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Performance of chip seals using local and minimally processed aggregates for preservation of low traffic volume roadways

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Abstract

Many roadways in the world are in locations without high quality aggregates. Therefore, high quality aggregates must be transported to these locations when pavement construction or preservation activities are needed. This transportation increases the cost of pavement construction and preservation in these areas of the state. Increased costs often mean that timely pavement preservation activities are postponed. This postponement leads to deterioration of the infrastructure and, ultimately, increased costs. In addition, many of the pavements requiring preservation are low volume facilities. These low volume roads may not require the very high quality aggregates necessary on higher traffic volume facilities. Therefore, if more economical local aggregates could be demonstrated to perform acceptably, pavement preservation could be accomplished within budget at appropriate intervals. This would save costs in both the short and the long terms. Chip seals are used extensively by many road authorities for extending pavement life. Chip seals utilizing locally available and minimally processed aggregates should be a more economical pavement preservation treatment than chip seals constructed with higher quality, more expensive aggregates. Although chip seals constructed on high traffic roadways require high quality, crushed and approximately single-sized aggregates, low traffic roadways may not demand such materials to perform acceptably. Therefore, an experiment was designed to demonstrate the performance of chip seals constructed using two different aggregates on two low volume state highways. The control aggregate was the material routinely used for chip seal construction and the second aggregate was a material that did not meet specifications for gradation or fracture. Construction of the test sections was conducted by agency maintenance forces in 2009. Condition surveys were performed to determine pre-chip seal condition and then periodically for the next three years to track performance. Two five hundred foot long evaluation sections were located within each test pavement for each aggregate resulting in two thousand lane-feet of test area for each roadway. Results of the experiment after three years of service indicate no significant difference in performance between the aggregates. Distress in both pavements is limited to a return of transverse and longitudinal cracks, but with low percentages of chip loss. Some limited areas of the pavements also contain longitudinal flushing streaks where distributor nozzles may not have been adjusted correctly and higher quantities of asphalt were applied. Based on the results of this research it appears that locally available, minimally

processed aggregates can be successfully applied as chip seal aggregate on low volume roadways. The report includes a recommended chip seal design procedure, aggregate and construction specification for low traffic volume roadways.

1. Introduction

Many roadways in the world are in locations without high quality aggregates. Therefore, high quality aggregates must be transported to these locations when pavement construction or preservation activities are needed. This transportation increases the cost of pavement construction and preservation in these parts of the state. Increased costs often mean that timely pavement preservation activities are postponed. This postponement leads to deterioration of the infrastructure and, ultimately, increased costs. In addition, many of the pavements requiring preservation are low volume facilities. These low volume roads may not require the very high quality aggregates necessary on higher traffic volume facilities. Therefore, if more economical local aggregates could be demonstrated to perform acceptably, pavement preservation could be accomplished at appropriate intervals and within budget. Both short and long term savings would result.

Chip seals are used extensively by roadway authorities for extending pavement life. Chip seals utilizing locally available and minimally processed aggregates may be a more economical pavement preservation treatment than chip seals constructed with higher quality, more expensive aggregates. Although chip seals constructed on high traffic roadways require high quality, crushed and approximately single-sized aggregates, low traffic roadways may not demand such materials to perform acceptably. Therefore, an experiment was designed to demonstrate the performance of chip seals constructed using two different aggregates on two low volume state highways. The control aggregate was the material routinely used for chip seal construction and the second aggregate was a material that did not meet specifications for gradation or fracture.

1.1. Objectives

1. Construct chip seal test and control sections using locally available and minimally processed aggregates and document the performance of these pavements for three consecutive years.
2. Develop and/or adopt monitoring and documentation procedures for evaluating the performance of the test sections.
3. Develop or adopt a design procedure, aggregate specifications, and construction guidelines for chip seals constructed with local, minimally processed aggregates on low traffic volume roadways.

