Towards a better understanding of moisture damage of hot mix asphalt using complex modulus

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TOWARDS A BETTER UNDERSTANDING OF MOISTURE DAMAGE OF HOT MIX ASPHALT USING COMPLEX MODULUS

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ABSTRACT

Various laboratory tests are used to evaluate the moisture sensitivity of bituminous mixtures. However, most of them are destructive and require a large number of specimens. Consequently, they do not permit continuous monitoring of the deterioration in mechanical performance or, still less, measurement of the recovery of this performance as water evaporates during the drying process. Evaluating the mechanical characteristics of bituminous mixtures using a Cole-Cole plot or in Black space provides new possibilities for evaluate the effect of water at the bitumen-aggregate interface.

Keywords: adhesion, complex modulus, bonding, rheology

1. INTRODUCTION

Moisture is the major environmental factor that adversely affects the quality of hot mix asphalt and causes stripping which the quality of service of pavements is lost. In bituminous mixtures water acts essentially at the aggregate-bitumen interface by impairing the bond between the two materials. Numerous testing procedures have been developed for evaluating the potential for aggregate to release the asphalt binder in the presence of water. The study presented in this paper describes a method for evaluating the effects of immersion and drying on the mechanical performance of a bituminous coated material. This work was conducted as part of doctoral research at Nantes University and conducted at the Laboratoire Central des Ponts et Chaussées.

2. EXPERIMENTAL PROCEDURE

The experiments described here were developed with the aim of finding a laboratory procedure that provides a reliable assessment of moisture damage and recovery after drying for bituminous mixtures[1]. We evaluate the modulus complex of the samples to temperatures controlled and frequencies between 1 and 40 Hertz [2], then the samples were conditioned by saturation and immersion (60°C) to simulate a mixture's moisture exposure, the drying process became in oven to temperature of 60 degrees and controlled relative humidity.

2.1 Materials and mix designs

The mix designs used in this study are shown in the Figures 1 and 2 and Tables 1 and 2 below.

Mix	Bitumen content %	Apparent Density T/m3	Asphalt Pen. Grade	Voids content %	Richness modulus* K
A (Diorite)	5.6	2.42	50-70	7.0	3.7
B (Gneiss)	5.15	2.44	50-70	5.0	3.15

Table 1 : Characteristics of mixtures

*Proportional magnitude to the thickness bitumen film surrounded the aggregate

Sieve mm	%Passing A	%Passing B
20	100	100
14	96,3	95,31
12,5	87,7	86,69
10	70,4	70,33
8	60,5	60,32
6,3	53,9	53,7
4	41,6	45,2
2	33,1	33
1	26,2	26
0,315	15	15
0,08	6,9	6,9

Table 2 : Grading aggregate used in mix A and B

2.2 Complex Modulus measurements.

Plots of the norm of the complex modulus against the phase angle (Black space) for various immersion durations at 60°C are distinct and appear to be correlated with the duration of immersion (Fig. 1).

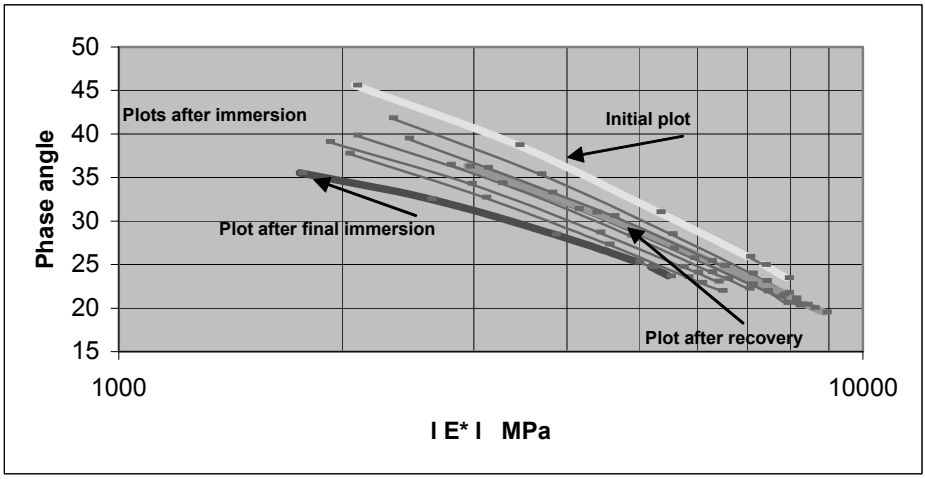

Figure 1. Plots for bituminous mixtures in Black space with different immersion times (Mix A)

