Evaluation of Surface Treatments Effectiveness Using Mechanical Testing

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ABSTRACT: One of the most important tasks for transportation agencies is to select the appropriate rehabilitation and maintenance technique. Currently, many agencies spend millions of dollars a year to maintain their pavement networks at acceptable conditions. Thus, a better understanding of the fundamental mechanisms controlling pavement deterioration and the process by which various maintenance and rehabilitation methods delay pavement deterioration becomes an important priority. Several researchers have investigated the benefits of using surface treatments to prolong the service life of existing asphalt pavements. The majority of the research focuses on the construction activities and on the calculation of economic benefits. Currently, there is limited research documenting the mechanism by which surface treatments seal and protect the existing pavement from further aging and deterioration from cracking. This paper investigates the effectiveness of surface treatments in preventing aging by means of mechanical testing using Semi-Circular Bending test (SCB), Bending Beam Rheometer (BBR) for asphalt mixtures and Dynamic Shear Rheometer (DSR), Direct Tension Test (DTT) and BBR for asphalt binders. Samples extracted from trunk highway 251 (Clarks Grove, MN, USA) were used to study the effectiveness of three surface treatments applied in 2002: Fog seal (CSS-1h), Rejuvenator (Reclamite) and Chip seal (CRS-2p, 3/8" Aggregate). Based on the experimental results and their analysis of variance it was found that the surface treatment that prevents aging the most is the chip seal.

KEY WORDS: Pavement Maintenance, Pavement Rehabilitation, Surface Treatments, Semi-circular Bending (SCB) test, Bending Beam Rheometer (BBR), Dynamic Shear Rheometer (DSR), Direct Tension (DT) test, Fog seal, Rejuvenator, Chip seal.

1 INTRODUCTION

One of the most important tasks for transportation agencies is to select the appropriate rehabilitation and maintenance technique. Currently, many agencies spend millions of dollars a year to maintain their pavement networks at acceptable conditions. The resources available to the agencies are limited and thus, to satisfactorily maintain the network, a better understanding of the fundamental mechanisms controlling pavement deterioration and the process by which various maintenance and rehabilitation methods delay pavement deterioration becomes an important priority.

Surface treatments are commonly used as pavement rehabilitation and maintenance techniques to prevent further aging of asphalt pavements during service life. Surface treatments, such as seal coat and fog seal, are widely used by transportation agencies as a cost-effective way to preserve existing pavements (Peshkin et al. 2004). It is well known that these maintenance techniques seal the pavement surface from moisture, reduce oxidation aging, decrease raveling, seal of small cracks, and increase surface friction.

The most popular surface treatment activities reported in the literature for flexible pavements are fog seals, rejuvenators and seal coats. Fog seals consist of the light application of a diluted slow setting asphalt emulsion to the pavement surface (Wade et al. 2001). Fog seals are usually diluted with water for better control of the lower asphalt application rate. They are primary used on low-volume roads in order to seal the pavement surface, rejuvenate the aged surface, provide better visibility of the road and postpone the use of a different surface treatment. Common fog seal emulsions are SS-1, SS-1h, CSS-1 and CSS-1h. Rejuvenators are used to restore the original properties of the aged pavement surface. Rejuvenators add maltenes to the oxidized surface. One of the most common rejuvenator products is Reclamite (Reclamite® Preservative Seal). It is used for relatively new pavements with minor severity of cracks or raveling. Reclamite penetrates the pavement to some depth and restores the maltene to asphaltene ratio to proper balance. Seal coats represent the most commonly used surface treatment method and numerous references describe and document their use (Janisch and Gaillard 1998, Johnson 2000, Wade et al. 2001, and Davis 2004). This method is also called bituminous surface treatment (BST), chip seal, and surface dressing in Europe. Generally, a seal coat is an application of asphalt binder to the pavement surface followed by a cover of aggregate. This treatment is used to prevent the surface from further oxidation, maintain water out of the pavement structure, seal low severity cracks, and increase the surface friction.

Several researchers have investigated the benefits of using surface treatments to improve the performance of asphalt pavements and to prolong their service life. The majority of the research focuses on the construction activities and on the calculation of economic benefits of surface treatment application. Detailed description of research performed on surface treatments can be found in Zofka et al. (2005). Currently, there is limited research available in the literature that documents the mechanism by which surface treatments seal and protect the existing pavement from further aging and deterioration from cracking.