2. Literature Review

There is a significant amount of information available on chip seal design, construction and performance. From two design methods by Hanson in New Zealand (Hanson, 1934-1935) and Kearby (Kearby, 1953) in Texas, most methods used today can be traced (McLeod, 1960, 1969; Potter and Church, 1976; Marais, 1981; Epps, 1981). These methods are essentially based on the concept that aggregate in a chip seal should be as one-sized as possible and that embedment of the aggregate in the asphalt binder should occupy a specific percentage of the aggregate dimension. How the aggregate dimension is determined and how the volume of asphalt binder is calculated vary between methods but usually require measuring the gradation of the aggregate in order to obtain the average least dimension (ALD) in the case of the Hanson method or the unit weight, specific gravity and spread quantity in the case of Kearby. The shape of the aggregate is considered important and is measured using the Flakiness Index in the case of the Hanson method and the percent embedment is varied as a function of traffic for both methods. However, although both of these methods are rational procedures, based on sound engineering principles, they have been shown to produce different results when applied to the same aggregates and emulsions on the same pavement (Shuler, 1998).

Once the chip seal has been designed, how it performs during construction and in early life under traffic is the greatest concern. Loss of chips during construction leads to construction delays and loss of chips during early trafficking may lead to vehicular damage. Therefore, reducing this potential has been a focus of research. Benson (Benson and Gallaway, 1953) evaluated the effects of various factors on the retention of cover stone on chip seals. Among other factors this study evaluated the effects of cover stone and asphalt quantity, aggregate gradation, time between asphalt and aggregate application, and dust and moisture content of chips on retention of cover stone. The type of binder used in the chip seal can have an effect on performance. Studies have been conducted to measure binder viscosity as function of chip size, precoated or not, damp or dry (Kari, 1962; Major, 1965; Kandhal, 1991) and make recommendations regarding the optimum consistency for desired performance. In addition, the performance of the chip seal after long term trafficking can be affected by the properties of the cover stone and the substrate pavement. A process of evaluating the ability of the substrate pavement to resist chip penetration is practiced in the UK and Africa (Hitch, 1981; Colwill, et al, 1995). Predicting early chip retention has been done using laboratory abrasion tests, impact tests, and traffic simulators (Kari, 1962; Shuler, 1996; Stroup-Gardiner, 1990; Davis, 1991).

The performance of chip seals has been reported by many (Jackson, 1990; Sebaaly, 1995; Temple, 2002; Chen, 2003; Jahren, 2004; Gransberg, 2005).

soon add little benefit and applied too late are ineffective.

2.1. Aggregate Specifications

The best chip seal performance is obtained when aggregate has the following characteristics (Caltrans Division of Maintenance, 2003):

- Single-sized
- Clean
- Free of clay
- Cubical (limited flat particles)
- Crushed faces
- Compatible with the selected binder type.
- Aggregates must be damp for emulsion use.

The aggregate should be carefully analyzed to determine its unit weight, specific gravity, percent of voids, and screen analysis. From the screen analysis the average particle size and effective mat thickness of the aggregate is determined by multiplying each individual screen size by its individual percentage and then obtaining the sum of the products. (Kearby, 1953).

Aggregate Cleanliness:

Dusty and dirty aggregate ultimately lead to problems with aggregate retention. Asphalt binders have difficulty bonding to dirty or dusty aggregate, causing the aggregate to be dislodged on opening to traffic (McLeod 1969; Gransberg & James, 2005). It is recommended that the aggregate be sprayed with water several days before the start of the project (Maintenance Chip Seal Manual 2000, Gransberg & James, 2005). Washing chip seal aggregate with clean, potable water before application may assist in removing fine particles that will prevent adhesion with the binder. In addition, damp chips will assist the binder in wetting the rock, thus increasing embedment (Maintenance Chip Seal Manual, 2000, Gransberg & James, 2005). In addition to washing with water, petroleum materials are sometimes used to clean the aggregate before application. Petroleum-based materials such as diesel fuel are commonly used to wash aggregate in Australia and New Zealand (Sprayed Sealing Guide 2004; Gransberg & James, 2005).

