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Field Evaluation of Pavement Surface Treatments

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The application of surface treatments (chip seals) is a highly economical highway maintenance option. Surface treatments offer protection against deterioration caused by traffic and weather. There are several material types used in surface treatments. A few years ago, the Wyoming Department of Transportation **(WYDOT)** initiated a comprehensive field experiment to determine the effect of materials selection on the field performance of surface treatments. Twenty-three test sections were constructed as part of this experiment. The materials used in the experiment represented the most widely used aggregates and binders in the state of Wyoming. Monitoring these sections over five years indicated that surface friction is affected by aggregate type alone while transverse cracks are predominately affected by the choice of the binder. Other interesting findings are described in the paper.

Keywords: Surface treatments, Field performance, Modified asphalt

INTRODUCTION

The application of surface treatments can be a highly economical highway maintenance option when properly constructed. The periodical application of surface treatments may help in extending the life and restoring surface properties of asphalt pavements. Surface treatments offer protection against deterioration caused by traffic and weather. There are several forms of surface treatments including: fog seals, slurry seals, sand seals, microsurfacing, aggregate seals, and multiple layered aggregate seals (SHRP, 1992). Each of these surface applications performs a specific function and restores unique properties to the pavement. In this study, only the single-layer aggregate seals, often referred to as chip seals, were evaluated.

There are a variety of materials that can be used for both the asphalt binder and cover aggregate in surface treatments. Asphalt grade, adhesion characteristics, durability, and application rates are some factors that govern the selection of the binder. The binder can also contain polymer or latex modifiers to improve temperature susceptibility and durability. Aggregate selection is based on the shape and size of the aggregate, in addition to aggregate availability. Normally, a one-sized aggregate is preferred with minimal fines present (Boyer, 1998).

The application of a surface treatment normally results in increasing the skid resistance of the pavement surface, sealing pavement cracks, and protecting the pavement from additional asphalt oxidation and weathering. Surface treatments help in reducing infil-

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tration of water into the pavement structure, thus increasing pavement life (Roque, 1991). The main objective of this study was to evaluate the effect of aggregate and binder types on the performance of surface treatments in Wyoming.

EXPERIMENTAL DESIGN

In order to determine the effect of material selection on the performance of surface treatments, a comprehensive field experiment was developed in 1991. This experiment included the construction of 23 test sections as part of the Reno Junction project on Wyoming Highway 59 south of Gillette, Wyoming. These sections were built in July of 1991. The 17.7-km (11 miles) stretch of highway was overlaid with 5 cm a few years prior to the application of the surface treatments. After applying the overlay, neither a wearing course nor a surface seal was applied to the pavement. Field distress evaluation revealed that the whole section was fairly uniform prior to applying the surface treatments. This project included a variety of asphalt and aggregate combinations. The sections were subjected to identical traffic loading and environmental conditions. Such unique features helped in reducing the number of variables that might influence the performance of surface treatments.

Traffic Conditions

The traffic volume on the surface treatment test sections is relatively high because Wyoming Highway 59 is a short cut between Interstate 25 and Interstate 90. In 1991, the Average Annual Daily Traffic (AADT) on the section was about 1900 mixed vehicles of which 455 were trucks. Most of the traffic on the test sections is local traffic traveling to Wright, Wyoming, which is located near Reno Junction. There are several coal mines in the area, generating a large number of passenger cars and heavy trucks. The sections also have a high amount of tourist traffic during the summer months.

Materials

The main objective of this study was to determine the effect of materials (aggregates and binders) on the performance of surface treatments. Therefore, other factors affecting the performance of surface treatments were eliminated by constructing all test sections on the same stretch of highway following similar construction techniques. The sections constructed included seven asphalt types in combination with two types of aggregate (scoria and limestone). These two aggregate types are the most widely used in surface treatments in Wyoming. Special construction techniques such as pre-coating the aggregate or application of hot aggregate were also incorporated in the experiment. Pre-coating the aggregate may help in establishing a better bond between the aggregate and the binder.

Aggregate

As mentioned earlier, the two types of aggregate used in the Reno Junction experiment were scoria and limestone. Scoria is a red, heat-expanded shale, also called crushed clinker. Scoria contains quartz and small amounts of smectite, illite, and kaolinite. The material has a maximum dry density of about 2115 kg/m^3(132 pcf). The surface texture of scoria is rough and porous. Limestone has a maximum dry density of about 2547 kg/m^3 (159 pcf). Its surface texture is smooth and it tends to flake when crushed (Boyer, 1998).