The focus of this study is to investigate the effectiveness of surface treatments in preventing aging. Asphalt aging is irreversible and related to chemical changes in binder structure (Johansson et al. 1998). Aging in asphalt binders is generally accepted to be the cause of the material hardening over time and it has been known from the earliest days of asphalt pavement construction in the United States (Bell et al. 1994).

The evolution of the asphalt pavement surface condition is mostly related with the change of the mechanical properties of both mixture and asphalt binder with time. In this paper, mechanical characterization of field samples by means of Semi-Circular Bending test (SCB), Bending Beam Rheometer (BBR) for asphalt mixtures and Dynamic Shear Rheometer (DSR), Direct Tension Test (DTT) and BBR for asphalt binders extracted from the mixtures is used to assess the effectiveness of three different surface treatments: fog seal (CSS-1h), rejuvenator (Reclamite), and Chip seal (CRS-2p, 3/8" Aggregate).

2 MATERIALS

Samples were obtained from four sections of Trunk Highway (TH) 251 near Clarks Grove, Minnesota, USA, to study the effectiveness of three surface treatments applied in 2002:

control section; fog seal (CSS-1h) treated section; rejuvenator (Reclamite) treatment section; and section treated with Chip seal (CRS-2p, 3/8" Aggregate). Three cores from the wheel path and three cores from between the wheel paths were extracted from each section to determine if the compaction effort from traffic in the wheel path results in differences in the mechanical response from samples coming from these two locations.

3 MECHANICAL CHARACTERIZATION

3.1 Mixture Testing

The cores cut from the pavement were 152 mm diameter with depths ranging from 124 mm to 165 mm. The top 10 mm of all cores were removed to ensure mechanical testing of the asphalt mixture and no of the surface treatment. Two cores were used for Semi-Circular Bending (SCB) and air voids testing and the third core was used for Bending Beam Rheometer (BBR) mixture testing.

Semi-Circular Bending (SCB) tests were performed following the procedure described in Marasteanu et al. (2004). The sample preparation for SCB testing consisted in removing the top 10 mm of the core to discard the surface treatment and then the core was cut into three 25 mm slices. The top slice was used to cut two SCB specimens.

SCB testing was done at two temperatures: -18°C and -30°C. It is important to mention that the specimens were cooled for 2 hours at the test temperature before testing to remove temperature gradients within the specimen. Two replicates for each condition were tested.

The load and load line displacement (LLD) data were used to calculate the fracture toughness and fracture energy using the equation developed in Lim et al. (1993). The fracture energy G_f was calculated according to RILEM TC 50-FMC specification (1985). Bar plots summarizing G_f and K_{IC} for the different surface treatments are presented in Figure 1.