Dust on the aggregate surface is one of the major causes of aggregate retention problems. Dust is defined as the percentage of fine material that passes the No. 200 sieve. To improve the quality of the material, the percentage of fines passing the No. 200 sieve should be specified as a maximum of 1% at the time of manufacture (Janisch & Gaillard, 1998).

The cover aggregate for a seal coat should not have a dust coat. Better results are obtained if the rock is damp when it is applied. The aggregate should be dampened in the stock pile (Washington State Department of Transportation, 2003).

Aggregate shape:

Flakiness: The flakiness of the aggregate particle is evaluated by determining the percentage of flat particles within the aggregate. The preferred shape of the cover aggregate is cubical rather than flaky. Flaky particles tend to lie on their flat side in the wheel paths and tend to lie randomly in the less trafficked areas. An excessive amount of flaky particles in a chip seal system may cause the system to bleed in the wheel paths and to be more susceptible to snow plow damage and aggregate dislodgment in the less trafficked areas. The flakiness characteristic of the aggregate is most often determined using the Flakiness Index. (Croteau, et al, 2005, Texas Test Method Tex-224F).

Gradation:

Uniformly graded aggregates usually develop better interlocking qualities and provide lateral support to adjacent particles, thereby preventing displacement from traction and friction of high speed traffic. (Kearby, 1953). The gradation of the aggregate is assessed to determine the average least dimension of an aggregate. The average least dimension of an aggregate is influenced by the mean size of an aggregate. An aggregate is considered coarse if its gradation is positioned in the lower part of the gradation band and fine if it is positioned in the upper part. Accordingly, the mean size of the aggregate varies from course to fine gradations within the same gradation band. The optimal binder spray rate for a single chip seal system may vary as much as ten percent between a coarse aggregate and a fine aggregate even when both chips comply with the same single-size gradation band. The impact of the aggregate gradation on the binder rate is less for the secondary layers of multi-layer chip seal systems (Croteau, et al, 2005).

3. Experiment Design

This experiment was designed to determine if aggregate characteristics affect performance of chip seals on low volume roads. To test this hypothesis the performance of two aggregates was evaluated on two two-lane state highways. Therefore, independent variables included two aggregates and two highways. This resulted in a 2 x 2 factorial experiment.

One aggregate was the material routinely used for chip seal construction by CDOT maintenance with a history of acceptable performance. The second aggregate represented a locally available and marginal material not meeting CDOT specifications with unknown performance. These materials will be identified as Control and Experimental, respectively.

Test sections were constructed on SH71 north of Snyder, CO and on SH59 south of Sedgwick, CO. Both of these pavements are rural, farm to market two lane highways with 12 foot wide driving lanes, no shoulders on SH71 and 10 foot shoulders on SH59. Traffic volumes are 360 AADT with 30 single unit trucks and 120 combination trucks on SH71 and between 160 and 470 AADT with 20 single unit trucks and 20 combination trucks on SH59.

Evaluation sections were established on each highway to measure performance over time for each aggregate being evaluated. Two 500 foot long evaluation sections were established for each highway for each aggregate. This resulted in four 500 foot long evaluation sections for each highway or eight evaluation sections total.

Analysis of this design is accomplished using conventional analysis of variance (ANOVA) techniques using the model shown below:

$$Yijk = \mu + Ai + \varepsilon ijk$$

Where,

Y_{ijk}= dependent variable, e. g. cracking, raveling, or chip loss

μ = overall mean

A_i = Effect due to ith aggregate

ε_{ijk}= Random error

The approximate locations of the evaluation sections on each pavement are shown in Figures 1 and 2.

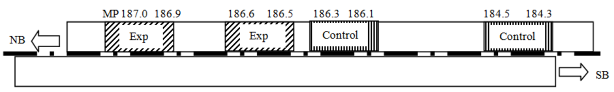

Figure 1. *Evaluation Sections on SH71.*

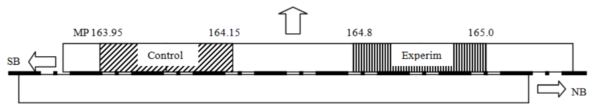

Figure 2. *Evaluation Sections on SH59.*

Dependent Variables

Performance of the chip seals was evaluated by conducting visual condition surveys of the sites after the winter and before fall each year. These condition surveys evaluated performance by measuring cracking, raveling and chip loss.

