Improving Chip Retention and Reducing Moisture Susceptibility of Seal Coats

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Seal coats are widely used as a surface treatment and maintenance tool. Thousands of lane miles are constructed annually, a sizable investment by state and local agencies. Life expectancy and performance of seal coats depends primarily on chip retention. In constructing a seal coat it is common for the liquid asphalt (emulsion or cutback) to be sprayed at 80 to 110°C (175 to 230°F), followed immediately by the spreading of wet chips from stockpiles at an ambient temperature between 10 and 40°C (50 and 104°F). This practice is believed to harm chip retention and, generally, the integrity of the seal coat. Improving chip retention can undoubtedly improve road performance and save state and local agencies some funds. A seal coat debonding test was used to evaluate chip retention of seal coats constructed by three methods. The first method was the classical method just cited, the second method included drying the chips before spreading, and the third method involved adding an antistripping agent to the liquid asphalt while the chips remained wet, as they were in the stockpile. The study revealed that chip retention improved significantly when the chips were dried and when antistripping agents were incorporated into the binder. The findings were based on the analysis of several treatments made with two types of liquid asphalt (MC-3000 and RC-3000R) and three types of chip (quartzite, pea rock, and blotter gravel).

The life expectancy of asphalt pavements is often affected by the presence of moisture. Unfortunately, the presence of moisture on pavements will continue to be a disturbing problem in the asphalt paving industry. Seal coats, commonly called chip seals, have been used in several countries, especially on many low- and moderate-volume roads, because limited budgets prohibit the construction of more expensive alternatives. The main functions of seal coats are to prevent moisture from entering the pavement, to increase skid resistance, and to enliven the weathered wearing surface.

In seal coats, the performance depends on many variables and can be related to aggregate, asphalt binder, construction techniques, or any combination thereof. Adhesion or bonding of aggregate to an asphalt binder plays an important role in the performance of seal coats. In the presence of moisture, the adhesion of asphalt and aggregate at their interface will be hindered. Loss of chips in newly constructed seal coats presents problems to motorists and shortens the life expectancy of the surface treatment.

Several methods are available to reduce the moisture susceptibility of asphalt pavements. The use of antistripping agents and hydrated lime are the most common methods in the United States.

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To examine chip retention among various seal coats, the research used three types of chip and two types of cutback. Quartzite, pea rock, and natural aggregates were used because they are readily available in the eastern part of South Dakota, where this study was conducted. The two asphalt binders—MC-3000 and RC-3000R—were used because several projects, both state and local, have employed them extensively during the past few years in South Dakota. Although emulsions and soft-grade asphalt cements are used in seal coats, cutbacks were used in this study because some chip seal projects in South Dakota failed when emulsion was used as a binder. Despite the national trend of promoting the use of emulsions in seal coats, cutbacks are still popular in South Dakota. The seal coat debonding test (SDT) was used to measure the moisture susceptibility of various seal coat specimens in the laboratory. Other tests such as the ASTM test method for coating and stripping of bitumen-aggregate mixture (ASTM D1664), the Texas boiling test, and the Texas-freeze pedestal test were not used in this study because they are qualitative tests and rely solely on judgment calls. The SDT, however, is a quantitative test, and a numerical value can be used to assess chip loss or retention.

In this study, three treatments were applied. In Treatment 1 (or "as is"), the aggregates were kept wet at the same moisture content as was found in the stockpile. This was accomplished by drying a preweighed amount of chips and then misting them with water till a precalculated amount had been applied. The amount of water added was calculated to produce the same moisture content as the original chips had in the stockpile. In Treatment 2 ("drying the aggregate"), the aggregates were oven-dried to remove water film from the aggregate surfaces. In Treatment 3 ("antistripping additive"), the aggregates had the same amount of moisture content as in Treatment 1 except that an antistripping agent was added to the asphalt binders at a rate of 1 percent of the weight of the binder. To determine which type of asphalt–aggregate–antistripping agent combination will produce the maximum chip retention in the presence of water, the SDT, developed by Selim and Heidari, was used (*1*). SDT was used to evaluate the moisture susceptibility of seal coat samples by weighing chip loss after every 2 days of soaking in a water bath at 25°C (77°F).