Asphalt Binder

As shown in Table I, several types of asphalt binder were used in the experiment. These binders were supplied by Koch Materials and Elf Asphalt. The experiment also included several sections with asphalt modifiers to determine their effects on performance of surface treatments.

TABLE I Asphalt materials used in reno Junction experiment

High float emulsions	HF-100P[a]
	HFE-150
	HFE-150 w/ Latex
	HFRS-2P
Cationic emulsions	CRS-2 CRS-2
	CRS-2 w/ Latex
Asphalt cement	AC-10
	AC-20

a. Polymer modified

TABLE II General description of test sections

Section number	*Lane*	*Milepost from*	*Milepost to*	*Aggregate type*	*Asphalt binder type*	*Applicate rate binder L/m^2(gal.sq.yd.)*
1	SBL	82.50	83.00	Scoria	HFE-150	1.81 (0.40)
2	SBL	82.00	82.50	Limestone	HFE-150	1.81 (0.40)
3	SBL	81.00	82.00	Limestone	HFE-150	1.81 (0.40)
4	SBL	80.00	81.00	Scoria	HFE-150	1.90 (0.42)
5	SBL	79.00	80.00	Scoria	CRS-2	1.90 (0.42)
6	SBL	78.00	79.00	Limestone	CRS-2	1.90 (0.42)
7	SBL	77.25	78.00	AC coated limestone	AC-10	1.13 (0.25)
8	SBL	76.50	77.25	Scoria	AC-10	1.13 (0.25)
9	SBL	75.75	76.50	AC coated scoria	AC-10	1.27 (0.28)
10	SBL	75.00	75.75	Hot scoria	AC-10	1.63 (0.36)
11	SBL	74.00	75.50	Scoria	ELF HFRS-2P	1.67 (0.37)
12	SBL	72.50	74.00	Limestone	ELF HFRS-2P	1.58 (0.35)
13	NBL	72.50	74.00	Limestone	HF-100P	1.81 (0.40)
14	NBL	74.00	75.00	Scoria	HF-100P	1.81 (0.40)
15	NBL	75.00	75.75	Hot scoria	AC-20R	1.22 (0.27)
16	NBL	75.75	76.50	AC coated scoria	AC-20R	1.22 (0.27)
17	NBL	76.50	77.25	Hot limestone	AC-20R	1.36 (0.30)
18	NBL	77.25	78.00	AC coated limestone	AC-20R	1.36 (0.30)
19	NBL	78.00	79.00	Scoria	CRS-2 w/Latex	1.81 (0.40)
20	NBL	79.00	80.00	Scoria	CRS-2 w/Latex	1.81 (0.40)
21	NBL	80.00	81.00	Scoria	CRS-2 w/Latex	1.81 (0.40)
22	NBL	81.00	82.00	Scoria	HFE-150 w/Latex	1.72 (0.38)
23	NBL	82.00	82.50	Scoria	HFE-150	1.72 (0.38)

Materials Combinations

Twenty-three different combinations of aggregate and binders were selected for incorporation in the Reno Junction experiment. Table II summarizes the materials used in each test section. The binder application rates were varied among the sections to reflect typical amounts normally used for the specific binder and aggregate combinations. The application rate of aggregate was 12 kg/m^2 (22 lb/sq. yd) on all test sections. Each test section ranged in length between 800 m (1/2 mile) and 1600 m (1 mile).

Construction Techniques

The test sections were swept prior to applying the surface treatment. Rubber tire rollers were utilized to set the aggregate and the surface was swept to remove excess aggregate once the binder had setup. Traffic was kept off of the test sections for 12 hours after construction. After that, traffic was allowed on the section at a reduced speed of 40 km/h (25 mph) for an additional 12 hours.

PERFORMANCE MEASURES

Field distress data were obtained on all test sections in both 1995 and 1996. Two pavement condition indices (PCI) were calculated for each of the test sections. The procedure for PCI calculations and deduct values is fully described in (SHRP, 1993) and (Shahin, 1994). The $\text{PCI}_{\text{CRACK}}$ included the deduct values for cracking only, while the PCI included all types of distresses related to surface treatments. These PCIs for all test sections are summarized in Table III. All of the test sections were in a good condition in 1995. However, the evaluations in 1996 indicated that some of the sections fell below 50, the break point between a good and a failed condition (Boyer, 1998). It should be mentioned here that all of the sections with PCIs below 50 have scoria as cover aggregate.