4. Methodology

The process used to conduct this experiment consisted of the following steps:

1. Evaluate condition of the pavement in the area of the evaluation sections prior to application of the chip seals.
2. Sample the materials used for construction and determine physical properties
3. Construct evaluation sections
4. Evaluate condition of the evaluation sections after winter and before fall each year for three years.

4.1. Pavement Condition Prior to Construction of Test Sections

Prior to construction of the test sections condition surveys were performed in the areas of the evaluation sections to determine pre-chip seal condition. These surveys were conducted visually following the procedures outlined by the Strategic Highway Research Program (SHRP 2003). Results of this survey are shown in Appendix A and consisted primarily of longitudinal, transverse, alligator cracking, and chip loss.

4.2. Materials

The two aggregates used in this study were obtained from L. G. Everist and McAtee Construction. One aggregate is representative of what is typically used in eastern Colorado for chip seal construction on low volume roads. This is the control aggregate. The other aggregate is finer in gradation and less processed with respect to crushing. This aggregate is the experimental aggregate. The gradations, percent of fractured faces and soundness loss measured for each of these aggregates is shown in Table 1 and compared with the CDOT 703-6 specification for chip seal aggregate and the Nebraska Department of Roads (NDOR) Section 1033 specification for what is termed ‘armour coat’ by NDOR. Armour coat is a chip seal constructed with minimally processed aggregates for use on low volume roads.

Asphalt emulsion used on the project was obtained from Cobitco in Denver, CO with the properties shown in Table 2.

4.3. Construction

Construction of the test sections was conducted by CDOT Region 4 maintenance forces in the summer of 2009. Equipment utilized consisted of a conventional asphalt distributor, self-propelled aggregate spreader and two pneumatic tired rollers. Traffic control consisted of diverting traffic on each of the two lane pavements around the chip seal operations until the strength of the emulsion was high enough to resist chip dislodgement.

Table 1. *Aggregates Used in Experimental Chip Seal Evaluation Sections.*

Sieve	Passing, %			
	Control	Experimental	CDOT 703-6 Spec	NDOR 1033
¾				100
3/8	100	100	100	94-100
4	32	62	0-15	
8	6	13		
10	5	10		30-35
50	3	6		0-10
200	1	3	0-1	0-4
L. A. Loss, %	29	31	< 35	< 40
2 Fractured Faces, %	25	15	> 90	n/a
Soundness Loss, %	3	3	n/a	< 12

Table 2. Asphalt Emulsion.

Property	CRS-2P Spec	Project
Tests on Emulsion		
Viscosity, 50C, Saybolt-Furol, s	50-450	120
Storage Stability, 24 hr, % max	1.0	0
Particle Charge Test	Positive	Positive
Sieve Test, % max	0.10	0
Demulsibility, % min	40	70
Oil Distillate by Volume, % max	3.0	0
Residue by Evaporation, % min	65	69
Tests on Residue		
Penetration, 25C, 100g, 5s, dmm, min	70-150	105
Solubility in TCE, % min	97.5	100
Toughness, in-lbs, min	70	95
Tenacity, in-lbs, min	45	75

Materials application rates for SH71 evaluation sections were 28 pounds per square yard for the control and 26 pounds per square yard for the experimental aggregate. Emulsion was applied at 0.28 gallons per square yard for both control and experimental sections. Chips on SH59 were applied at 28 pounds per square yard for both control and experimental aggregates and at 0.29 gallons per square yard for the emulsion. Design application rates were estimated using the Texas chip seal design procedure (Epps, et al, 1981). Results of this design are shown in Table 3.

