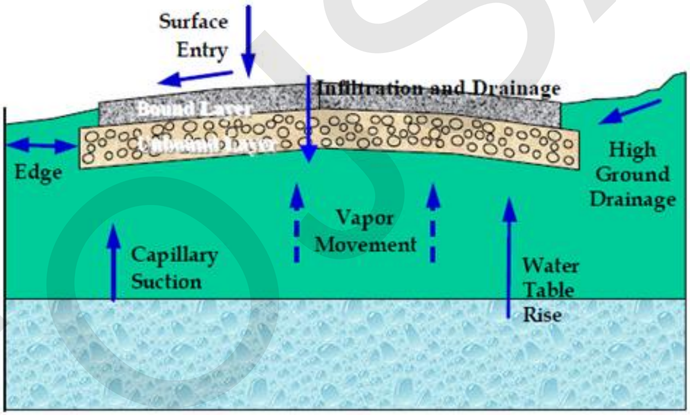

Figure 1: Possible Sources of Water in Pavement (after Elsayed and Lindly, 1996)

The majority of studies on moisture or water damage in asphalt mixtures deals with an observed phenomenon called stripping. Stripping is the dis-placement of asphalt films from aggregate surfaces that occurs when the aggregate has greater affinity for water than the asphalt. It has been speculated that asphalt may be able to strip from an aggregate under dry conditions, especially after it has aged many years, but most losses of adhesion are attributed to the action of water.

The aggregates and asphalt for mixtures susceptible to stripping can be treated with a variety of anti-stripping additives; these additives commonly include the following:

- Liquid anti-stripping additives
- Portland cement
- Hydrated lime

Studies done by Terrel and Al-Swailmi (1994), Kiggundu and Roberts, (1988), Taylor and Khosla (1983) revealed at least five different mechanics of stripping: detachment, displacement, spontaneous emulsification, pore pressure, and hydraulic scour. Kiggundu and Roberts (1988) mentioned additional mechanisms that may play a significant role in moisture damage. These incorporate pH instability and the effects of the environment or climate on asphalt–aggregate material systems.

Moisture Damage Theories

No single theory properly explains moisture damage. Considering this, Kiggundu and Roberts (1988) attempted to combine some of the theories discussed earlier. They tabulated the primary and secondary contribution relationships shown in Table 2. This table attempts to relate theories that explain loss of adhesion to stripping mechanisms. For example, the mechanism of pH instability is, according to Kiggundu and Roberts, explained by both chemical reaction theory and physical and chemical components of interfacial energy theory. Detachment, as a second example, is assumed to be explained by physical and chemical aspects of interfacial energy theory as well as physical aspects of mechanical interlock theory. The physical aspects are manifested, according to Kiggundu and Roberts, by surface energy, while the chemical aspects are attributed to the effects of polarity of the molecules present at the common boundary. Even with this attempt to simplify the interaction of different theories and mechanisms, the interactive complexity of the processes becomes clearly evident. For example, surface bond is not solely a physical process because surface bond is dictated by the chemical nature of bonding at the asphalt and aggregate surface as well as by the presence of broken bonds or incomplete coordination of atoms due to broken bonds resulting in an increase in free energy.

Table 2: Proposed Relationships between Theories of Adhesive Bond Loss and Stripping Mechanisms (After Kiggundu and Roberts, 1988)

		THEORY								
		Mechanical Interlock			Chemical Reaction			Interfacial Energy		
	Proposed Operating Mode	P	C	P-C	P	C	P-C	P	C	P-C
Stripping Mechanism	Detachment	S						S	W	
	Displacement					S		S		
	Spontaneous Emulsification				S	W				
	Film Rupture	S								
	Pore Pressure	S								
	Hydraulic Scouring	S								
	pH Instability					S				S

P= Physical C= Chemical P-C= Physical- Chemical S = Primary Contributor W= Secondary Contributor

TEST METHODS TO CHARACTERIZE MOISTURE SENSITIVITY

Numerous tests have been used to evaluate moisture susceptibility of HMA; however, no test to date has attained any wide acceptance (Roberts et al., 1996). In fact, just about any performance test that can be conducted on a wet or submerged sample can be used to evaluate the effect of moisture on HMA by comparing wet and dry sample test results

The tests that have been developed can be classified into two main categories based on the type of outcome: qualitative and quantitative. Qualitative tests provide a subjective evaluation of the stripping potential and include

- Boiling water test.
- Freeze–thaw pedestal test.
- Quick bottle test.
- Rolling bottle method.

