Successful Chip Seal Construction with Marginal Aggregates on Low Traffic Volume Roadways

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The performance of two low traffic volume full-scale experimental chip seals after four years of service are presented in this paper. The objective of this work was to evaluate the feasibility and cost/benefit of using aggregates in chip seals which did not meet current specifications with respect to gradation on low volume roadways. Because the cost of transporting high quality aggregates is increasing and because much of the pavement preservation activities in the world are on low volume roadways, utilizing locally available aggregates provides economic benefits if acceptable performance can be achieved. Condition surveys of each pavement were conducted after each winter and summer to document pavement condition. Results indicate that pavement distress is in the form of longitudinal and transverse cracking and localized flushing due to non-uniform asphalt emulsion application during construction. Based on results from the last condition survey both test pavements should perform acceptably for the next several years assuming no significant change occurs in traffic levels. No significant differences were measured in performance for any of the evaluation sections. A recommendation is provided regarding the chip seal materials, design and construction methods to be used for low traffic volume pavements.

Keywords: Pavement maintenance, pavement performance, pavement preservation, chip seals, low traffic volume

Background

Many roadways are in locations without high quality aggregates. Therefore, high quality aggregates must be transported to these locations when pavement construction activities are needed. This transportation increases the cost of pavement construction in these parts of the world. Increased costs often mean that timely pavement construction activities are postponed. This postponement leads to deterioration of the infrastructure and, ultimately, increased costs. In addition, many of these roadways are low traffic 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 construction could be accomplished at appropriate intervals and within budget. Both short and long term savings would result.

Chip seals are used extensively throughout the world for pavement construction and rehabilitation. Chip seals utilizing locally available and minimally processed aggregates would be a more economical pavement preservation treatment than chip seals constructed with high 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 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.

Objectives

1. Construct chip seal test and control sections using locally available and minimally processed aggregates and document the performance of these pavements for four 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.

Literature Review

There is a significant amount of information available on chip seal design, construction and performance. From two design methods by Hanson (Hanson, 1934-1935) and Kearby (Kearby, 1953), most methods used today can be traced (McLeod, 1960; Epps, 1981). 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 (Major, 1965; Kandhal, 1991) and make recommendations regarding the optimum consistency for desired performance. Predicting early chip retention has been done using laboratory abrasion tests, impact tests, and traffic simulators (Shuler, 1991, 2011; Stroup-Gardiner, 1990).

The performance of chip seals has been reported by many (Jackson, 1990; Jahren, 2004; Gransberg, 2005).

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, and 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).

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 1960; 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).

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).

The tolerance limits for the flakiness of the aggregate are based on traffic but generally should be less than 30 (Croteau, et al, 2005).

Aggregate shape is typically characterized by angularity. As the orientation of the embedded chip is important, cubical aggregate shapes are preferred because traffic does not have a significant effect on the final orientation of aggregate (Janisch and Galliard, 1998).

Australian practice requires that 75% of the aggregate have at least two fractured faces (Sprayed Sealing Guide, 2004). Rounded aggregates, as indicated by low percent fracture, are susceptible to displacement by traffic because they provide the least interfacial area between the aggregate and binder. The roundness of the aggregate will determine how resistant the chip seal will be to turning and stopping movements. (Gransberg & James, 2005).

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).

Experimental Method

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 the maintenance department with a history of acceptable performance. The second aggregate represented a locally available and marginal material not meeting state specifications with unknown performance. These materials will be identified as Control and Experimental, respectively.

Test sections were constructed in two different locations in the state which will be identified as Sites 1 and 2, respectively. Both of these pavements are rural, farm to market two lane highways with 12 foot wide driving lanes. Traffic volumes are 360 AADT (average annual daily traffic) with 30 single unit trucks and 120 combination trucks at Site 1and between 160 and 470 AADT with 20 single unit trucks and 20 combination trucks at Site 2.

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:

$$Y_{ijk} = \mu + A_i + \varepsilon_{ijk}$$

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.

