Reducing Windshield Damage on Fresh Seal Coats

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The adhesive and cohesive strength of the emulsion residue used as the binder in a chip seal is directly related to when the chip seal can be opened to traffic after construction. This strength is usually judged subjectively during construction by experienced personnel. Unfortunately, this experience is often gained by trial and error, the error leading to vehicle damage when residues that have not gained sufficient strength release chips under traffic loads. This research was conducted to help eliminate the subjectivity involved in determining when a chip seal can be safely opened to traffic without undue chip loss. The study began with the hypothesis that the existing ASTM D7000 sweep test could be used for this purpose. The ASTM procedure was evaluated and it was determined the test would be adequate for relative comparison of different emulsions for the same aggregates, but not sufficient to evaluate different aggregates for the same or different emulsions. The reason for this is because D7000 uses a template to establish residue depth. Chip gradation is roughly controlled so embedment depth is relatively equal for different chips but variability remains high so predicting actual times to traffic are not feasible. Therefore, a revision of the D7000 test was done to eliminate these variables so that actual project materials could be used and time to trafficking could be estimated. Results indicate the amount of water remaining in the emulsion is directly related to residue strength, as expected. Therefore, by establishing the relationship between water content and chip loss in the revised sweep test the time required in the field before traffic is allowed on the fresh chip seal can be estimated in advance. Results indicate little correlation between emulsion particle charge and aggregate type and also that chip loss is directly related to aggregate moisture content upon embedment.

Keywords: Chip seal, sweep test, chip loss, aggregate-emulsion compatibility

LITERATURE REVIEW

Sweep tests have been developed for various purposes with respect to chip seal construction (*1, 2*). The Montana Sweep Test is the most direct method (*3*). This procedure sweeps the actual chip seal during construction. When the amount of chips dislodged during the test is less than 10 percent, the chip seal is judged ready for traffic. With practice this procedure probably works well. However, it requires personnel conduct the test in the field during construction. This exposes technicians to traffic and construction hazards. The ASTM D7000 (4) procedure was developed from earlier research (*1, 2*) to predict chip loss in emulsion chip seals. This procedure is relatively effective at estimating differences in adhesive abilities of different emulsions when the same aggregate is tested. However, the procedure is not as useful when different aggregates are evaluated with different emulsions. This is because the test utilizes a template to establish the thickness of emulsion application rate. While a single emulsion application rate is suitable for relative comparison between emulsions, when aggregate sizes differ the embedment percentage changes which affects adhesive strength.

BACKGROUND

The objective of this study was to determine whether a new laboratory method of measuring strength of an emulsified asphalt chip seal binder could be utilized to predict binder strength in the field during construction of a full scale chip seal. To determine the utility of the new method a laboratory experiment was designed to evaluate four aggregates and four emulsions at two cure periods under two moisture conditions. The hypothesis was that the moisture content of the emulsion was directly related to binder adhesive strength. This hypothesis was tested in the laboratory using a modified version of ASTM D7000, "Standard Test Method for Sweep Test of Bituminous Surface Treatment Samples" and in the field by constructing two chip seals.

METHOD

The laboratory experiment was designed as a full-factorial with replication using the following independent and dependent variables:

Independent variables in this experiment are shown below:

Aggregates:	Basalt, Granite, Limestone, Alluvial
Emulsions:	RS-2, RS-2P, CRS-2, CRS-2P
Emulsion Cure:	40%, 80%
Aggregate Moisture:	Dry, Saturated Surface Dry

The full-factorial experiment was analyzed according to the model shown below:

$$Y_{ijkl} = \mu + A_i + E_j + W_k + M_l + AE_{ij} + AW_{ik} + AMil + EW_{jk} + EMjl + WMkl + AEW_{ijk} + AEMijl + EWMjkl + AEWMijkl + \varepsilon_{ijkl}$$

Where,

Y_{ijklm}	= Chip Loss, %
μ	= mean loss, %
A_i	= effect of aggregate i on mean
E_j	= effect of emulsion j on mean
W_k	= effect of water removed k on mean
M_l	= effect of aggregate moisture l on mean
AE_{ij}, AW_{ik}, EW_{jk}, AEW_{ijk}	= effect of interactions on mean
e_{ijklm}	= random error for the ith aggregate, jth emulsion, kth water removed, and lth replicate

The experiment was blocked with respect to emulsion so that each emulsion could be utilized at the same time after formulation. This eliminated potential variability that could be associated with differences in emulsion age.