The second performance measure included in the analysis was friction measurements. In this study, the friction measurements were obtained with the WYDOT K. J. Law lock trailer which meets the ASTM E-274 requirements. Table IV summarizes the friction values for test sections. Each section was tested once at 55 MPH. The table indicates significant variations in skid numbers among the test sections.

TABLE III PCIs of test sections

Section number	*1995*		*1996*	
	PCI_{CRACK}	*PCI*	PCI_{CRACK}	*PCI*
1	78	75	72	67
2	88	84	77	71
3	90	84	82	68
4	83	64	74	44
5	80	62	78	39
6	89	82	82	75
7	90	84	84	77
8	91	83	84	68
9	85	80	84	70
10	95	95	86	81
11	90	64	87	52
12	83	79	80	52
13	83	80	82	79
14	89	79	87	62
15	87	82	83	79
16	86	81	84	71
17	88	83	85	66
18	79	74	76	73
19	79	63	79	45
20	80	71	72	39
21	81	64	77	43
22	82	67	81	45
23	78	68	72	46

TABLE IV Friction measurements of test sections

Section number	*1994 friction number*
1	-
2	-
3	33.9
4	-
5	66.0
6	36.1
7	-
8	59.0
9	47.1
10	52.6
11	62.2
12	39.3
13	45.0
14	59.1
15	59.3
16	52.0
17	29.9
18	-
19	63.7
20	-
21	64.2
22	-
23	61.9

STATISTICAL ANALYSIS

Compared with most available sources of data on surface treatments in Wyoming, the Reno Junction study is very well controlled and complete. Many confounding factors such as age of treatment, road base, environmental conditions, and traffic intensity are constant by design in this study. This experimental design makes any significant differences among surface treatment materials easily detected. To determine the effects of binder and aggregate types on surface performance, a standard analysis of variance models (ANOVA) was performed. The 1996 results are presented here because they reveal relationships more clearly than do measures taken in 1995. This is primarily due to the sections being in service for an extra year, which resulted in magnifying the differences.

The seven types of binder used in the 23 sections of the test area were grouped into three classes possessing similar intraclass properties. These classes were asphalt cements (AC: AC-10 and AC-20R); cationic emulsions (CRS: Koch CRS-2, with and without latex); and high float emulsions (HF: Koch High Float, with and without latex, and Elf Asphalt Modified High Float). Small sample size along with the presence of interactions between binder and aggregate types precluded analysis at a more detailed level. Potential effects of special aggregate conditions such as pre-coating were also excluded from consideration because special aggregate conditions were used almost exclusively in the presence of a single factor level for binder which was AC. In addition to the three classes of binders, the two aggregate types, and aggregate-binder interactions, the effect of binder modification was considered as a separate factor.

Surface performance was measured in terms of cracking, weathering, bleeding, and skidding. Cracking was subdivided into a deduct-score for longitudinal cracking and one for transverse cracking. A pavement condition index based on cracking of all types (PCI_{crack}) was also used as a third measure of cracking. Weathering and bleeding were each measured using single deduct scores, and friction measures were available for a subset of 16 sections. Lastly, an overall pavement condition index (PCI) was also used. PCI differs from PCI_{crack} in that the former also reflects problems with bleeding, weathering, uniformity, and polished aggregate. Correlations between performance measures are presented in Table V.

Statistical Results

Results of the analysis showed that choice of binder, aggregate, and binder modification all have potential effects on pavement performance, but not all dimensions of pavement performance are affected in the same way. In summary, cracking is affected by choice of binder and binder modification. Skidding is affected by choice of aggregate. Weathering and bleeding are affected by the combination of aggregate and binder that is used. These results are consistent with what is known about properties of surface treatment materials. Details of the analysis are shown in Tables VI and VII and in Figs 1 and 2. The tables summarize the mean values and standard errors of performance measures for the different materials. The figures show the confidence intervals for different material combinations.