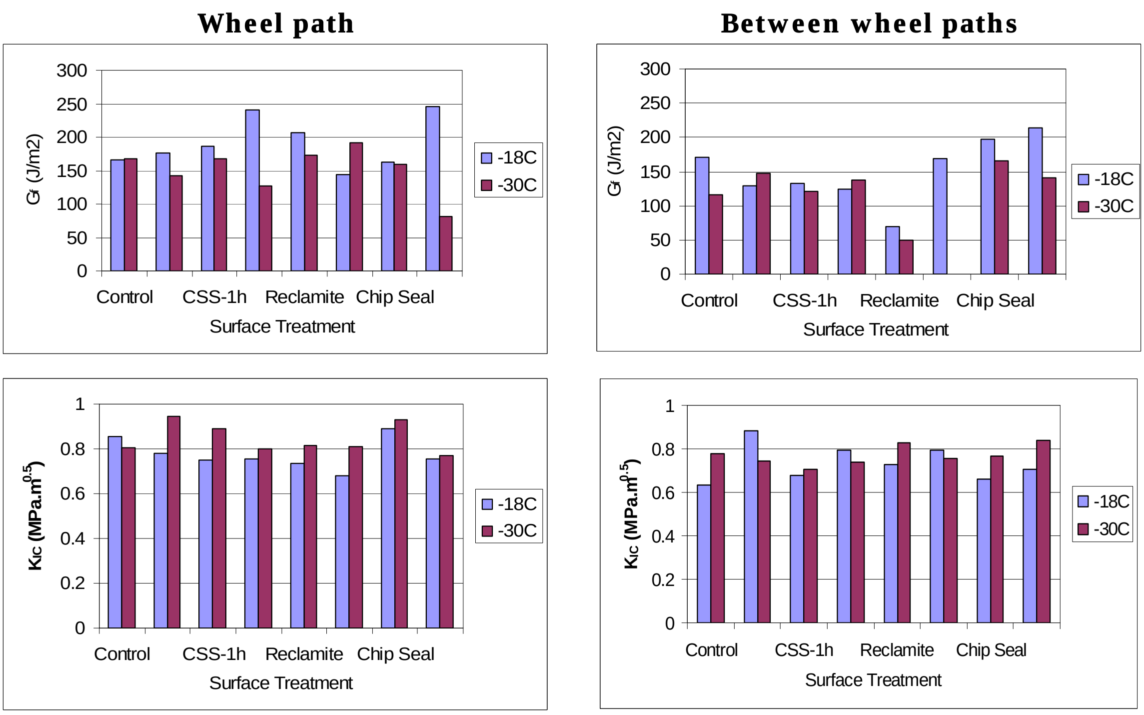

Figure 1: G_f and K_{IC}

Analysis of variance (ANOVA) was performed using G_f and K_{IC} as dependent variables and type of treatment, location, voids and temperature as independent variables. Table 1 presents the results of this analysis.

Table 1: ANOVA of SCB results

Coefficient	G_f		K_{IC}	
	Estimate	**p-value**	**Estimate**	**p-value**
Constant	135.20	0.034	0.848	0.000
{F}Treatment[CSS-1H]	13.46	0.486	-0.051	0.154
{F}Treatment[RECLAMITE]	-16.19	0.390	-0.040	0.249
{F}Treatment[CHIP-SEAL]	-1.06	0.960	0.009	0.816
Location	-55.21	**0.001**	-0.038	0.187
Temperature	3.12	**0.008**	-0.004	**0.035**
Voids	21.61	**0.046**	-0.024	0.217

Using 5% of significance level, it is observed that temperature is important in the prediction of G_f and K_{IC} for TH 251 sections. Void content and location are significant for the prediction of the fracture energy. No significant differences are observed between the fracture energy and fracture toughness of the control section and the sections with surface treatments.

Creep tests were performed on asphalt mixture beams following a new procedure developed at the University of Minnesota based on AASHTO T 313-05 (2005). The mixture beams were cut from the remaining core extracted from the pavement following the procedure described in Marasteanu et al. (2008). Four replicates of the thin mixture beams for each section were tested at -12˚C and -18˚C.

The mixture 60 second creep stiffness and m–value are plotted in Figure 2. The control section samples located in the wheel path have the highest mixture stiffness at both temperatures. On the other hand, the mixtures treated with chip seal have the lowest stiffness and the highest m-values. It is also observed that for the samples located between the wheel paths, the highest stiffness corresponds to the mixture treated with CSS-1h.

For the ANOVA analysis, the type of surface treatment was treated as a dummy variable with the control section as the reference level. ANOVA results for the BBR mixture results are presented in Table 2.

The parameters that are important in the prediction of the mixture stiffness are location and temperature. From the negative coefficient estimate of the reclamite treatment it is observed that the samples treated with reclamite have significantly lower stiffness compared to the control section samples. Although the estimated coefficients from the other two treatments are also negative, they are not significant for the linear model proposed. The only parameters significant in the prediction of the m-value of the mixture are temperature and location. The location coefficient estimate for the prediction of S_{mix} is not consistent to what it is expected. The positive sign indicates that the samples located in between the wheel paths have higher stiffness than the samples located in the wheel path.