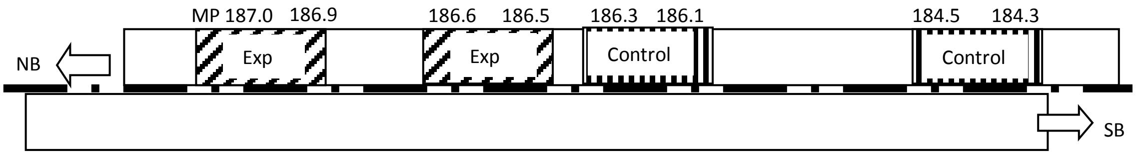

Figure 1. Evaluation Sections at Site 1

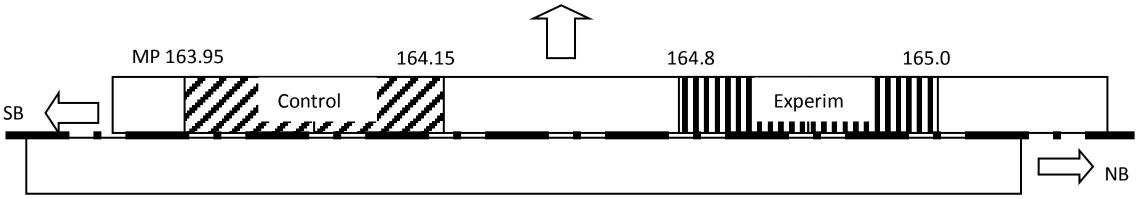

Figure 2. Evaluation Sections at Site 2

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. The procedure utilized was the visual method described by the Strategic Highway Research Program (SHRP 1993)

Pre-Construction

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.

Construction

Materials

The two aggregates used in this study were obtained from two separate private sand and gravel sources. One aggregate is representative of what is typically used in the state 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 state specification for chip seal aggregate.

Table 1. Aggregates Used in Experimental Chip Seal Evaluation Sections

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

Asphalt emulsion used on the project had properties shown in Table 2.

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

Construction

Construction of the test sections was conducted by 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.

Materials application rates for Site 1 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 at Site 2 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).

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 3.

Table 3. Environment During Construction

Location	Pavement Temp, F	Weather	Wind
Site 1	90-105	Clear/Sun/Dry	270 @ 10 mph
Site 2	80-95	Clear/Sun/Dry	270 @ 5 mph

Results

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 Site 1 and Figures 8 to 12 for Site 2. Each of the groups of five evaluation sections are presented separately on the graphs.