MATERIALS

Asphalt emulsions consisted of anionic and cationic materials both conventional and polymer modified as shown in Table 1. Aggregates consisted of limestone (LSTN), granite (GRNT), basalt (BSLT) and alluvial (ALLV) materials with properties presented in Table 2.

Table 1. Emulsion Properties

Test	Emulsion			
	RS-2P DSAT-Lab (PG64-28)	**RS-2 (64-22)**	**CRS-2 (58-28)**	**CRS-2P (64-28)**
Saybolt, 50° C	108	96	78	19
Residue, %	65.1	68.0	68.0	68.0
Residue Tests				
Pen, 25° C, 100 g, 5 sec	115		125	
Ductility, 25° C, 5 cm/min	150+		55	
Float (HFRS only) 60° C	Not Needed	Not Needed	Not Needed	Not Needed
DSR, G*	1.11		1.12	
DSR, sin delta	1.13		1.12	
BBR, m	.481		.476	
BBR, s	71		87	
Residue and PAV Tests Age with PAV for these tests. Do NOT do RTFO aging.				
PAV, DSR, G*	1210		3170	
PAV, DSR, sin delta	1020		2450	
BBR, m	.395		.361	
BBR, s	114		151	

Table 2. Aggregate Properties

Sieve No. (in.)	Sieve Size (mm)	Passing, %			
		LSTN	GRNT	BSLT	ALLV
1/2"	12.5	100%	100%	100%	100%
3/8"	9.5	100%	99%	100%	99%
5/16"	8	100%	50%	79%	73%
1/4"	6.3	48%	9%	30%	33%
no. 4	4.75	1%	1%	1%	2%
no. 8	2.36	1%	1%	1%	2%
no. 16	1.18	1%	1%	1%	2%
no. 30	0.0006	1%	1%	1%	2%
no. 50	0.0003	1%	1%	1%	2%
no. 100	0.00015	1%	1%	1%	2%
no. 200	0.000075	1%	1%	1%	2%

Bulk specific gravity	2.615	2.612	2.773	2.566
Loose unit weight (lb/c.ft.)	78.31	83.97	92.20	86.05
Mat depth (in.) = 4Q/3W	0.176	0.256	0.206	0.219
Median Size (in.)	0.252	0.315	0.277	0.277
ALD (in.)	0.170	0.265	0.218	0.222
McLeod Aggregate Coverage, (lb/sy)	16.48	26.11	22.95	21.73
D7000 agg. coverage (lb/sy)	13.31	14.98	14.96	13.56
Kearby Agg Coverage. (lb/sy)	10.32	16.09	14.26	14.14

REVISED TEST PROCEDURE

Revisions to ASTM D7000 were many and cannot be described in detail here due to editorial constraints. However, the significant differences include determination of aggregate quantity to obtain one-stone thick coverage, determination of emulsion quantity to obtain 40 percent embedment, a new technique for applying the stone uniformly and consistently, and evaluating the emulsion water loss prior to testing. The remainder of D7000 was kept the same with respect to the apparatus utilized.

RESULTS

Figures 1 through 4 show the results of the modified sweep test for each of the aggregates in the dry and SSD conditions and for emulsions at 40 and 80 percent cured conditions.

ANALYSIS

Results of the ANOVA indicate significant differences between the 40 percent and 80 percent cured test specimens, as expected. This result is also readily seen comparing Figures 1 (average of approximately 70 percent loss) and 2 (average of approximately 15 percent loss) for the dry aggregates and Figures 2 (approximately 65 percent loss) and 4 (approximately 10 percent loss) for the SSD specimens. The test indicates a real difference in chip loss between aggregates that are dry when embedded in the emulsion compared with those that are in the SSD condition when embedded. This finding is consistent with common beliefs that damp aggregates allow the emulsion to wick into the aggregate pores, providing improved adhesion and cohesion properties. Also, there appear to be real differences between the emulsions. The RS-2P performed poorer than the other emulsions at 80 percent cure, but approximately equal at 40 percent cure. The particle charge on the emulsion appears to have no effect on chip loss at 40 percent cure based on Figures 1 and 3. And, at 80 percent cure the CRS-2P appears to adhere to all of the aggregates approximately equally, and only a small effect on chip loss was measured for the RS-2 at 80 percent cure (8 percent loss for the limestone vs 12 percent for the granite).

