

Testing Asphalt Emulsion Full Depth Reclamation Mixes for Pavement Design

Todd W. Thomas, P.E. and Richard W. May, Ph.D., P.E.
SemMaterials, L.P.
6120 South Yale Avenue, Suite 700
Tulsa, Oklahoma, USA
tthomas@semgrouplp.com
rmay@semgrouplp.com

Abstract

Full Depth Reclamation (FDR) with asphalt emulsion is an effective method for rehabilitating distressed roads. A reclaimer mills through the asphalt layer, incorporates underlying aggregate base, adds asphalt emulsion, mixes the material, and lays it back down. Compactors and motor graders complete the process, and the new layer is ready for traffic that same day. The process adds strength and flexibility to the pavement, as well as removes distresses to improve future performance.

Pavement design methods used in the U.S. do not account for the unique properties of FDR. These mixes behave somewhat similar to granular bases in nature in their early life. After curing, this material exhibits the same visco-elastic stiffness and performance-related properties of asphalt concrete. This change in behavior depends on the materials that were stabilized and the properties of the asphalt emulsion with which they were stabilized.

The asphalt emulsion used in this study is designed for returning the pavement to traffic on the same day as construction and for a quicker time to overlay compared to other emulsified asphalts. Two aggregate combinations were studied – one consisted of 25% reclaimed asphalt pavement (RAP) and 75% base rock, and the other consisted of 75% RAP and 25% base rock.

This paper will discuss the laboratory testing performed on FDR cold mixes and how those tests relate to the expected performance in a pavement structure. In addition, this paper will also describe results measured with the new American Association of State Highway and Transportation Officials (AASHTO) dynamic modulus test and the determination of temperature-shifted master curves.

Retraitement en place (RP) aux liants hydrocarbonés est une méthode efficace pour réhabiliter les chaussées abimées. Une stabilisatrice désintègre le béton bitumineux, incorpore la couche d'assise, ajoute une émulsion de bitume, mélange les matériaux, et repend le tout. Rouleaux de compactage et niveleuses terminent le procédé, et la nouvelle couche est prête à être ouverte au trafic le même jour. Le procédé renforce et ajoute flexibilité à la chaussée, et également traite les défauts d'usures afin d'améliorer la performance future.

Les méthodes de dimensionnement utilisées aux Etats-Unis ne prennent pas en compte les caractéristiques uniques du RP. Ces mélanges se comportent

quelque peu comme des couches de granulats par nature dans leur durée de vie initiale. Après maturation, ces matériaux présentent les mêmes performances et propriétés viscoélastiques de module que les enrobés bitumineux. Ce changement de comportement dépend des matériaux stabilisés et des propriétés de l'émulsion de bitume utilisée pour leur stabilisation.

L'émulsion de bitume utilisée dans cette étude est conçue pour ouvrir la chaussée au trafic le même jour de sa construction et pour une plus rapide couverture par une nouvelle couche d'enrobé bitumineux comparé à d'autres émulsions de bitume. Deux combinaisons de granulats ont été étudiées – une composée de 25% d'agrégats d'enrobés et 75% de granulats de couche d'assise et l'autre composée de 75% d'agrégats d'enrobés et 25% de granulats de couche d'assise.

Cette étude traitera d'essais en laboratoire faits sur des mélanges stabilisés à froid et comment ces essais se rapportent aux prédictions de performance au sein de la chaussée. En supplément, cette étude décrira aussi des résultats de module dynamique obtenus par la nouvelle méthode American Association of State Highway and Transportation Officials (AASHTO) ainsi que la détermination de courbe maîtresses décalées en fonction de la température.

1 - Introduction

1/1 - Background

Full Depth Reclamation (FDR) is a road rehabilitation technique in which the full thickness of asphalt pavement and a predetermined portion of underlying base rock materials are uniformly pulverized and blended to create an upgraded, homogenous base material. A road reclaimer distributes the asphalt emulsion within the pulverization process and simultaneously mixes the emulsion with the existing road materials. Motor graders and compactors complete the mixing, grading, and compaction process and, with a properly selected asphalt emulsion, the new layer is ready for traffic on that same day with a final surface to be applied later. The overall process improves material shear strength and adds flexibility to the pavement, while removing and directly addressing existing distresses. The process facilitates longer-lasting and smoother performance from the overlying new surface layer. A typical alternative approach to FDR is to use a Portland cement additive, but this strategy usually restricts traffic for more than four to seven days after construction, and the stiffer binder in this matrix has also been known to crack prematurely due to hydration shrinkage, thermal expansion/contraction, and high bending stresses.