The quantitative tests provide a value for a specific parameter such as strength before and after conditioning. These tests include

- Immersion–compression test.
- Indirect tensile test.
- Marshall immersion test.
- Double punch method.
- Resilient modulus tests.

On the other hand, the tests for identifying the moisture damage potential of an asphalt-aggregate mixture can be divided into two major categories based on mixture type: those on loose mixtures and those on compacted mixtures (Mansour et al., 2003). Tables 3 and 4 summarize the tests for moisture sensitivity on loose and compacted mixtures, respectively.

Table 3: Moisture Sensitivity Tests on Loose Samples

Test	ASTM	AASHTO	Other
Methylene blue			Technical Bulletin 145, International Slurry Seal Association
Film stripping			(California Test 302)
Static immersion	D 1664*	T182	
Dynamic immersion			
Chemical immersion			Standard Method TMH1 (Road Research Laboratory 1986, England)
Surface reaction			Ford et al. (1974)
Quick bottle			Virginia Highway and Transportation Research Council (Maupin 1980)
Boiling	D3625		Tex 530-C Kennedy et al. 1984
Rolling bottle Net adsorption			Isacsson and Jorgensen, Sweden, 1987 SHRP A- 341 (Curtis et al. 1993)
Surface energy			Thelen 1958, HRB Bulletin 192 Cheng et al., AAPT 2002
Pneumatic pull-off			Youtcheff and Aurilio (l997)

Table 4: Moisture Sensitivity Tests on Compacted Specimens

Test	ASTM	AASHTO	Other
Moisture vapor susceptibility			California Test 307 Developed in late 1940s
Immersion-compression	D1075	T165	ASTM STP 252 (Goode 1959)
Marshal immersion			Stuart 1986
Freeze-thaw pedestal test			Kennedy et al. 1982
Original Lottman indirect tension			NCHRP Report 246 (Lottman 1982); Transportation Research Record 515 (1974)
Modified Lottman indirect tension		T283	NCHRP Report 274 (Tunnicliff and Root 1984), Tex 531-C
Tunnicliff-Root	D 4867		NCHRP Report 274 (Tunnicliff and Root 1984)
ECS with resilient modulus			SHRP-A-403 (Al-Swailmi and Terrel 1994)
Hamburg wheel tracking			1993 Tex-242-F
Asphalt pavement analyzer			
ECS/SPT			NCHRP 9-34 2002-03
Multiple freeze-thaw			

Tests on Loose Mixtures

These are the tests conducted on asphalt-coated aggregates in the presence of water. Examples incorporate boil, film strip, and static/dynamic immersion tests. Major advantage of these tests is that they are simple to conduct and less costly to run than tests conducted on compacted specimens. The major disadvantage is that the tests are not capable of taking the pore pressure, traffic action, and mix mechanical properties into account. The results are mostly qualitative, and interpretation of the results becomes a subjective matter depending on the evaluator's experience and judgment. Loose mixture tests are best used for comparison between different aggregate- asphalt mixtures in terms of compatibility, strength of adhesion, and stripping. Mixtures failing in these tests, on the basis of some pre-established criteria, have the potential to strip and should be avoided. However, good results should not mean that a mix can be used, since the effects of the other contributing factors are overlooked in these tests.

In recent years, significant amount of research has been carried out to establish relationship between surface free energy and moisture damage potential. The principle behind using the concept of surface free energy is that the cohesive bonding within asphalt and the adhesive bonding between asphalt and aggregate are related to the surface free energy of the asphalt and aggregate. Researchers at Texas A&M University demonstrated the effectiveness of this concept by using three different aggregates (one granite and two limestone aggregates) and two of the SHRP asphalts (AAM and AAD).

The permanent deformation on compacted specimens using compressive testing correlated well with measured values of surface free energy of the asphalts and aggregates used in the research when tested in dry and wet conditions.