The slopes are such that for a given modulus, the phase angle is lower the longer the immersion time ; this means that the viscosity of the material is being reduced. After drying, the specimen partially regains this viscous component, without however entirely recovering the performance of the initial specimen (Fig 1). About 15% of the specimen's voids remain filled with water, and stripping is observed

after fracture of the specimen. We can see that the stiffness modulus measured after drying are higher than the initial values. This indicates that evaluation conducted solely on the basis of the stiffness modulus values can lead to an overestimation of a material's ability to retain aggregate-bitumen bond.

A Cole-Cole plot provides similar results (Fig. 2).

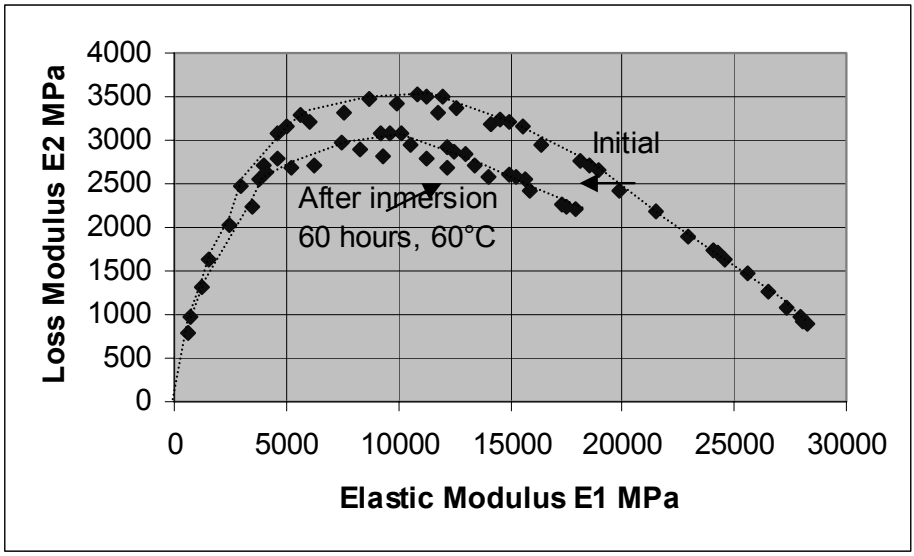

Figure 2. Variation in a Cole-Cole plot, after immersion (Mix B, Test -10 to 30°C)

This change clearly shows that what is occurring is structural deterioration. However, this graph provides no information about the strength of the binder-aggregate bond (area affected by debonding or the density of debonding sites, the scale and depth of water penetration within the aggregate particles). In order to compare the moisture resistance of different mix designs, an initial empirical approach consists of classifying the modulus loss levels before and after immersion for each mix design under given temperature and immersion time conditions. We therefore need to construct an absolute scale of comparison.

3. MICROMECHANICAL MODEL

3.1 Theoretical Development

In order to develop a model of variation of the Cole-Cole plane by moisture damage of hot mix asphalt, it will be used the micromechanical (n+1)-phase model developed by Hervé and Zaoui [3]. This model appears as a self –consistent scheme for which the problem of localization considers an isotropic elastic spherical inclusion of radius R1. This sphere is overlapped by concentric shells de radius R2…Rn. The composite sphere is embedded in an equivalent homogeneous medium whose bulk modulus is K* and shear modulus is μ^*.