1/2 - Mix Design

For FDR, the asphalt emulsion is formulated in the laboratory and produced at a manufacturing facility to give the desired chemical properties selected based on laboratory evaluations of the milled existing reclaimed asphalt pavement (RAP). The overall mixture properties are designed as influenced by the final blended binder properties, the relative proportion of RAP and base rock materials, and the final compacted volumetric composition of the components. The final mix design is further checked for moisture susceptibility, stability, and low temperature cracking potential.

1/3 - Construction

The emulsion is transported to the road construction site by truck. The truck is pushed by the road reclaimer, which pumps the emulsion from the delivery truck and meters the emulsion through a spray bar with nozzles in the mixing chamber. This chamber encloses the milling head, which simultaneously mills through the road and mixes the base material with the asphalt emulsion. The emulsion application rate is linked to the forward speed of the reclaimer; the quantity in liters per meter is determined in the laboratory evaluation before construction. Behind the road reclaimer, the fully processed base material is ready for immediate breakdown rolling by a pneumatic roller and final rolling by a static finishing roller.

The final product of the road reclaimer and rolling process serves as a uniform stable foundation for a suitable wearing course. This properly constructed base layer is typically allowed to be open to traffic for some additional final curing period until the final surface is placed. The thickness of the final surface depends on the amount of traffic and the strength of the natural subgrade beneath the base.

2 - Design of Pavement Structure

2/1 - Current Pavement Design Method

The total FDR pavement structure is designed based on the quality and strength of the soil subgrade, the volume and composition of traffic, the seasonal climatic conditions, and the material characterization of the homogenized base layer. In the U.S, nearly all state departments of transportation (DOT) currently use the 1993 AASHTO Guide (1) as the primary design method for determining the required pavement thickness and evaluating the overall cross-section. This particular design method uses an empirical relationship between the condition and roughness of the roadway, in terms of Present Serviceability Index (PSI), and traffic, in terms of the number of 80 kN Equivalent Single Axle Loads (ESAL) using the roadway. The required pavement is characterized in this relationship by a structural number (SN), which represents the sum of the contributions of each layer component. For each layer above the subgrade, the layer coefficient of each type of material (which is a function of the modulus) is multiplied by the proposed layer thickness. Since 1960, much research has been devoted to refining and updating this empirical method for changing technologies, such as material characterization and statistical reliability, and changing traffic characteristics such as tire type, suspension systems, and tire pressures. However, the inherent weaknesses of the basic 1960 regression equation eventually dictated the need for a new approach.

2/2 - Future Pavement Design Method

Under the National Cooperative Highway Research Program (NCHRP), Project 1-37A was initiated to develop the framework for a new Mechanistic-Empirical Pavement Design Guide (MEPDG) (2). The researchers developed a greatly expanded capacity for describing the details of each axle configuration in the design traffic mixture and for accounting for the moisture and temperature impacts on the material properties. This method also allows the designer to enter the actual material properties for a layered-elastic analysis of a flexible pavement and it contains default transfer functions for predicting distress deterioration for fatigue, rutting, and low temperature cracking. More research is planned to improve these basic components and increase the flexibility of the new MEPDG for handling innovative materials. The work described in this paper is an example of how the MEPDG could be used in the future to incorporate a different type of layer, such as FDR made with emulsion, within the pavement cross-section.

3 - Materials

3/1 - FDR Materials

Virgin aggregate and representative RAP samples were used to produce blends for mixing with chemically engineered asphalt emulsion. One mix was a blend of 75% limestone aggregate from the state of Illinois and 25% RAP mixed with 5.5% asphalt emulsion. Since small amounts of cement are sometimes blended with the base materials before the addition of the emulsion, mixes with 1% cement added to this blend were compared to mixes without cement (two blends). The second mix was a blend of 25% limestone and 75% RAP mixed with 3.7% asphalt emulsion; no cement was used in this blend (one blend). The particle size distributions of these blends are shown in Figure 1. The first blend

simulates thin existing asphalt surface and the second blend simulates thicker asphalt surface, which incorporates more of the existing asphalt-bound material.