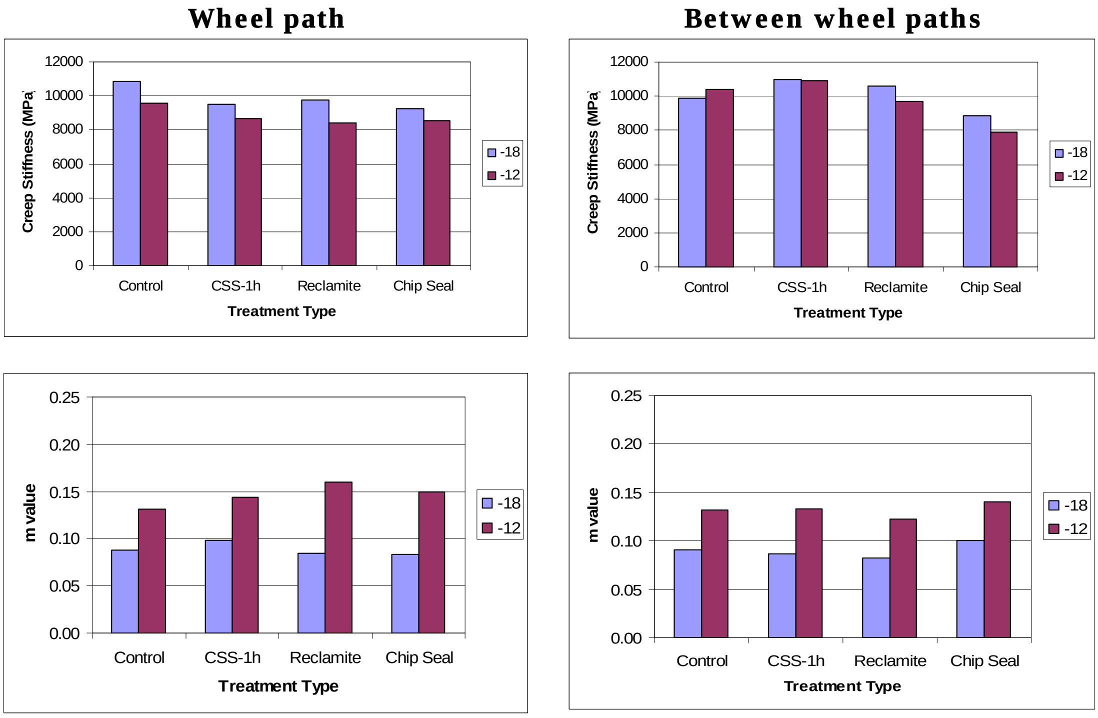

Figure 2: BBR Creep stiffness and m-value at 60 sec for cored mixtures

Table 2: ANOVA of BBR mixture results

Coefficient	S_{mix}@60 sec.		m_{mix}@ 60 sec.	
	Estimate	**p-value**	**Estimate**	**p-value**
Constant	13275	0.000	0.190	0.000
{F}Treatment[CSS-1H]	-661	0.065	0.010	0.195
{F}Treatment[RECLAMITE]	-788	**0.027**	0.004	0.550
{F}Treatment[CHIP-SEAL]	-614	0.127	0.000	0.971
Location	1404	**0.001**	-0.014	**0.049**
Temperature	-120	**0.007**	0.008	**0.000**

3.2 Binder Testing

The asphalt binders used for BBR, DTT and DSR testing were extracted from the mixture specimens tested in SCB according to AASHTO T164 method.

The Bending Beam Rheometer (BBR) testing was performed on a Cannon thermoelectric rheometer, according to AASHTO T 313-05 (2005). Tests were conducted at -18˚C and -24˚C and two replicates were tested for each specific condition. Minor differences are observed between the creep stiffness functions of the sections with different surface treatments. Figure 3 shows bar plots for the creep stiffness and the m–value at 60 seconds. It is observed that at -18˚C there is not a significant difference between the creep stiffness at 60 seconds of the different surface treatments. Also, the m-values for both temperatures did not vary significantly with respect to the surface treatment type.