TABLE V Correlations between response variables

	Longitudinal cracking	*Transverse cracking*	*Bleeding*	*Weathering*	*PCI_{crack}*	*PCI*	*Skid resistance*
Longitudinal cracking	1						
Transverse cracking	−0.11	1					
Bleeding	−0.16	−0.42	1				
Weathering	0.05	0.51	−0.66	1			
PCIcrack	0.13	0.9	−0.44	0.36	1		
PCI	0.01	0.64	−0.51	0.95	0.49	1	
Skid resistance	0.08	0.38	−0.56	0.63	0.26	0.62	1

TABLE VI Adjusted means (and standard errors) of surface treatment properties for combinations of binder and aggregate type. (Observed significance levels below response names are for most important effects.)

	Limestone/asphalt cement	*Scoria/asphalt cement*	*Limestone/cationic emulsion*	*Scoria/cationic emulsion*	*Limestone/high float emulsion*	*Scoria/high float emulsion*
Longitudinal cracking	9.47	10.34	3.74	9.16	5.02	7.08
(aggregate: p=.261)	(3.00)	(2.55)	(4.65)	(2.85)	(2.48)	(1.78)
*Transverse cracking	12.92	9.75	13.05	21.47	17.11	19.90
(binder: p=.004)	(2.19)	(1.86)	(3.39)	(2.08)	(1.81)	(1.30)
*Bleeding	10.02	16.55	11.35	−1.32	8.78	0.23
(interact: p=.048)	(4.33)	(3.68)	(6.71)	(4.11)	(3.58)	(2.57)
*Weathering	10.70	5.67	12.47	60.94	10.54	47.44
(interact: p=.001)	(7.21)	(6.12)	(11.17)	(6.84)	(5.95)	(4.27)
*Skid resistance	30.42	36.62	37.35	54.52	66.52	59.48
(aggregate: p=.0001)	(5.11)	(5.11)	(3.57)	(3.17)	(3.57)	(3.45)
*PCI$_{crack}$	84.49	87.17	85.19	77.83	79.95	78.37
(binder: p=.035)	(2.79)	(2.37)	(4.32)	(2.65)	(2.30)	(1.65)
*PCI	72.84	74.88	76.30	42.86	72.68	50.53
(interact: p=.004)	(5.02)	(4.23)	(7.77)	(4.76)	(4.14)	(2.97)

TABLE VII Adjusted means (and standard errors) for surface treatment properties of binder modifications (observed significance levels below response names)

		Unmodified	*Polymer modified*	*Latex modified*
Longitudinal cracking		4.93 (1.30)	9.87 (2.84)	7.60 (3.24)
perfect=0	(p=.208)			
Transverse cracking		19.25 (0.95)	11.03 (1.81)	16.82 (2.37)
perfect=0	(p=.003)			
Bleeding		9.95 (1.87)	4.45 (3.58)	8.40 (4.69)
perfect=0	(p=.394)			
Weathering		21.06 (3.17)	25.07 (5.96)	27.76 (7.80)
perfect=0	(p=.672)			
Skid resistance		46.97 (1.70)	50.81 (3.22)	44.67 (6.03)
perfect=100	(p=.578)			
PCI$_{crack}$		79.18 (1.21)	85.90 (2.31)	81.43 (3.02)
perfect=100	(p=.053)			
PCI		64.11 (2.17)	68.50 (4.15)	62.43 (5.42)
perfect=100	(p=.564)			

Binder material and aggregate type were related to most responses. The major exception was longitudinal cracking, a result that was expected because longitudinal cracking results from structural breakdown below the level of surface treatment. Transverse cracking and PCIcrack were predominantly affected by the choice of binder, not by aggregate type. According to these cracking measures, asphalt