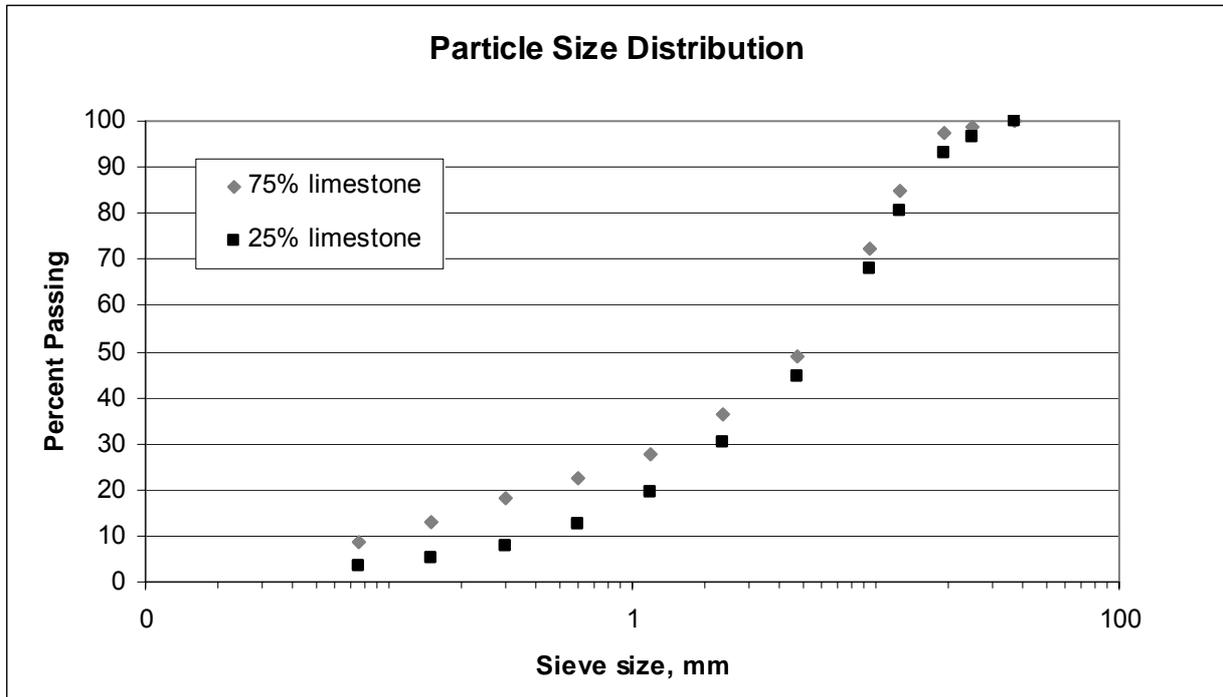


Figure 1

3/2 - Asphalt Emulsion

Two asphalt emulsions (referred to as Emulsion A and Emulsion B) were used in the three blends for a total of six blends. The asphalt emulsions are cationic and differ slightly in the chemicals used to emulsify them. Each emulsion was composed of 65% asphalt and 35% water. The base asphalt was tested in a Dynamic Shear Rheometer (DSR), according to AASHTO T 315 (3); the shear modulus (G^*) properties are shown in Table 1. $G^*/\sin(\delta)$ is the rutting criterion (1.0 kPa on unaged binder) used in the Performance Grade (PG) binder system.

Temperature, °C	52	58	64
Shear modulus G^* , kPa	2.980	1.323	0.623
Phase angle delta, °	85.91	87.42	88.66
$G^*/\sin(\delta)$	2.988	1.324	0.623

Table 1 – Shear Modulus Properties of Base Asphalt

3/3 - Water

Before the emulsion was added, the 75% limestone mixture had 4.9% water and the 25% limestone mixture had 3% water. These water contents represent expected moisture contents that are typically measured in a road for these types of materials.

4 - Testing of Mixtures

4/1 - Preparation of Dynamic Modulus Mixtures

After mixing, the loose material is cured for 30 minutes at 40°C before being compacted in a Superpave Gyrotory Compactor (SGC) set for 30 gyrations to a height of 170 mm in a 150 mm diameter mold. The compacted specimen is extruded from the mold and allowed to cure for another 48 hours at 40°C. For measuring Dynamic Modulus (E^*), the center 100 mm of the lab-compacted specimens are cored out and then the ends are sawed off to achieve a final test specimen that is 100 mm in diameter by 150 mm high and has more uniform air voids.