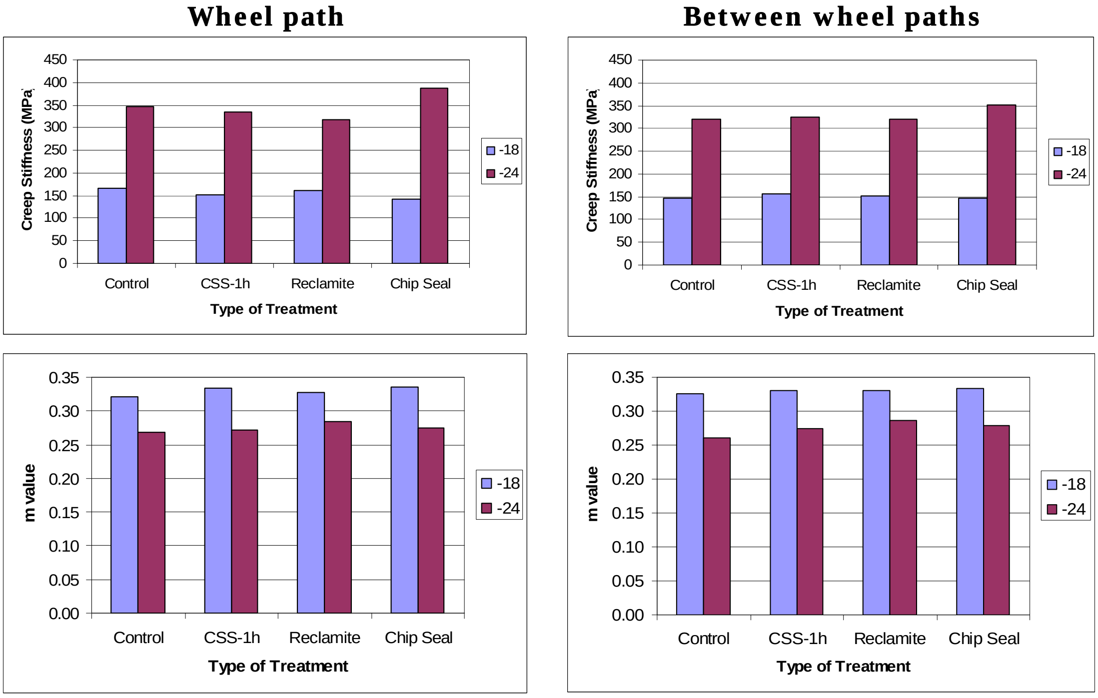

Figure 3: Creep stiffness and m at 60 sec, extracted binder

Table 3 shows the ANOVA analysis of the creep stiffness and m-value at 60 seconds with respect to type of surface treatment, location and temperature. The analysis was performed assuming linear relation between variables.

Table 3: ANOVA of BBR binder results

Coefficient	S@60 sec.		m@ 60 sec.	
	Estimate	**p-value**	**Estimate**	**p-value**
Constant	-398.903	0.000	0.486	0.000
Location	-11.038	0.236	0.000	0.966
Temperature	-30.896	**0.000**	0.009	**0.000**
{F}Treatment[CSS-1H]	-3.299	0.795	0.009	**0.035**
{F}Treatment[RECLAMITE]	-7.224	0.572	0.013	**0.004**
{F}Treatment[CHIP-SEAL]	11.927	0.358	0.012	**0.008**

The parameters that are important in the prediction of the creep stiffness and m-value at 60 seconds are presented in bold. Estimated surface treatment coefficients for prediction of m-value presented in Table 3 are all positive and significant, indicating that the m-values in the treated sections are higher than the m-values in the control section. The m-value is an indicator of the relaxation properties of the asphalt binder; higher values of this parameter indicate that the binder relax stresses faster. This result seems to indicate that the application of surface treatments changes the relaxation properties and does not affect stiffness. This finding supports recent discussions in the asphalt chemistry community that aging not only increases the amount of ketones but also changes the aromaticity of binders, which is related to relaxation properties.

Uniaxial tension tests at a constant strain rate of 3% per minute on dog-bone shaped specimens were performed using the Direct Tension Test (DTT) following the AASHTO T 314-02 (2002). The average stress and strain at failure at two different temperatures, -18˚C and -24˚C, obtained from two replicates are presented in Figure 4.