This design procedure uses a one-square yard board to estimate the quantity of chips required to cover the surface one stone thick. The asphalt quantity is estimated by calculating the amount of asphalt to fill the voids between the chips to a specific embedment depth. That relationship is as follows:

$$A = \{5.61\ e\ [1.33Q/W][1-(W/(62.4G))]\ T + V\}/\ R$$

Where the terms are as shown in Table 8 and,

G = aggregate specific gravity, and

R = emulsion residue, %

Construction proceeded with no difficulties for either test pavement. Aggregate embedment was achieved after approximately four passes of the pneumatic tired rollers and vehicular traffic was allowed back onto the fresh chip seals after approximately two hours from the time of application.

The environmental conditions at the time of construction are summarized in Table 4.

Table 3. Design Quantities for Materials.

	SH 71 Control	Experiment	SH 59 Control	Experiment
Quantity of chips*, Q, psy	26	24	27	28
Loose Unit Weight, W, pcf	113	115	113	115
Design Embedment, e, %	40	40	40	40
Traffic Correction, T	1.1	1.1	1.1	1.1
Surface Correction, V	-0.03	-0.03	-0.03	-0.03
Emulsion, gsy	0.30	0.26	0.32	0.31

* From Board Test during laboratory design

Table 4. Environment During Construction.

Location	Pavement Temp, F	Weather	Wind
SH 71	90-105	Clear/Sun/Dry	270 @ 10 mph
SH 59	80-95	Clear/Sun/Dry	270 @ 5 mph

4.4. Pavement Condition after Construction of Test Sections

Evaluation sections were monitored to measure performance from the spring of 2010 until the fall of 2012. Methods used to evaluate performance were visual condition surveys conducted by walking along the shoulders of the pavements and observing condition according to the methods described by SHRP (SHRP 2003) for the cracking and flushing and Epps, et al (Epps, et al, 1981) for the chip loss. The results of these surveys are shown in Figures 3 to 7 for SH71 and Figures 8 to 12 for SH59. The evaluation sections are presented separately on the graphs. That is, sections 1 to 5 are the first five, 100 foot long control sections, sections 6 to 10 are the second five, 100 foot long control sections; sections 11 to 15 are the first five, 100 foot long experimental sections, and sections 16 to 20 are the second five, 100 foot long experimental sections.

Distress in both pavements is limited to a return of transverse and longitudinal cracks to pre-chip seal conditions after approximately 2.5 years. Alligator cracking, which was only present in the control sections prior to treatment, has returned to approximately 22 to 35 percent of that present prior to treatment. Chip loss ranges from 0.35 to approximately 0.50 percent of the area of the evaluation sections. Some areas of the pavements also contain longitudinal flushing streaks where distributor nozzles may not have been adjusted correctly and higher quantities of asphalt were applied. The cause of this is not related to either type of chip, but is reported for thoroughness.

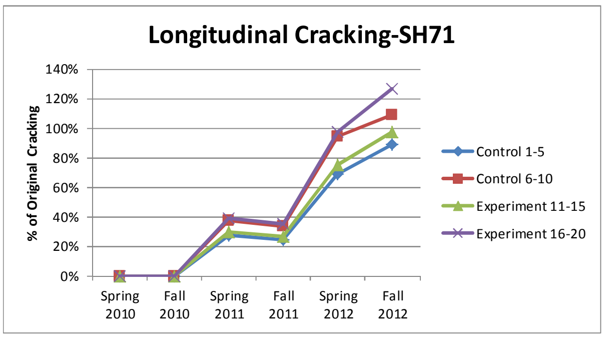

Figure 3. Longitudinal Cracking on SH71.