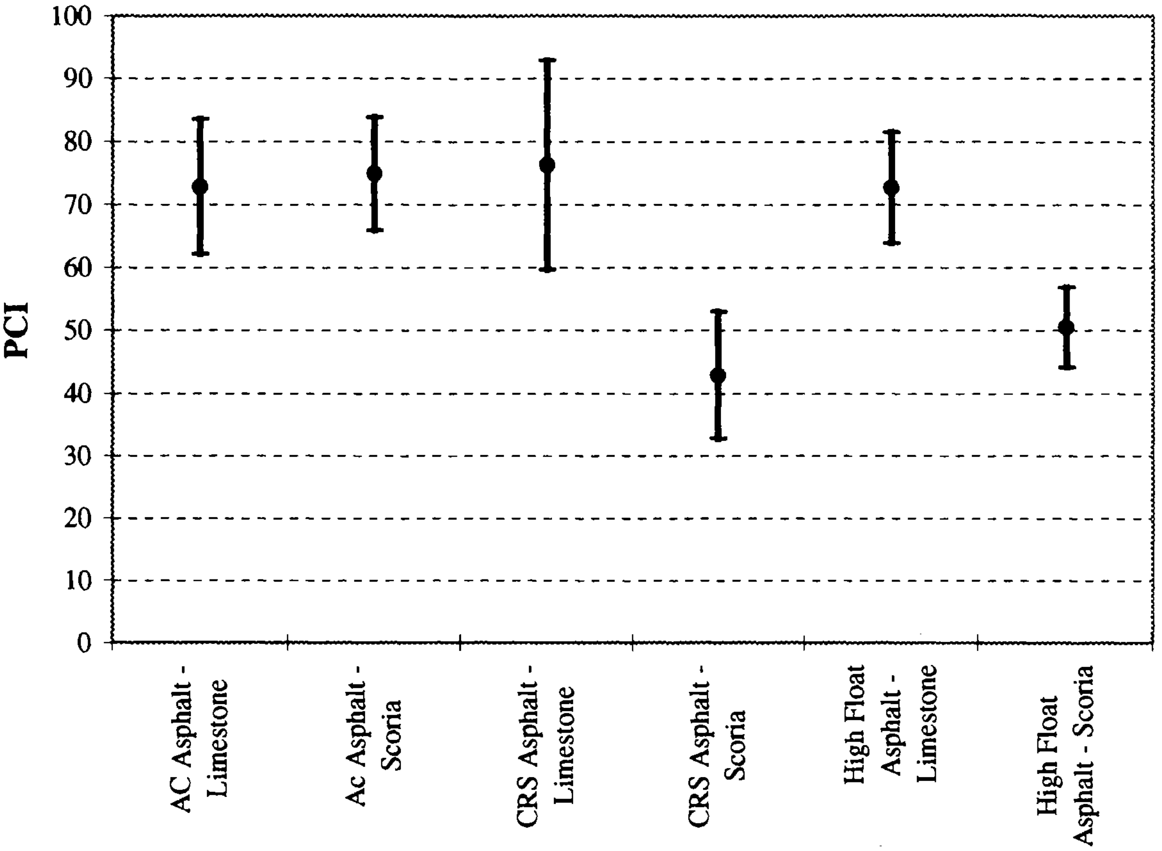

FIGURE 1 Individual 95% confidence intervals for asphalt and binder combinations

cements (AC) are expected to be superior to the emulsion-based binders (CRS and HF). This difference may be unique to, or at least more pronounced with, scoria, however, as is discussed below. These two cracking measures were also affected (modestly but significantly) by the use of modified asphalt. The use of polymer-modified binders resulted in significantly less transverse cracking and an improved PCIcrack as compared with unmodified and latex-modified binders.

Frictional resistance was affected by aggregate type alone, apparently as a function of particle roughness. Silicaceous rocks like scoria are expected to offer more friction than does the softer limestone, and scoria yielded consistently superior friction values.

The above relations are unambiguous in that they are not seriously complicated by interactions. Other properties such as weathering and bleeding were affected by the particular combinations of binder and aggregate. The source of interaction in each case was a differential performance of scoria depending upon binder type. Scoria is relatively porous, and it is speculated that scoria particles may absorb different amounts of the emulsion-type binders than of the asphalt cements. Limestone has smaller pores and was not associated with differential performance based on binder type. Measures of weathering and bleeding, as well as PCI, performed consistently for all limestone treatments but strongly differed for scoria with AC as opposed to scoria with HF or CRS. Weathering and PCI were both dramatically poorer