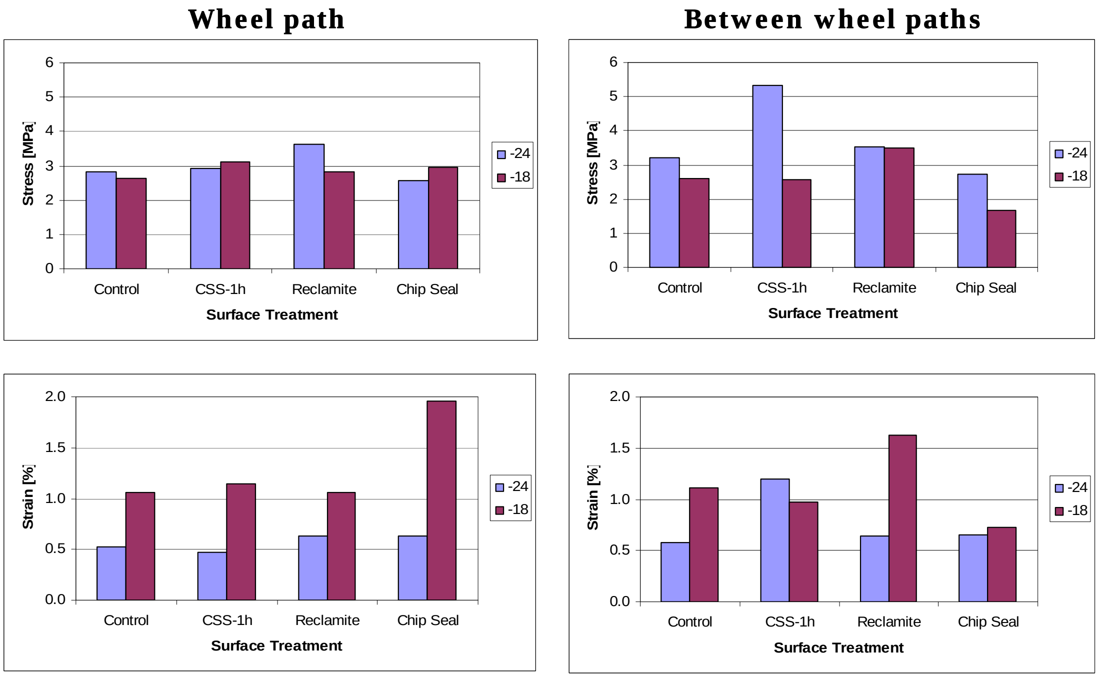

Figure 4: Stress and strain at failure from DTT, extracted binder

The samples located in the wheel path, treated with reclamite and tested at -24˚C have the highest stress and strain at failure. For samples tested at the same temperature but located in between the wheel paths the higher stress and strain at failure correspond to the CSS-1h treatment. For samples located between the wheel paths, the largest stress and strain at failure at -18˚C correspond to the reclamite treatment.

ANOVA of DTT data is presented in Table 4. The parameters that are important (5% of significance) in the prediction of the stress and strain at failure are presented in bold. Temperature is significant in the prediction of both stress and strain at failure. However, there are no significant differences between the stress and strain at failure of the control section and the sections treated with CSS-1h, reclamite and chip seal.

Table 4: ANOVA of DTT results

Coefficient	**Stress @failure**		**Strain @failure**	
	Estimate	**p-value**	**Estimate**	**p-value**
Constant	0.577	0.551	2.688	**0.000**
{F}Treatment[CSS-1H]	0.669	0.077	0.130	0.514
{F}Treatment[RECLAMITE]	0.552	0.156	0.185	0.371
{F}Treatment[CHIP-SEAL]	-0.335	0.365	0.174	0.384
Temperature	-0.101	**0.028**	0.089	**0.001**
Location	0.211	0.427	-0.003	0.985

Dynamic Shear Rheometer (DSR) testing was performed following the standard test method, AASHTO T 315 (2002). Frequency sweep tests were performed at 4˚C, 10˚C, 16˚C, 22˚C and 28˚C. The tests were run on 8-mm parallel plates with a 2.0 mm gap. The frequency sweep data obtained from DSR testing was used to construct frequency master curves at a reference temperature of 10°C using the CAM model (Marasteanu 2004). Figure 5 shows the complex modulus master curves generated for the wheel path (W) and between the wheel paths (B) samples. It is observed that the binders extracted from the wheel path of the section treated with CSS-1h are the stiffest across the entire range of frequencies. The lowest moduli are observed for the binders from between the wheel paths of the control and chip seal sections. The sample with the highest temperature susceptibility is the binder from the wheel path of the section treated with CSS-1h. The lowest susceptibility is observed for the samples from between the wheel paths of the control and chip seal sections.

ANOVA analysis (Table 5) indicated that |G*| is significantly higher for the sections treated with CSS-1h and reclamite compared to the control section. Location is significant in the prediction of |G*|; the negative sign in the estimate of the location coefficient indicates that the moduli of the samples coming from between the wheel paths are lower than the moduli of samples from the wheel path.