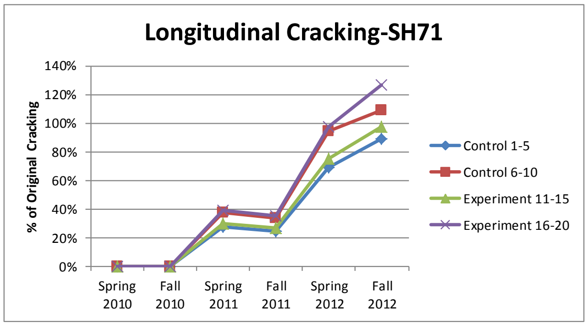

Figure 3. Longitudinal Cracking at Site 1

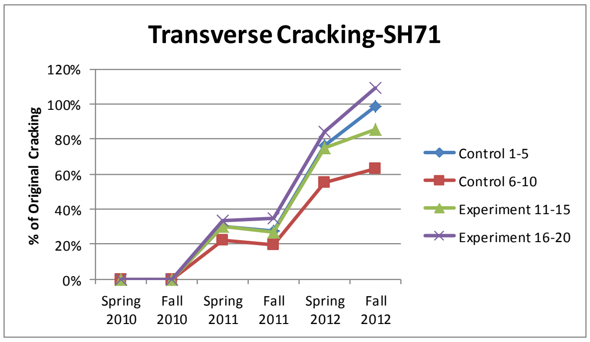

Figure 4. Transverse Cracking at Site 1

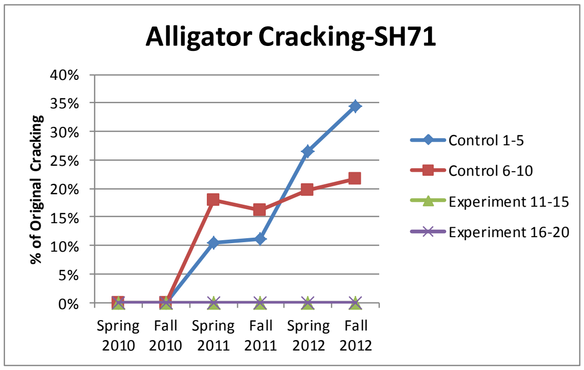

Figure 5. Alligator Cracking at Site 1

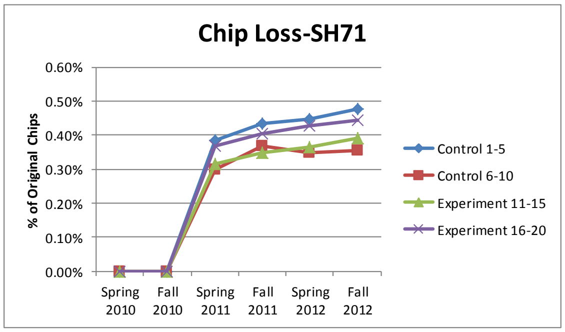

Figure 6. Chip Loss at Site 1

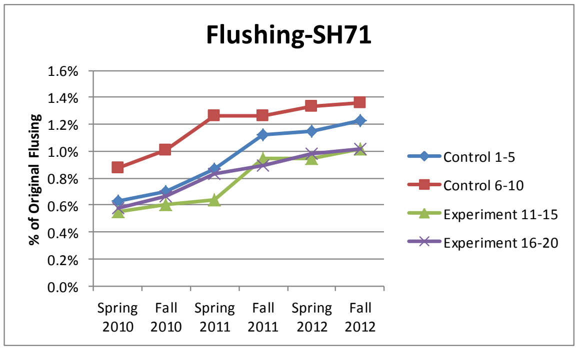

Figure 7. Flushing at Site 1

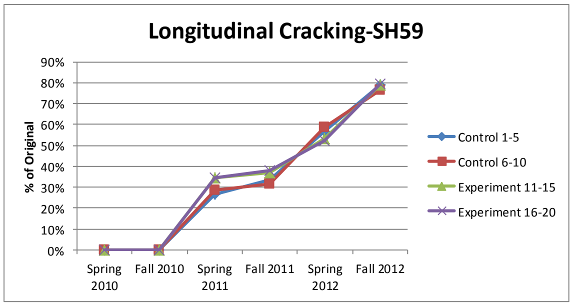

Figure 8. Longitudinal Cracking at Site 2

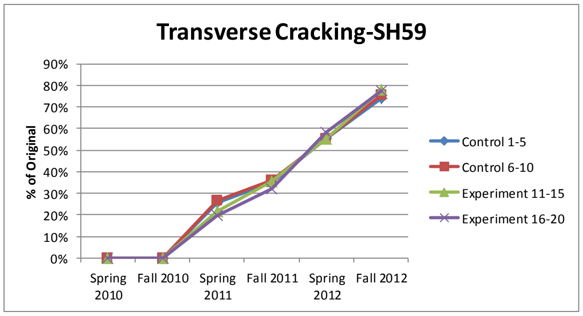

Figure 9. Transverse Cracking at Site 2

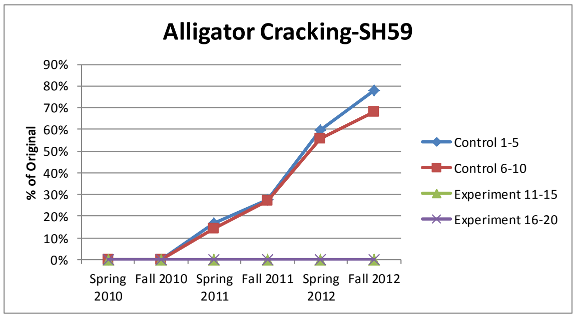

Figure 10. Alligator Cracking at Site 2

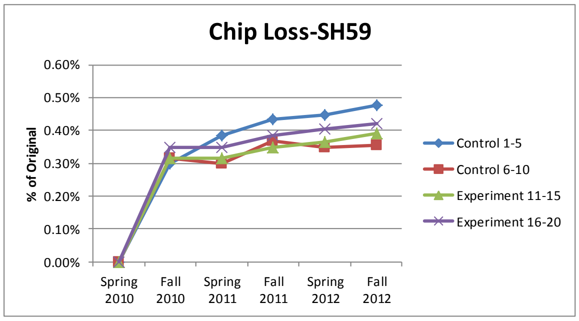

Figure 11. Chip Loss at Site 2

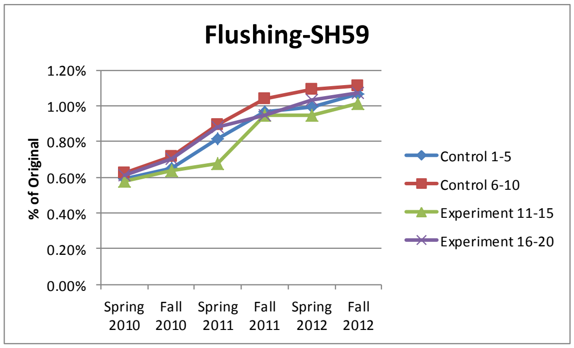

Figure 12. Flushing at Site 2

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.

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 dependent variable was 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. A summary of this analysis is shown in Table 4. Based on this analysis there was no significant difference between any of the dependent variables except flushing for Site 1.

Table 4. Summary of ANOVA Results for SH71

Performance, % of Orig @ Yr 3	Site 1			Site 2		
	Control	Experiment	P-value	Control	Experiment	P-value
Longitudinal Cracking	99	107	0.67	62	56	0.69
Transverse Cracking	77	101	0.20	75	71	0.63
Alligator Cracking	n/a	n/a	n/a	n/a	n/a	n/a
Chip Loss	0.42	0.42	0.99	0.42	0.41	0.86
Flushing*	1.3	1.0	0.04	1.1	1.0	0.71

- Flushing was not judged caused by the difference in the aggregate chips, but instead, due to construction practices

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 and chip loss for both control and experimental aggregate chips.

2. A procedure 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.

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