DEPENDENT VARIABLE: RS2 RS2

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR > F
AGGREGATE	3	0.13191250	0.04397083	27.81	<.0001
MOISTURE	1	0.01125000	0.01125000	7.11	0.0169
CURE	1	2.31125000	2.31125000	1461.66	<.0001
AGGREGATE*MOISTURE	3	0.00722500	0.00240833	1.52	0.2468
AGGREGATE*CURE	3	0.06257500	0.02085833	13.19	0.0001
MOISTURE*CURE	1	0.00061250	0.00061250	0.39	0.5425
AGGREGA*MOISTUR*CURE	3	0.01136250	0.00378750	2.40	0.1064

SNK GROUPING	MEAN	N	AGGREGATE
A	0.47125	8	ALLVL
B	0.38625	8	GRNT
B			
B	0.35750	8	LSTN
C	0.29250	8	BSLT

STUDENT-NEWMAN-KEULS TEST FOR RS2

SNK GROUPING	MEAN	N	MOISTURE
A	0.39563	16	DRY

B	0.35813	16	SSD

STUDENT-NEWMAN-KEULS TEST FOR RS2

SNK GROUPING	MEAN	N	CURE
A	0.64563	16	40
B	0.10813	16	80

DEPENDENT VARIABLE: RS2P RS2P

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR > F
AGGREGATE	3	0.71885132	0.23961711	46.47	<.0001
MOISTURE	1	0.03367353	0.03367353	6.53	0.0220
CURE	1	0.33800294	0.33800294	65.55	<.0001
AGGREGATE*MOISTURE	3	0.01776447	0.00592149	1.15	0.3618
AGGREGATE*CURE	3	0.12397500	0.04132500	8.01	0.0020
MOISTURE*CURE	1	0.04026176	0.04026176	7.81	0.0136
AGGREGA*MOISTUR*CURE	3	0.02637237	0.00879079	1.70	0.2088

STUDENT-NEWMAN-KEULS TEST FOR RS2P

SNK GROUPING	MEAN	N	AGGREGATE
A	0.56625	8	ALLVL
A			
A	0.51143	7	GRNT
A			
A	0.51000	8	BSLT
B	0.18000	8	LSTN

STUDENT-NEWMAN-KEULS TEST FOR RS2P

SNK GROUPING	MEAN	N	MOISTURE
A	0.48000	15	DRY
B	0.40188	16	SSD

STUDENT-NEWMAN-KEULS TEST FOR RS2P

SNK GROUPING	MEAN	N	CURE
A	0.54125	16	40
B	0.33133	15	80

DEPENDENT VARIABLE: CRS2 CRS2

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR > F
AGGREGATE	3	0.00667500	0.00222500	1.07	0.3887
MOISTURE	1	0.00451250	0.00451250	2.17	0.1597
CURE	1	2.86801250	2.86801250	1382.17	<.0001
AGGREGATE*MOISTURE	3	0.01536250	0.00512083	2.47	0.0994
AGGREGATE*CURE	3	0.00661250	0.00220417	1.06	0.3927
MOISTURE*CURE	1	0.00000000	0.00000000	0.00	1.0000
AGGREGA*MOISTUR*CURE	3	0.00137500	0.00045833	0.22	0.8805

SNK GROUPING	MEAN	N	AGGREGATE
A	0.50250	8	LSTN
A			
A	0.49250	8	GRNT
A			
A	0.47375	8	BSLT
A			
A	0.46625	8	ALLVL

STUDENT-NEWMAN-KEULS TEST FOR CRS2

SNK GROUPING	MEAN	N	MOISTURE
A	0.49563	16	SSD
A			
A	0.47188	16	DRY

STUDENT-NEWMAN-KEULS TEST FOR CRS2

SNK GROUPING	MEAN	N	CURE
A	0.78313	16	40
B	0.18438	16	80

DEPENDENT VARIABLE: CRS2P CRS2P

SOURCE	DF	TYPE III SS	MEAN SQUARE	F VALUE	PR > F
AGGREGATE	3	0.07093750	0.02364583	6.34	0.0049
MOISTURE	1	0.07801250	0.07801250	20.91	0.0003
CURE	1	1.81451250	1.81451250	486.30	<.0001
AGGREGATE*MOISTURE	3	0.00443750	0.00147917	0.40	0.7574
AGGREGATE*CURE	3	0.11793750	0.03931250	10.54	0.0005
MOISTURE*CURE	1	0.00001250	0.00001250	0.00	0.9546
AGGREGA*MOISTUR*CURE	3	0.05723750	0.01907917	5.11	0.0114

SNK GROUPING		MEAN	N	AGGREGATE
	A	0.38750	8	GRNT
	A			
B	A	0.33250	8	ALLVL
B	A			
B	A	0.32250	8	BSLT
B				
B		0.25500	8	LSTN