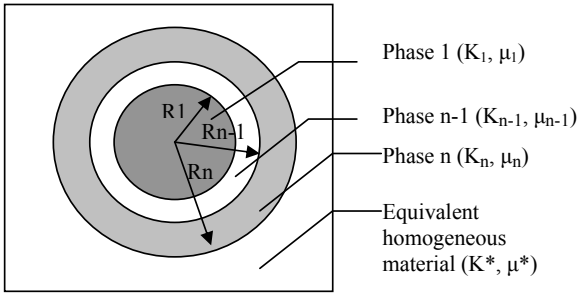

Figure 3. Spherical core-concentric shell model

When:

$$K^* = K_n^{eff} = K_n + \frac{R_{n-1}^3 / R_n^3}{\frac{1}{K_{(n-1)}^{eff} - K_n} + \frac{3(R_n^3 - R_{(n-1)}^3)}{R_n^3} \frac{1}{3K_n + 4\mu_n}}$$

Complex shear modulus is the solution of the following quadratic equation:

$$A\left[\frac{\mu^*}{\mu_n}\right]^2 + B\left[\frac{\mu}{\mu_n}\right] + C = 0$$

A, B and C are the complex coefficients which may be calculated from equations suggested by Hervé and Zaoui [3]. These constants depend on the Radius R1, Rn-1,Rn and the mechanical characteristics of each constituent.

3.2 Application to Hot Mix Asphalt

We have used a model of three phases and a mix internal structure (figure 4), to calculate bulk modulus and shear modulus of bituminous mix, in three successive steps (Figure 5):

- Step 1. Calcule K* and μ* of mastic (filler overlapped by asphalt)
- Step 2. Calcule K* and μ* of matrix (Voids surrounded by mastic)
- Step 3. Calcule K* and μ* of HMA (Aggregate surrounded by matrix)

R1 and R2 are obtained by the ratio of the filler volume on the mastic volume, or by ratio of the aggregates volume on the volume total of the mix.

$$\text{(R1 and R2, step 1):} \quad \frac{FillerVolume}{MasticVolume} = \frac{R_{filler}^3}{R_{Bitumen}^3}$$

(R1 and R2, step 2): $$\frac{VoidsVolume}{MasticVolume + VoidsVolume} = \frac{R_{voids}^3}{R_{Mastic}^3}$$

(R1 and R2, step 3): $$\frac{AggregateVolume}{TotalVolume} = \frac{R_{aggregate}^3}{R_{Matrix}^3}$$

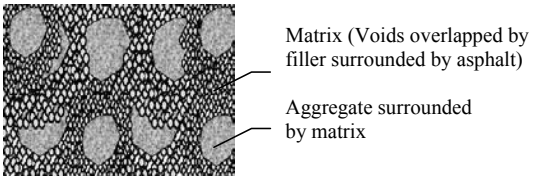

Figure 4. Structure supposed for HMA

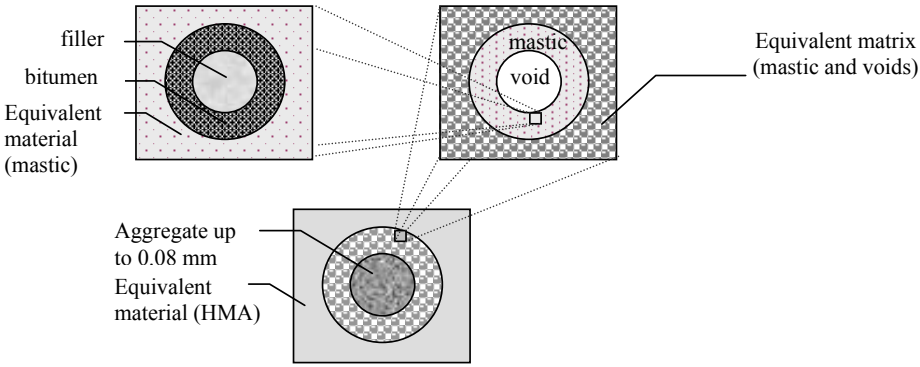

Figure 5. Representation of Hot Mix Asphalt by three spherical core-concentric shell model

3.3 Comparison Model-Experimental Data At Initial State

Application of the previous model to Hot mix asphalt requires the knowledge of the characteristics of each constituent of the mixture.