OBJECTIVES

The main objectives of this research were to determine

1. Which type of aggregate is most susceptible to moisture,

2. Which combination of aggregate and asphalt binder yields the best results in terms of chip retention,
3. Whether the amount of aggregate retention will be improved by drying the aggregate or by adding antistripping additive to the asphalt binder, and
4. Whether the use of polymer-modified asphalt cutback (RC-3000R) improves chip retention over the normal plain-asphalt cutback (MC-3000).

The three types of treatment, three types of aggregate chip, two types of binder, and three specimens in each combination of treatment/chips/binder resulted in 54 specimens.

MATERIAL SELECTION

The first cutback is the plain MC-3000, which is commonly used for chip seals, and the other was the polymer-modified RC-3000R, which is known by its trade name of Flexform. The three aggregates were quartzite (QZ), pea rock (PR), and blotter gravel (BG). As stated, the binders and chips were used because of their popularity with local and state agencies in the area in which this study was conducted (*2*). Representative samples of the three aggregates were taken from the stockpiles in sufficient amounts to perform the needed laboratory tests. The materials were taken from these stockpiles, which are owned by a local highway agency, because an earlier study that dealt with the field performance of seal coats used the same three aggregates (*3*). Table 1 shows the gradation of the three aggregates with suggested specifications from the South Dakota Department of Transportation. The additive used to treat the asphalt binders in this study is Redicote 82–S from Armak Highway Chemical. A brief description of all the materials is given in the following.

MC-3000

MC-3000 is a plain, hard grade of medium-curing cutback. It is commonly used for seal coats during the high temperatures of summer. MC-3000 has been chosen so as to compare its effectiveness with polymer-modified cutback in terms of chips retention.

RC-3000R

RC-3000R (Flexform) is a polymer-modified, rapid-curing cutback that is a harder asphalt than MC-3000. The polymer is a virgin synthetic styrene-butadiene rubber specifically designed to give the greatest enhancement of physical properties to the asphalt. When this study was conducted, asphalt suppliers were not yet producing polymer-modified medium-curing cutbacks, so the rapid-curing cutback was used instead.

Quartzite

Quartzite is a type of crushed aggregate that exists in abundance in the eastern part of South Dakota, where this study was performed. Chips 6.25 mm (¼ in.) in size were used with the gradation shown in Table 1. This gradation represented the stockpile from which a representative specimen was obtained for analysis.

Pea Rock

Pea rock is a relatively clean aggregate, mostly rounded in shape, and the maximum size is 6.25 mm (¼ in.). This smooth-surface aggregate was obtained from nearby gravel pits.

Blotter Gravel

Blotter gravel is the least expensive type of aggregate because it is abundant and considered to be of very low quality. It contains many foreign materials and a large amount of fines such as clays. The maximum size of this type of aggregate is 12.5 mm (½ in.).

TABLE 1 Gradation of Aggregate Chips

	PERCENT PASSING (%)					
Sieve Size	1/2"	3/8"	#4	#10	#40	#200
QUARTZITE	100.0	100.0	42.5	3.8	1.9	0.5
Type 3B Specs.*	(100)	(100)	(40-75)	(0-60)	(0-35)	(0-18)
PEA ROCK	100.0	100.0	41.8	2.3	1.2	0.9
Type IB Specs.**	(100)	(100)	(45-90)	(0-20)		(0-4)
BLOTTER GRAVEL	96.2	90.0	79.5	60.0	9.7	2.9
Type IA Specs.***	(100)	(100)	(80-100)	(55-90)	(5-45)	(0-7)

* Suggested gradation for crushed material used in seal coats by South Dakota DOT.
** Suggested gradation for uncrushed clean chips in seal coats by South Dakota DOT.
*** Suggested gradation for unclean chips in seal coats by South Dakota DOT.

Redicote-82-S

Redicote, a heat-stable and cationic surfactant, was added to the asphalt binder. It is mildly basic chemically and exceeded the stability test [4 weeks at 177°C (350°F)].