4/2 - Dynamic Modulus Testing

Three replicate E^* specimens for each mix are tested in uniaxial compression with a servo-hydraulic loading frame, in accordance with the AASHTO provisional test method, TP-62. Each specimen is subjected to six frequencies of loading (25, 10, 5, 1, 0.5, and 0.1 Hz) at each of five temperatures (-10, 4.4, 21.1, 37.8, and 54.4°C), beginning with the fastest frequency and the coolest temperature. For each loading condition, a sinusoidal load is applied to maintain a peak-to-peak controlled strain magnitude of 50 to 150 $\mu\epsilon$ (microstrains) within the specimen. The elastic strain is measured with 100 mm gauge length extensometers placed at three points (each 120°) around the circumference of the specimen.

5 - Test Results

5/1 - Results of Dynamic Modulus Tests

The E^* testing results for each mixture are determined for all 30 testing conditions (six frequencies at five temperatures) for each of the three replicate specimens and the overall average for the mixture. The values for the individual specimens are also averages based on the three strains measured around the circumference of the specimen. Level 1 of the MEPDG software, which allows the user to enter the actual measured mixture properties for asphalt concrete in lieu of using calculated values from a regression equation (Level 2) or default values (Level 3), constructs the master curves from the individual mixture values by shifting the data based on binder information. The binder Complex Shear modulus (G^*) and phase angle (δ), measured with the DSR, are used to calculate the binder viscosity over a range of temperatures with the following equation:

$$\text{Viscosity} = (G^*/10) * (1/\sin(\delta))^{4.8628}$$

The viscosity information is then used to establish a temperature susceptibility relationship for the binder using the following equation:

$$\text{Log Log Viscosity} = A + VTS (\text{Log Temp } (^\circ\text{R}))$$

Normally, the binder information is measured on material that has been aged in the Rolling Thin Film Oven (RTFO) to represent a condition that simulates the aging of the binder at the mixing plant. However, with the emulsions used in FDR, no aging is required or appropriate.

The master curve is determined using a reference temperature of 21.1°C (70°F). A polynomial shift function, that relates the shift factor, a_T , to temperature, T ,

($\text{Log } a_T = AT^2 + BT + C$), is used to fit the data using numerical optimizations of the following equation:

$$\text{Log } (E^*) = \delta + \left(\frac{\alpha}{1 + \text{EXP}(\beta + \gamma((\text{Log } (F) + c(10^{(A + \text{VTS } (\text{Log Temp } (^{\circ}\text{R}))) - \text{Log}(\text{Viscosity } 70^{\circ}\text{F}))))))} \right)$$

This sigmoidal shaped function is the basic model format of the asphalt concrete E^* used in the MEPDG. The E^* master curves of all six mixtures are plotted in Figure 2. The emulsified mixtures are more clearly delineated at the lower reduced frequencies (warmer temperatures and slower frequencies). At this lower end of the scale, the mixtures with 75% RAP have a lower modulus with 1.5 to 2% less air voids (and are more rutting susceptible) than the mixtures with 25% RAP. As expected, by adding 1% cement, these 25% RAP mixtures exhibit an even higher modulus at this lower range of the scale. At the upper reduced frequencies (cooler temperatures and higher frequencies), the 25% RAP, with binder A and 1% cement had the lowest modulus, implying that it is less susceptible to thermal cracking.