- Young's modulus and Poisson's ratio of the aggregate which behavior is assumed to be isotropic, linear and elastic. On cylindrical samples cored from block of Diorite (Aggregate Mix A), the following values are obtained: Young's modulus E = 104000 MPa and Poisson's Ratio ν= 0,25 [4].
- Complex modulus of the binder in a range of temperature and frequency. We take into account the assumptions of quasi-incompressibility for the binder, we used ν= 0,49 for bitumen 10/20 and 0,47 for bitumen 50/70 (to obtain a good fitting of the model on experimental data) and the complex modulus of binder tested with Metravib rheometer, in calculations (Figure 6).
- Young's modulus and Poisson's ratio of the voids is assumed. Young's modulus E = 0,01 MPa and quasi-total compressibility, Poisson's Ratio ν= 0,01.

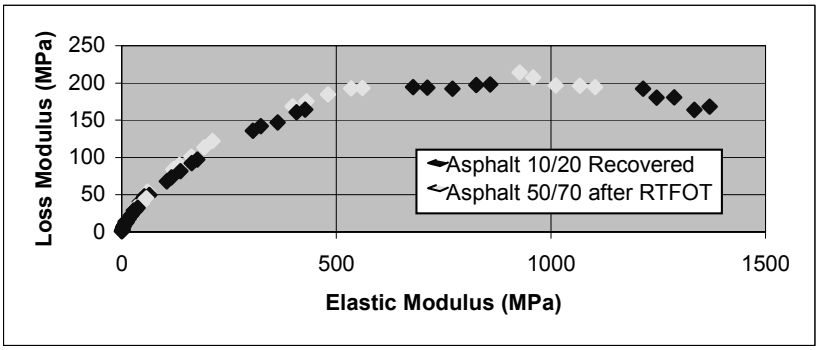

Figure 6. Rheological curves of two bitumen with different penetration grade

The results from the model when compared with experimental data shown in Figures 7, 8 and 9 indicate the theoretical predictions fall short of the experimental data.

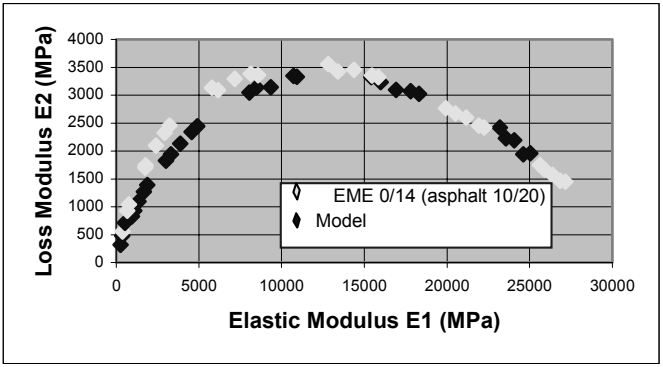

Figure 7. Rheological curves predicted by model and measured for EME 0/14 (High Modulus Mixture)

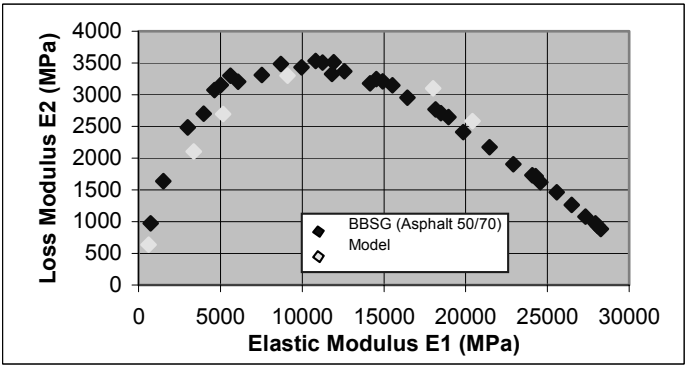

Figure 8. . Rheological curves predicted by model and measured for BBSG 0/10 (Mixture Dense)