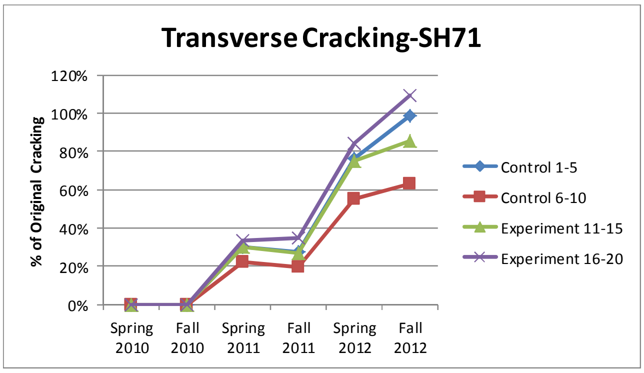

Figure 4. *Transverse Cracking on SH71.*

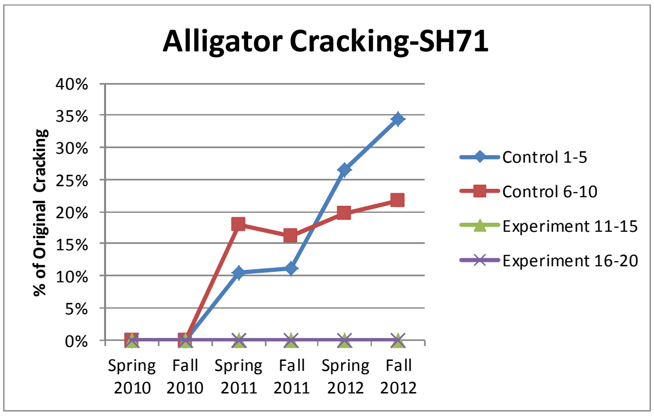

Figure 5. *Alligator Cracking on SH71.*

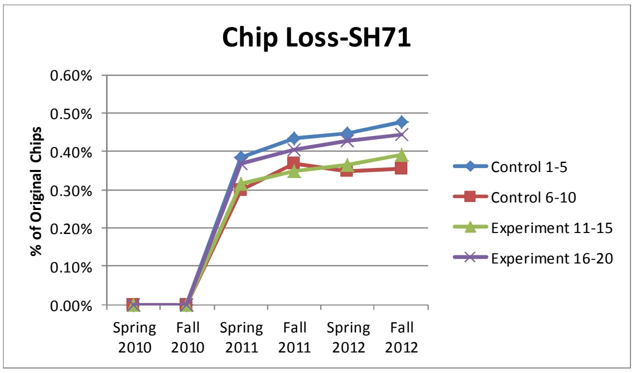

Figure 6. *Chip Loss on SH71.*

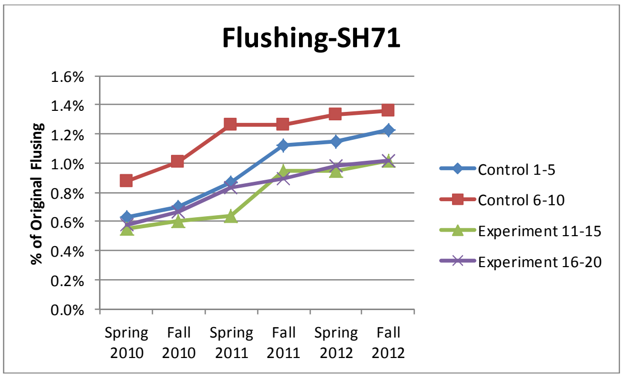

Figure 7. *Flushing on SH71.*

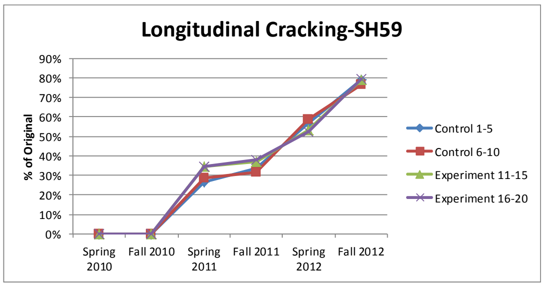

Figure 8. *Longitudinal Cracking on SH59.*

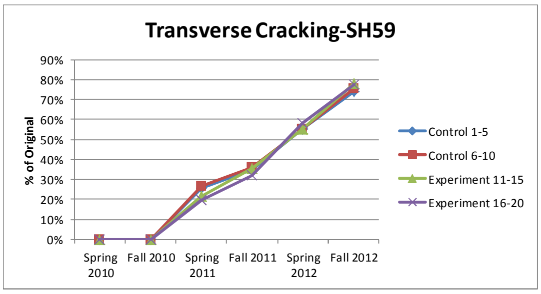

Figure 9. *Transverse Cracking on SH59.*

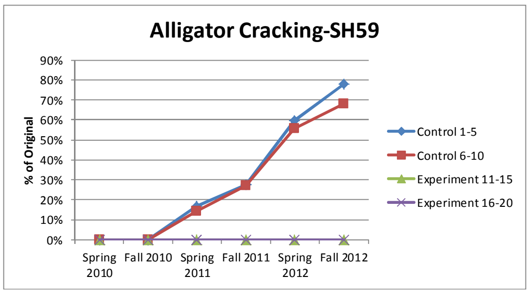

Figure 10. *Alligator Cracking on SH59.*

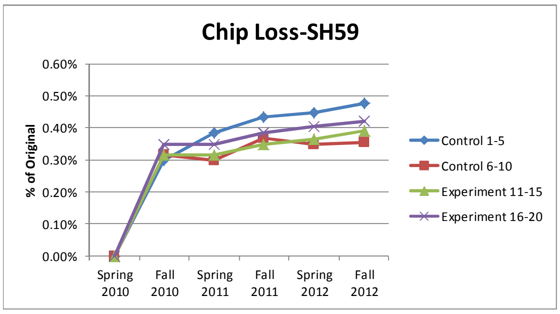

Figure 11. *Chip Loss on SH59.*

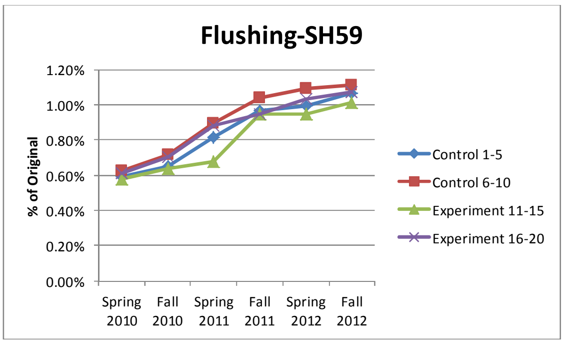

Figure 12. *Flushing on SH59.*

5. Analysis

The results of the condition surveys after three years service were analyzed using conventional analysis of variance techniques (ANOVA) to determine whether any significant differences exist in performance for any of the evaluation sections. The results of this analysis are shown in Tables 5 to 9 for SH71 and Tables 10 to 14 for SH59. The dependent variable analyzed to determine differences in performance was the percent of the original distress observed for each evaluation section at the end of the performance period in the fall of 2012. For example, Table 5 indicates that the control sections on SH71 had an average of 99 percent of the original longitudinal cracking returning during the fall 2012 condition survey while the experimental sections had an average of 107 percent. The ANOVA indicates that at α=0.05 significance, there is no statistical difference between these values, that is, the P-value = 0.67 in this case. This means there is only a 33 percent probability that a difference exists between the cracking observed in the control section compared with the experiment section.

Table 5. *ANOVA for Longitudinal Cracking on SH71.*

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Control	10	9.90	0.99	0.10		
Experiment	10	10.66	1.07	0.20		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.03	1	0.03	0.19	0.67	4.41
Within Groups	2.75	18	0.15			
Total	2.78	19				

Table 6. *ANOVA for Transverse Cracking on SH71.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	7.65125	0.765125	0.117613		
Experiment	10	10.1125	1.01125	0.217923		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.302888	1	0.302888	1.8054	0.195755	4.413873
Within Groups	3.019817	18	0.167768			
Total	3.322705	19				

Table 7. *ANOVA for Alligator Cracking on SH71.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control 1	5	1.07	0.21	0.06		
Control 2	5	0.22	0.04	0.01		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.07	1	0.07	2.07	0.19	5.32
Within Groups	0.28	8	0.04			
Total	0.36	9				