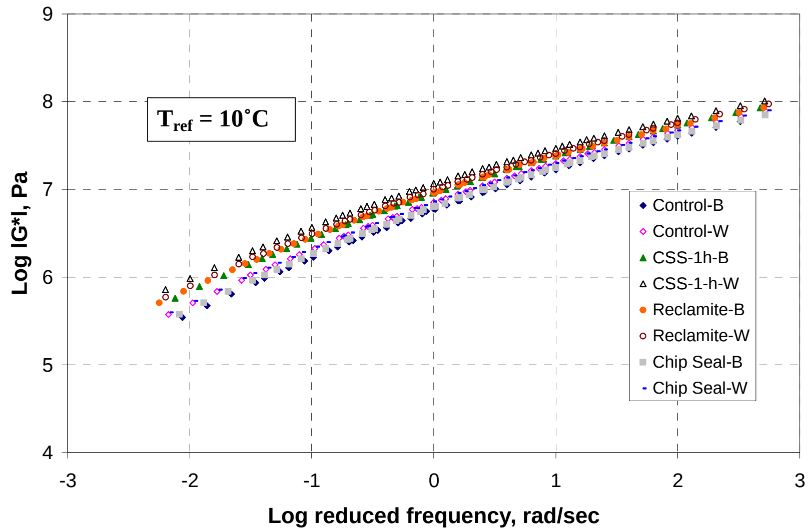

Figure 5: Complex modulus master curves

Table 5: ANOVA for |G*| and δ at 10 rad/sec and 4˚C, TH 251 sections

Coefficient	|G*|		δ	
	Estimate	**p-value**	**Estimate**	**p-value**
Constant	37.477	0.000	31.616	0.000
{F}Treatment[CSS-1-H]	12.667	**0.004**	-2.810	**0.004**
{F}Treatment[RECLAMITE]	10.006	**0.008**	-2.110	**0.008**
{F}Treatment[CHIP-SEAL]	1.178	0.509	-0.475	0.251
Location	-6.066	**0.012**	0.678	0.064

4 TREATMENT RANKING

Table 6 presents a ranking of the three surface treatments used in this study with respect to the parameters obtained from mechanical testing at -18˚C. In Table 6 rank 1 indicates most desired value and rank 4 the least desired value. Note that for low temperature performance higher values are desired for G_f, K_{IC}, m_{mix}, m_{binder}, σ_f and ε_f and lower values are desired for S_{mix} and S_{binder}.

Table 6: Ranking of surface treatments @ -18˚C

Rank	G_f	K_{IC}	S_{mix}	m_{mix}	S_{bin}	m_{bin}	σ_f	ε_f
1	Chip Seal	Control	Chip Seal	CSS-1h	Chip Seal	Chip Seal	Reclamite	Reclamite
2	CSS-1h	Chip Seal	Reclamite	Chip Seal	CSS-1h	CSS-1h	CSS-1h	Chip Seal
3	Control	CSS-1h	CSS-1h	Control	Control	Reclamite	Control	Control
4	Reclamite	Reclamite	Control	Reclamite	Reclamite	Control	Chip Seal	CSS-1h

Based on the limited number of tests performed in TH 251 samples it appears that the surface treatment that prevents aging best is the chip seal. Samples from the section treated with chip seal show the highest fracture energy, the lowest stiffness of the mixture and the binder and the highest m-value of the binder. Additionally, the binders extracted from the section treated with chip seal show one of the highest strains at failure.

These conclusions should be interpreted with caution due to the inherent variability of pavement samples and to the fact that a small number of replicates were available in this study.

4 CONCLUSIONS

A number of important conclusions can be drawn from the results obtained in this study:

- It was found that the m-values of the binders in the treated sections are higher than the m-value of the binder in the control section. This result seems to indicate that the application of surface treatments changes the relaxation properties and does not affect stiffness.
- No significant differences between the binder DTT stress and strain at failure of the control vs. treated sections were identified.
- |G*| is significantly higher for the sections treated with CSS-1h and Reclamite compared to the control section. |G*| of the samples coming from between the wheel paths are lower than the |G*| of samples from the wheel path.
- At -18˚C, the mixture treated with the chip seal has slightly lower creep stiffness with respect to time compared to the other mixtures. At -12˚C, the mixtures treated with Reclamite and chip seal have the lowest creep stiffness.
- The BBR test on thin mixture beams appears to be a promising tool for evaluation of asphalt mixtures. The pavement sections where surface treatments were applied have less S_{mix} and higher m_{mix} compared to the control section.
- From the limited number of tests performed, the surface treatment that prevents aging the best is the chip seal. Specimens with chip seal treatment show the highest fracture energy, the lowest stiffness of the mixture and the binder and the highest m-value of the binder.

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