Tests on Compacted Mixtures

These tests are conducted on laboratory compacted specimens or field cores or slabs. Typical compacted mixture tests include indirect tensile freeze-thaw cyclic with modulus and strength measurement, immersion-compression, abrasion weight loss, and sonic vibration tests. The major advantage of these tests is that the mix physical and mechanical properties, water/traffic action, and pore pressure effects can be taken into account. Major disadvantages of these tests are the requirement of more elaborate testing equipment, longer testing times, and more laborious test procedures.

The AASHTO Standard Method of Test T283, "Resistance of Compacted Bituminous Mixture to Moisture Induced Damage," is one of the most commonly used procedures for determining HMA moisture susceptibility. This test is a modified version of Lottman Indirect Tension Test. The test involves curing of loose mixtures for 16 hours at 60° C, followed by an aging period of 2 hours at 135° C. At least six specimens are prepared and compacted. The compacted specimens are expected to have air void contents between 6.5% and 7.5%. Half of the compacted specimens are conditioned through a freeze (optional) cycle followed by a water bath. First, vacuum is applied to partially saturate specimens to a level between 55% and 80%. Vacuum-saturated samples are kept in a -18° C freezer for 16 hours and then placed in a 60° C water bath for 24 hours. After this period the specimens are considered conditioned. The other three samples remain unconditioned. All of the samples are brought to a constant temperature, and the indirect tensile strength is measured on both dry (unconditioned) and conditioned specimens. Test results are reported as a tensile strength ratio:

$$TSR = \frac{S_2}{S_1}$$

where, TSR = Tensile strength ratio,
S_1 = average dry sample tensile strength and
S_2 = average conditioned sample tensile strength.

The Hamburg Wheel Tracking Device (HWTD) is used to measure combined effects of rutting and moisture damage by rolling a steel wheel across the surface of an asphalt concrete specimen that is immersed in hot water. Originally, both beam and cylindrical samples were tested with device. However, with the increase in use of superpave gyratory compactor (SGC), researchers have adopted a testing protocol using cylindrical specimens compacted in the SGC as shown in Figure 2.

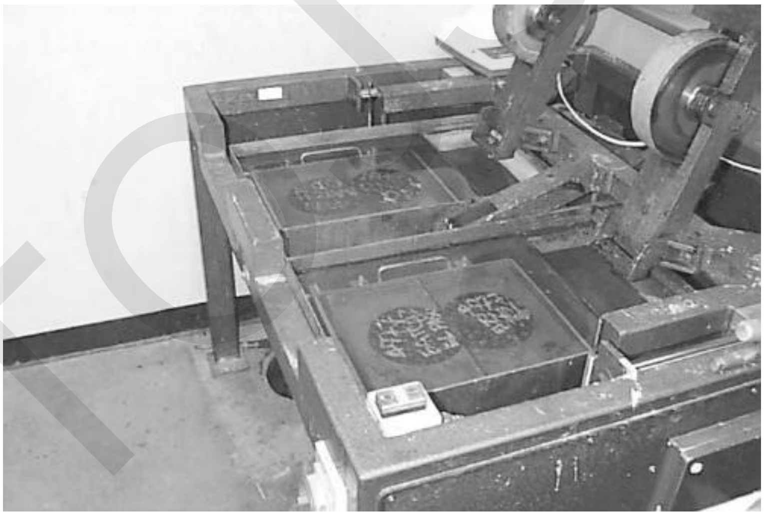

Figure 2: HWTD with Cylindrical Specimens

CONCLUSIONS

Water effect on pavement deterioration is a complex phenomenon involving thermodynamic, chemical, physical, and mechanical processes that contribute to pavement deterioration. This study has discussed some of major failure mechanisms associated with the presence of water. In addition this study has also summarized some of the widely used methodology for the evaluation of water susceptibility. It was found that the empirical nature of test methods and the inherent variability of the results are the two primary challenges that impede the reliable characterization and assessment of water effect on pavement deterioration. This study successfully conveys the fact that water effect on pavement deterioration is an open ended problem which is to be solved by the broader understanding of representative failure mechanism and site-specific treatments applicable to the problem.

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