Table 8. *ANOVA for Chip Loss on SH71.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	0.0417	0.0042	0.0000		
Experiment	10	0.0418	0.0042	0.0000		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0000	1	0.0000	0.0001	0.9912	4.4139
Within Groups	0.0000	18	0.0000			
Total	0.0000	19				

Table 9. *ANOVA for Flushing on SH71.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	0.13	0.013	0.00		
Experiment	10	0.10	0.010	0.00		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00	1	0.00	4.70	0.04	4.41
Within Groups	0.00	18	0.00			
Total	0.00	19				

Table 10. *ANOVA for Longitudinal Cracking on SH59.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	6.20	0.62	0.11		
Experiment	10	5.55	0.56	0.15		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02	1	0.02	0.16	0.69	4.41
Within Groups	2.33	18	0.13			
Total	2.35	19				

Table 11. *ANOVA for Transverse Cracking on SH59.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	7.48	0.75	0.01		
Experiment	10	7.05	0.71	0.06		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01	1	0.01	0.25	0.63	4.41
Within Groups	0.68	18	0.04			
Total	0.68	19				

Table 12. *ANOVA for Alligator Cracking on SH59.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control 1-5	5	3.13	0.63	0.12		
Control 6-10	5	3.27	0.65	0.01		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00	1	0.00	0.03	0.87	5.32
Within Groups	0.53	8	0.07			
Total	0.54	9				

Table 13. *ANOVA for Chip Loss on SH59.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	0.0417	0.0042	0.0000		
Experiment	10	0.0407	0.0041	0.0000		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0000	1	0.0000	0.0309	0.8624	4.4139
Within Groups	0.0000	18	0.0000			
Total	0.0000	19				

Table 14. *ANOVA for Flushing on SH59.*

Groups	**Count**	**Sum**	**Average**	**Variance**		
Control	10	0.1089	0.0109	0.0000		
Experiment	10	0.1043	0.0104	0.0000		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.0000	1	0.0000	0.1404	0.7123	4.4139
Within Groups	0.0001	18	0.0000			
Total	0.0001	19				

A summary of the previous ANOVA results indicates the following:

Table 15. *Summary of ANOVA Results for SH71.*

Performance Criteria, % of Original at 3 Years	**Control Average**	**Experiment Average**	**P-value**
Longitudinal Cracking	99	107	0.67
Transverse Cracking	77	101	0.20
Alligator Cracking	n/a	n/a	n/a
Chip Loss	0.42	0.42	0.99
Flushing	1.3	1.0	0.04

Table 16. *Summary of ANOVA Results for SH59.*

Performance Criteria, % of Original at 3 Years	**Control Average**	**Experiment Average**	**P-value**
Longitudinal Cracking	62	56	0.69
Transverse Cracking	75	71	0.63
Alligator Cracking	n/a	n/a	n/a
Chip Loss	0.42	0.41	0.86
Flushing	1.1	1.0	0.71

6. Conclusions

1. Locally available, minimally processed aggregates can be successfully applied as chip seal aggregate on low volume roadways. After three years of service two experimental pavements provided the same performance with respect to cracking, chip loss and flushing for both control and experimental aggregate chips.
2. The design procedure used to estimate aggregate chip application quantity and emulsion spray rates matched the actual quantities placed reasonably well and these quantities resulted in acceptable performance for three years.

7. Recommendations and Observations

The design procedure reported herein provided good estimates of the chip and emulsion quantities actually utilized during construction and which resulted in good performance of the chip seals during the analysis period of three years.

Longitudinal streaking of the emulsion occurred on both pavements which lead to flushing. This over application could have been caused by plugged nozzles in parts of the spraybar, spraybar height, or nozzles not adjusted to the same angle. In addition, although chip loss was minimal, much of the loss occurred at or near the roadway centerline. An edge nozzle designed to provide half the fan of a full nozzle can be used to reduce this potential loss of chips.

In some cases, tandem dump trucks delivering chips to the aggregate spreader overfilled the spreader hopper and excess chips were applied to the surface. These excess chips may also have been a source of some of the flushing observed.

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