STUDENT-NEWMAN-KEULS TEST FOR CRS2P

SNK GROUPING	MEAN	N	MOISTURE
A	0.37375	16	DRY
B	0.27500	16	SSD

STUDENT-NEWMAN-KEULS TEST FOR CRS2P

SNK GROUPING	MEAN	N	CURE
A	0.56250	16	40
B	0.08625	16	80

FIELD TRIALS

The promising results of the laboratory experiment lead to two field trials to determine if prediction of emulsion strength in the field could be based on laboratory test results. Two projects were identified to test this hypothesis. The first field trial was conducted on approximately eight miles of the main entrance road to Arches National Park, Utah on

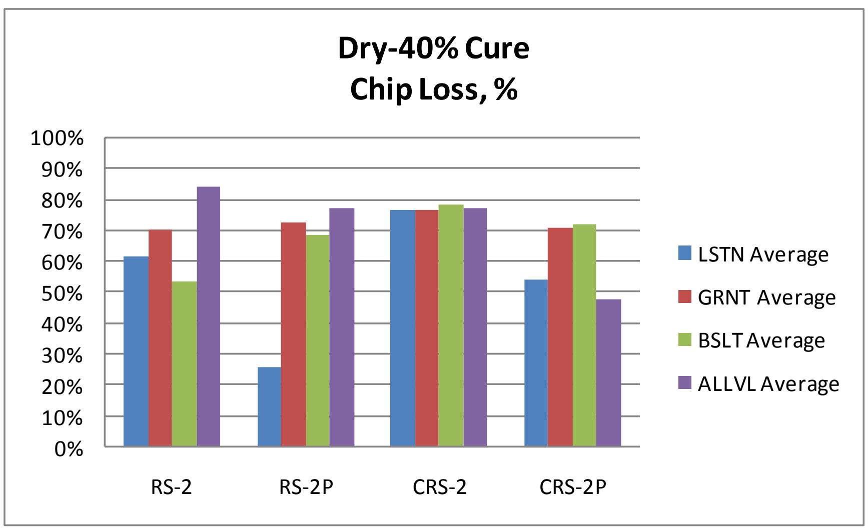

Figure 1. Sweep Test Results for Dry Aggregates at 40% Cured Emulsion

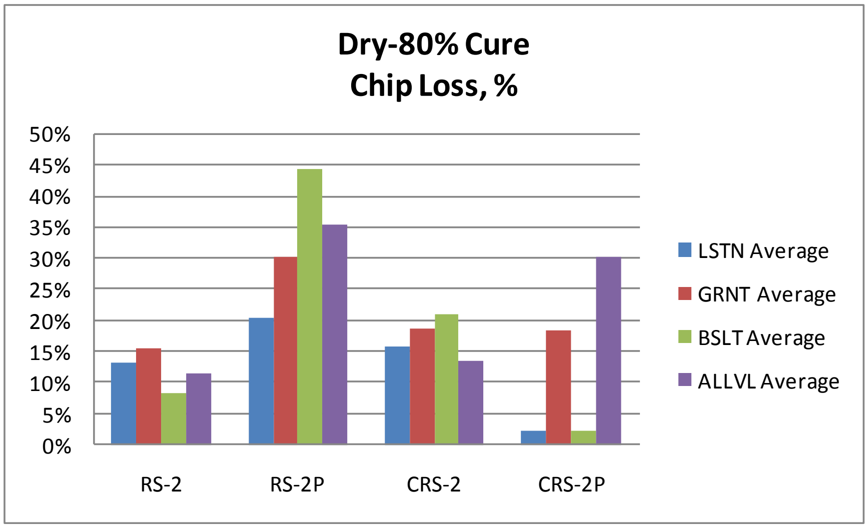

Figure 2. Sweep Test Results for Dry Aggregates at 80% Cured Emulsion

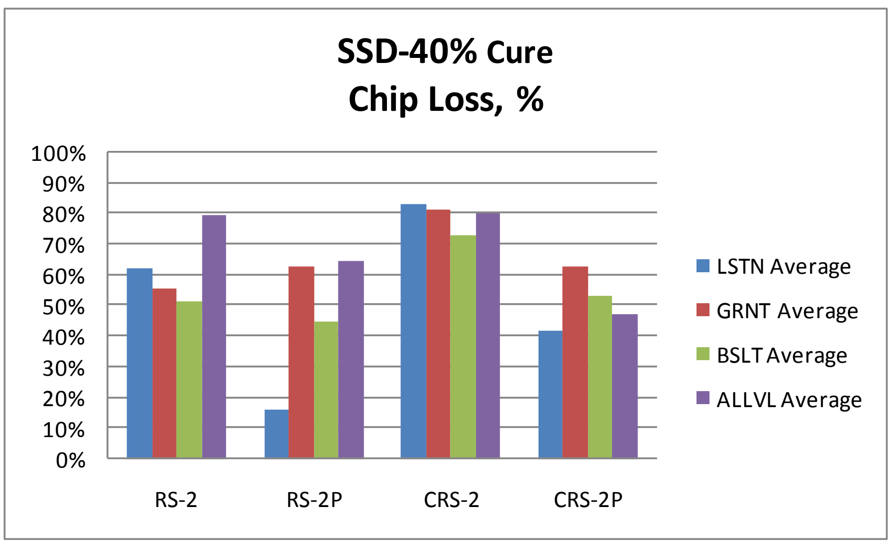

Figure 3. Sweep Test Results for SSD Aggregates at 40% Cured Emulsion

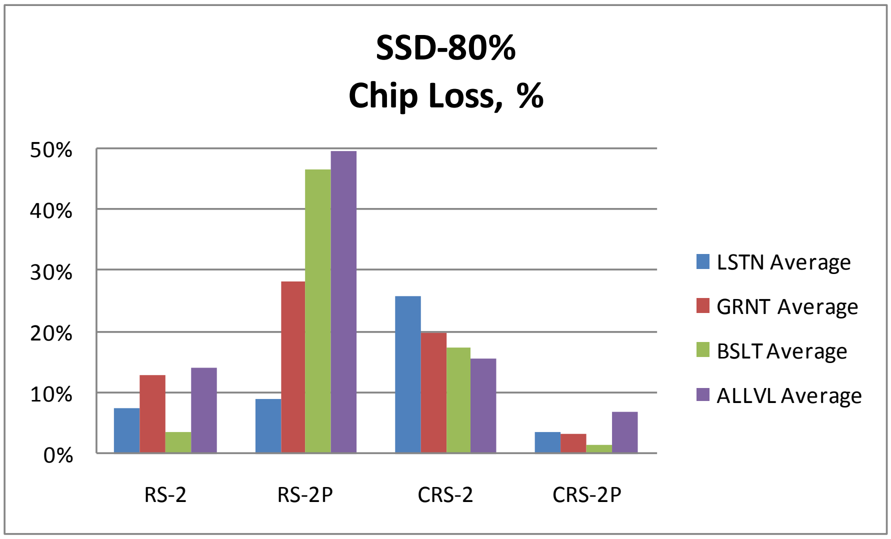

Figure 4. Sweep Test Results for SSD Aggregates at 80% Cured Emulsion

September 8, 2008. The second trial was on approximately eight miles of County Road 11 in Frederick, Colorado on September 10, 2008. Both projects were constructed by contractors for the Federal Highway Administration and the City of Frederick, respectively. Aggregates and emulsions utilized on the field sites consisted of the basalt and RS-2P at Frederick and the alluvial and CRS-2P at Arches. Conditions for chip sealing both sites were dry with air temperatures ranging from 70F to 85F and pavement temperatures ranging from 95F to 125F. Wind was calm to 5 mph. The quantity of emulsion and aggregate applied at Arches and Frederick compared with design values of 22 psy and 0.44 gsy and 21 psy and 0.37 gsy, respectively.