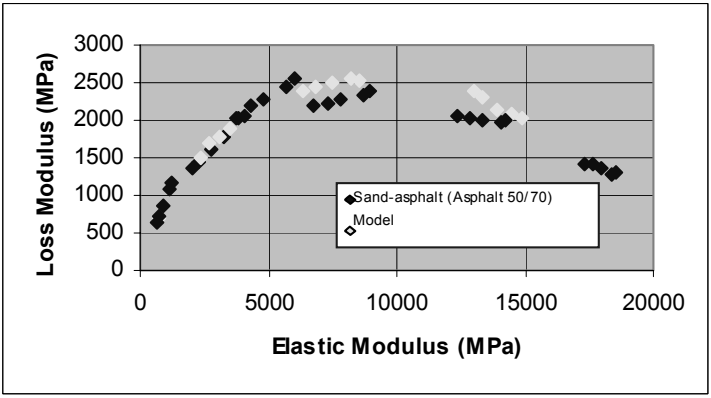

Figure 9. . Rheological curves predicted by model and measured for Sand-asphalt 0/6

3.3 Deterioration Model

Using the model of 4 phases of Hervé and Zaoui, we developed a model of deterioration of the mixture by action of the water in the aggregate-asphalt interface.

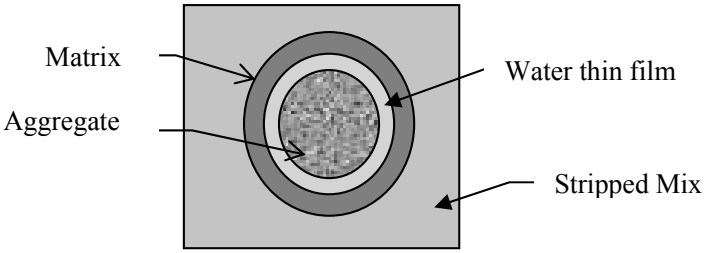

Figure 10. Model to Calculate Moisture Damage

The model indicates that the Bulk Modulus was practically constant for the state initial mix and stripped mix. However, the corresponding Shear Modulus was affected. The ratio of the Shear Modulus of the Composite and the shear modulus of the matrix is near 1.0.

Based on this deterioration model, we assumed that the moisture has an effect on the aggregate size up to 0.08 mm. The percentage of damage is obtained from inclusions of stripped mixture in the original Hot mix asphalt; we are obtained the following Cole-Cole plots for a stripped bituminous mixture at different percentage of damage:

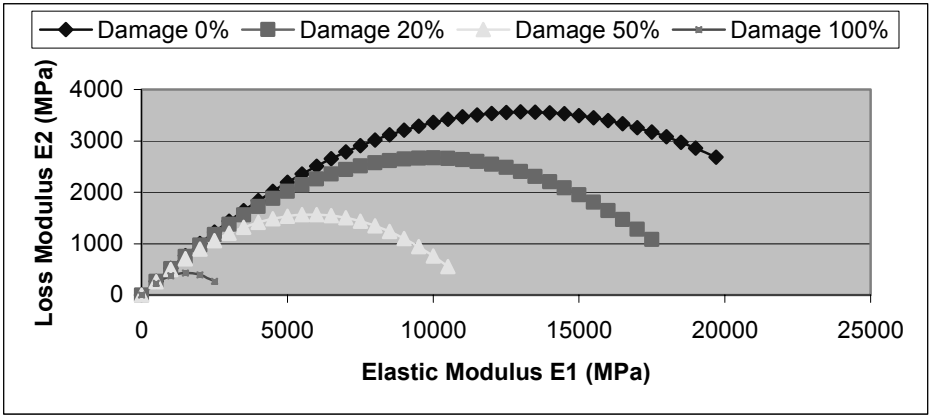

Figure 11. Cole-Cole Plots of Moisture Damage

The variation of elastic modulus to infinite frequency has not been explained. With this methodology, it is expected to make other developments towards a better understanding of the stripping evolution.

4. CONCLUSIONS

The evolution of master curves of the complex modulus of mixes in Black space or Cole-Cole plots may be used as a criterion for determining moisture susceptibility and the recovery of this performance as water evaporates.

The micro-mechanical models are important in understanding the behavior of composite systems. The Hervé and Zaoui model allow to calculate the HMA rheological curve from the characteristics of its components.

The proposed methodology provides a method for determining evolution of stripping and recuperation bonding bitumen-aggregates.

The evolution of rheological curves showed in this work is appropriate method to evaluate a mixture's moisture sensitivity when the time of conditioned specimens is small.

5. ACKNOWLEDGEMENTS

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