TEST PROCEDURES

Although a full description of the SDT procedure, apparatus, and equipment is published elsewhere (*1*), the following statement outlines the test procedure:

1. Asphalt roofing shingles are cut 150 × 150 mm (6 × 6 in.).
2. The designed amount of cutback and chips is applied to the shingle, which is confined inside a steel frame.
3. The specimen (shingle and cutback and chips) is compacted at 310 KPa (45 psi) four times.
4. The specimen is cured at room temp for 24 hr.
5. The specimen is soaked in water at 22°C (72°F) for 48 hr.
6. Chips separated from the specimen during soaking and rubbing are collected, dried, and weighed.
7. Steps 5 and 6 are repeated five times, and data are recorded as shown in Table 2.

The total percentage loss was then calculated and termed the degree of vulnerability (DV), which is expressed mathematically as

$$DV = \sum \left(\frac{X_i}{w}\right) \times 100 \text{ percent} \quad (1)$$

where X_i is the individual 2-day weight of separated aggregate (in grams) and w is the initial weight of both intact aggregate and asphalt binder before the first immersion (in grams).

The percentage of chip loss was based on the combined weight of base bitumen and the totally intact aggregate before water-bath immersion. Seal coats with a chip loss of more than 20 percent were graded as highly vulnerable; those with chip loss between 10 and 20 percent, as having medium vulnerability; and those with chip loss of less than 10 percent, as having low vulnerability. Table 2 shows the results of a typical treatment with three trials.

DATA COLLECTION AND ANALYSIS

Table 3 shows the test results of the SDT performed on 54 specimens. Figure 1 depicts typical chip loss with time for some specimens. According to the established criteria of chip loss as described by DV (*3*), Table 4 summarizes the classification of each treatment, showing whether it has a low, medium, or high degree of vulnerability. (It should be understood that a high degree of vulnerability means high chip loss or low chip retention.)

TABLE 2 Sample Results of SDT

DATA SHEET FOR TREATMENT #2A												
DATE	7/8/1991											
BINDER					AGGREGATE							
TYPE	MC-3000				TYPE				QUARTZITE			
TEMPERATURE	235°F				TEMPERATURE				78°F			
AMOUNT USED	26.4 g				AMOUNT USED				252.0 g			
CURING TIME	24-HOUR				MOISTURE CONTENT				0.0%			
TRIAL #	SHINGLE WEIGHT, g				SPECIMEN WEIGHT, g				INITIAL WEIGHT, g			
1	112.7				269.5				156.8			
2	108.2				259.6				151.4			
3	106.9				269.1				162.2			
INDIVIDUAL 2-DAY PERIOD WEIGHT LOSS, X_i												
TRIAL #	2-DAY		4-DAY		6-DAY		8-DAY		10-DAY		TOTAL = ΣX_i	
	g	%	g	%	g	%	g	%	g	%	g	%
1	8.7	5.5	3.3	2.1	3.1	2.0	1.5	1.0	0.5	0.3	17.1	10.9
2	8.2	5.4	4.0	2.6	3.5	2.3	2.9	1.9	1.1	0.7	19.7	13.0
3	8.4	5.2	3.1	1.9	2.2	1.4	1.0	0.6	0.8	0.5	15.5	9.6