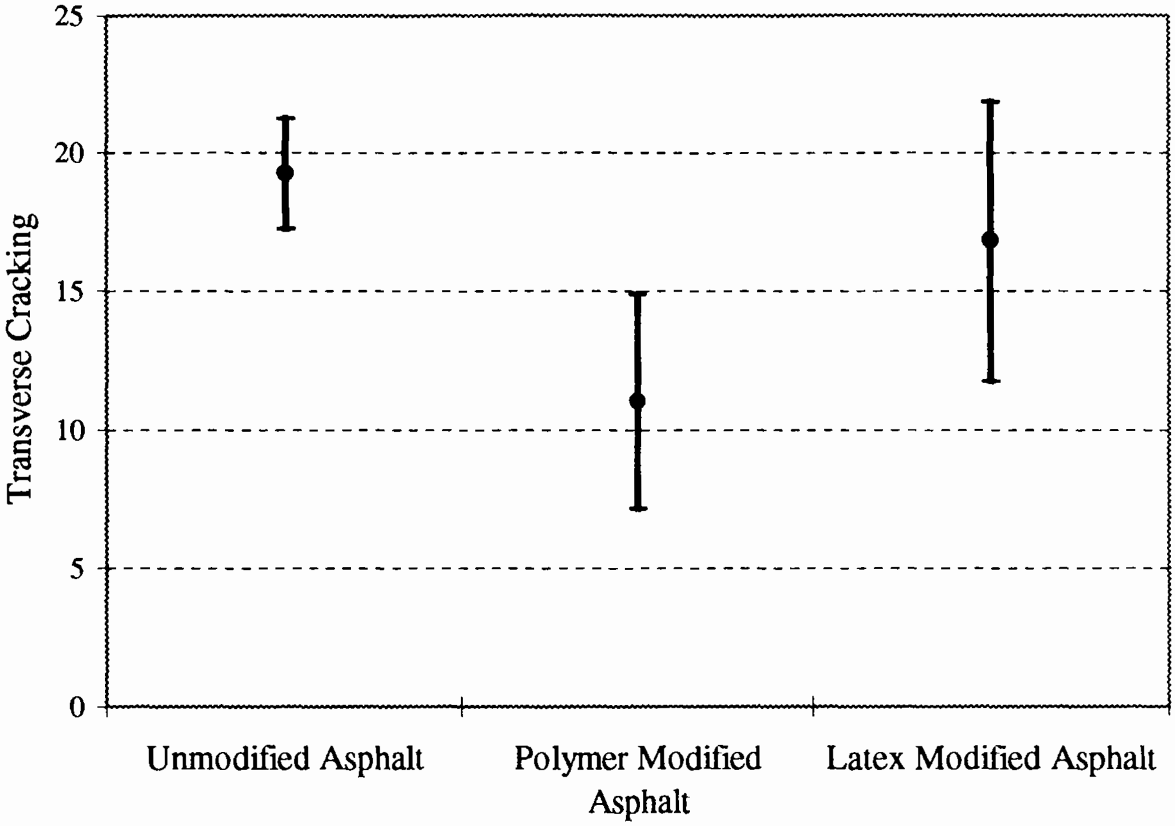

FIGURE 2 Individual 95% confidence intervals for asphalt binders vs. transverse cracking deduct values

for the scoria-emulsion combinations, while bleeding was less for these treatments. This contrast is reasonable in that bleeding and weathering are inversely related to each other (Table VII). The use of binder modification had no apparent effect on weathering, bleeding, or PCI.

It is worth noting that the pattern of inferior performance for the combination of scoria and emulsion-type binders is discernible, although not significant, for cracking measures (p=0.062 for transverse cracking).

CONCLUSIONS

Selecting the optimum combination of aggregate and asphalt binder is important for insuring good performance of surface treatments. By design, the Reno Junction experiment eliminated the effects of environmental and traffic variations on surface treatment performance. The analysis on the Reno Junction test sections lead to the following conclusions:

- Friction number is affected by aggregate type alone. Friction numbers of limestone sections are significantly lower than scoria sections. This is due to the scoria particle surface roughness and the softness of limestone.
- In general, scoria sections have lower PCIs than limestone sections. The difference was as high as 20 PCI points in some cases. This is due mainly to aggregate loss associated with scoria. Very few scoria sections, had bleeding. This is due to the porous nature of scoria which absorbs significant amounts of binders.

- Transverse cracks are predominately affected by the choice of binder. Using polymer-modified asphalt in surface treatments results in fewer transverse cracks than unmodified or latex-modified asphalts.

It is clear from the findings of this study that limestone aggregates have a higher pavement condition index than scoria. Therefore, limestone is a better choice where the main objective of applying the treatment is to seal the pavement surface. On the other hand, scoria should be selected where there is a need to increase skid resistance. The polymer modification of the binder resulted in fewer transverse cracks and better material handling in the field. It is recommended that polymer-modified surface treatments be studied further to determine the cost-effectiveness of modification.

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