Measuring Emulsion Moisture Loss

The quantity of water loss in the emulsion used to construct the chip seal was required to determine if a correlation to the laboratory sweep test could be developed. Therefore, plywood pads measuring 24 by 24 inches and covered with aluminum foil were laid in front of the asphalt distributor prior to spraying with emulsion. The pads were weighed before and after spraying and chipping and the loss in weight was determined periodically during the day until approximately 95 percent of the water had evaporated. This practice was done at three locations for each project. The loss in weight was correlated to percent moisture loss in the emulsion so a comparison to the laboratory sweep test rests could be obtained. As moisture evaporated from the chip sealed pavement and test pads, this resulting moisture loss was measured and compared with the strength of the emulsion residue with respect to adhesion to the aggregate chips. The results of this experiment indicate that at approximately 75 to 85 percent water loss chip adhesion reaches the point where significant force is required to dislodge the chip. This is the point where sweeping can commence and traffic can be allowed to travel on the new surface.

CONCLUSIONS

1. A laboratory sweep test has been developed that can measure the increase in adhesive strength of asphalt emulsions as a function of moisture content in the aggregate/emulsion system.
2. A correlation between the sweep test results and full-scale field tests indicates the new test has promise in predicting when traffic controls can be removed from fresh chip seals thus reducing risk to vehicles due to aggregate projectiles.

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