TABLE 3 SDT Results

Obs.	Agg.	Binder	Treatment	Sub-Sample	Cumulative Chip Loss in % With Time in Days				
					2 day	4 days	6 days	8 days	10 days
1	QZ	MC	AS-IS	1	55.5	68.2	75.5	77.7	79.3
2	QZ	MC	AS-IS	2	54.2	67.9	75.2	78.5	80.3
3	QZ	MC	AS-IS	3	56.4	71.9	76.3	79.4	80.4
4	PR	MC	AS-IS	1	2.9	5.8	8.9	9.2	9.6
5	PR	MC	AS-IS	2	6.6	8.6	11.5	12.2	12.4
6	PR	MC	AS-IS	3	4.7	6.8	10.7	12.1	12.8
7	BG	MC	AS-IS	1	3.6	5.8	6.4	6.6	6.7
8	BG	MC	AS-IS	2	2.1	5.2	6.0	6.3	6.5
9	BG	MC	AS-IS	3	2.9	4.7	5.3	6.6	7.1
10	QZ	RC	AS-IS	1	64.1	72.5	77.0	79.3	79.7
11	QZ	RC	AS-IS	2	58.2	69.9	73.5	77.4	79.4
12	QZ	RC	AS-IS	3	42.7	59.6	66.4	73.8	77.7
13	PR	RC	AS-IS	1	5.4	8.1	8.8	9.5	10.2
14	PR	RC	AS-IS	2	3.6	6.8	7.2	7.8	8.6
15	PR	RC	AS-IS	3	5.5	7.3	7.5	7.6	7.7
16	BG	RC	AS-IS	1	4.3	6.3	7.1	7.7	8.1
17	BG	RC	AS-IS	2	4.2	6.2	7.1	7.6	8.1
18	BG	RC	AS-IS	3	4.5	6.5	7.4	7.9	8.2
19	QZ	MC	DRY	1	5.5	7.7	9.6	10.6	10.9
20	QZ	MC	DRY	2	5.4	8.1	10.4	12.3	13.0
21	QZ	MC	DRY	3	5.2	7.1	8.4	9.1	9.6
22	PR	MC	DRY	1	1.0	2.6	4.2	4.5	5.0
23	PR	MC	DRY	2	2.0	2.5	3.9	4.2	4.6
24	PR	MC	DRY	3	2.4	3.8	5.0	5.9	6.0
25	BG	MC	DRY	1	0.6	1.6	2.4	3.1	4.1
26	BG	MC	DRY	2	0.9	2.1	3.1	4.1	5.0
27	BG	MC	DRY	3	0.5	1.9	2.8	3.5	4.2
28	QZ	RC	DRY	1	3.4	4.4	5.3	5.7	5.9
29	QZ	RC	DRY	2	5.0	5.9	7.5	7.7	7.9
30	QZ	RC	DRY	3	6.4	7.3	9.1	9.4	9.7
31	PR	RC	DRY	1	2.2	4.6	6.4	7.2	7.6
32	PR	RC	DRY	2	3.4	5.1	7.5	8.6	9.1
33	PR	RC	DRY	3	4.6	5.3	9.0	9.3	10.4
34	BG	RC	DRY	1	1.3	2.5	3.2	3.9	4.4
35	BG	RC	DRY	2	1.3	2.5	3.1	4.1	5.1
36	BG	RC	DRY	3	1.0	2.3	3.0	3.9	4.6
37	QZ	MC	REDICOTE	1	0.7	0.7	0.7	0.8	0.9
38	QZ	MC	REDICOTE	2	0.2	0.2	0.5	0.5	0.5
39	QZ	MC	REDICOTE	3	0.2	0.4	0.6	0.7	0.7
40	PR	MC	REDICOTE	1	0.6	0.9	1.8	1.8	1.8
41	PR	MC	REDICOTE	2	1.4	1.6	2.1	2.1	2.4
42	PR	MC	REDICOTE	3	2.1	2.3	2.4	2.4	2.4
43	BG	MC	REDICOTE	1	0.5	0.8	1.1	1.2	1.3
44	BG	MC	REDICOTE	2	0.7	1.0	1.4	1.4	1.4
45	BG	MC	REDICOTE	3	0.9	1.2	1.5	1.7	1.7
46	QZ	RC	REDICOTE	1	0.5	0.8	1.3	1.3	1.3
47	QZ	RC	REDICOTE	2	0.8	1.1	1.4	1.4	1.5
48	QZ	RC	REDICOTE	3	0.6	0.8	0.9	1.1	1.1
49	PR	RC	REDICOTE	1	0.8	1.5	2.2	2.4	2.4
50	PR	RC	REDICOTE	2	1.6	3.3	4.3	5.2	5.2
51	PR	RC	REDICOTE	3	0.5	1.3	1.7	2.0	2.0
52	BG	RC	REDICOTE	1	0.4	0.7	1.0	1.2	1.2
53	BG	RC	REDICOTE	2	0.5	0.8	1.1	1.1	1.2
54	BG	RC	REDICOTE	3	0.4	0.8	1.1	1.1	1.2