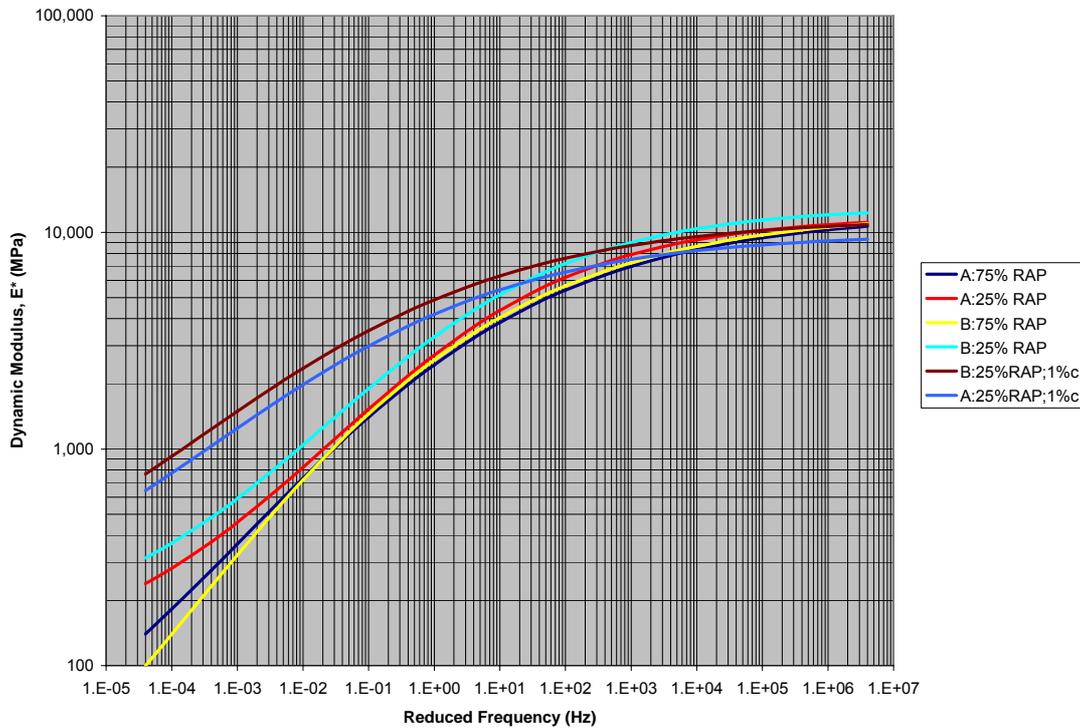


Figure 2

5/2 – Results of Software Analysis

The MEPDG software (version 0.800, 11-4-2005) was used to analyze a typical pavement structure with the E^* results for the mixture with Emulsion A, 25% RAP, and no cement. The pavement cross-section modeled in the software had an asphalt concrete surface of 50 mm and a 150 mm thick FDR layer over a 200 mm thick aggregate base layer. The assumed subgrade soil was lean clay. Since the MEPDG software does not currently have performance models for emulsion mixes, the default distress models for asphalt concrete were used for

this analysis. Fatigue cracking models for these emulsion mixes are being developed. For 150 heavy trucks initially per day with 4% annual growth, the software predicted 1.0 m/km of top-down longitudinal cracking, 0.64% bottom-up alligator cracking, 0.04 m/km of thermal transverse cracking, 2.97 mm of asphalt layer rutting (FDR and HMA layers combined), and 7.47 mm of total rutting (asphalt layers, aggregate base layer, and subgrade combined).

6 – Conclusions

These actual materials were used to construct a rural highway with this technology in the summer of 2003 and it is performing well, carrying mostly car traffic and agricultural equipment. Similar construction has also been used in ten different states in the U.S.

Currently, due to a lack of research effort in this area, the MEPDG treats FDR as an unbound material with a default constant modulus of 69 MPa. This value is unrealistic considering that the mixture with Emulsion A, 25% RAP, and no cement had an E^* of 4415 MPa at 21°C and 10 Hz. Although the stress-strain behavior (modulus) of emulsified recycled asphalt mixtures does vary significantly with mix composition, binder type, and quantity of RAP, it has been clearly demonstrated that these FDR mixes would be better characterized as a less-aged asphalt concrete. In addition, there is much opportunity for further optimization of these types of materials.

7 – Acknowledgments

The authors gratefully acknowledge the contributions of Bill Criqui, Lou Harper, Stephane Charmot, and Matt Carnal of SemMaterials, L.P. for their contributions to this paper. The authors also thank Mickey Blizzard and Brian Majeska of SemMaterials, L.P. for sponsoring this work.

References

- (1) American Association of State Highway and Transportation Officials, *AASHTO Guide for Design of Pavement Structures*, 1993.
- (2) NCHRP Project 1-37A, *Development of the 2002 Guide for the Design of New and Rehabilitated Pavement Structures. Design Guide and Supplemental Documentation*, Transportation Research Board of the National Academies, Washington, D.C., 2004.
- (3) American Association of State Highway and Transportation Officials, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 2001.