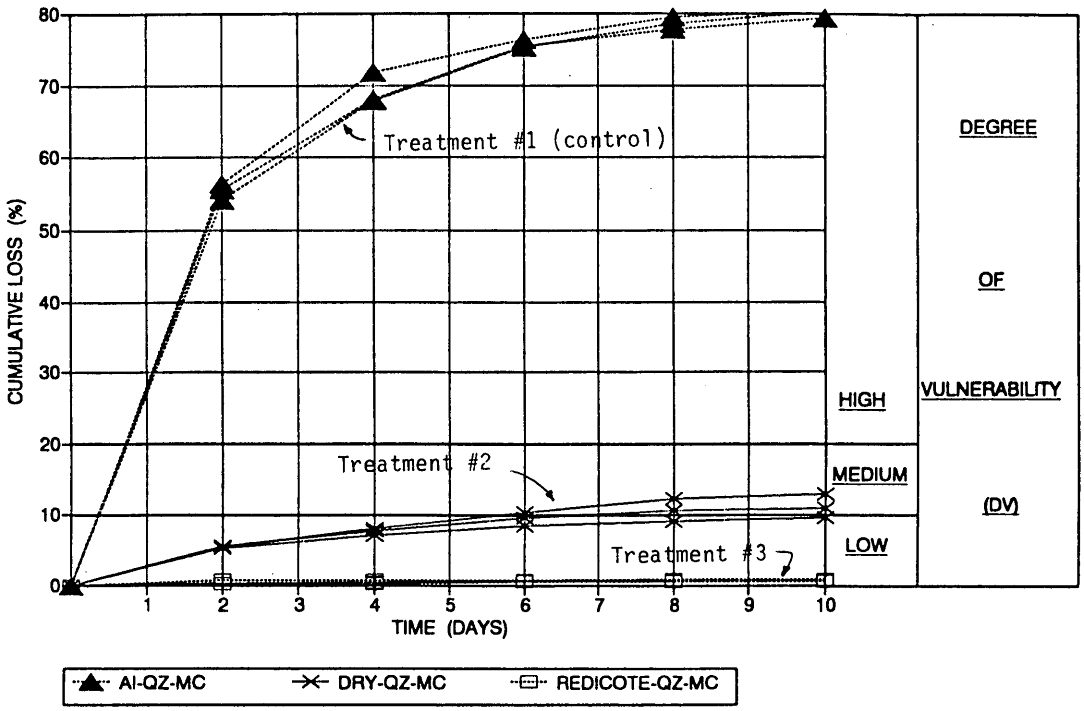

FIGURE 1 Plot of cumulative loss (%) versus time (days): QZ-MC observations 1, 2, 3, 19, 20, 21, 37, 38, 39.

TABLE 4 Treatment Classification by DV

Main Treatment	Subtreatment	Degree of Vulnerability to Moisture Susceptibility (DV)
Aggregate Has The Field Moisture Content	AS-IS-BG-MC	LOW
	AS-IS-BG-RC	LOW
	AS-IS-PR-MC	MEDIUM
	AS-IS-PR-RC	LOW
	AS-IS-QZ-MC	HIGH
	AS-IS-QZ-RC	HIGH
Aggregate Was Oven Dried	DRY-BG-MC	LOW
	DRY-BG-RC	LOW
	DRY-PR-MC	LOW
	DRY-PR-RC	LOW
	DRY-QZ-MC	MEDIUM
	DRY-QZ-RC	LOW
Aggregate Has The Field Moisture Content. Liquid Asphalts Treated with Anti-Stripping	REDICOTE-BG-MC	LOW
	REDICOTE-BG-RC	LOW
	REDICOTE-PR-MC	LOW
	REDICOTE-PR-RC	LOW
	REDICOTE-QZ-MC	LOW
	REDICOTE-QZ-RC	LOW

TABLE 5 Summary of Chip Retention Results (LSD *t*-Test)

	Mean % Cumulative Loss
I. TREATMENT	
As Is	32.4
Drying the Aggregate	7.1
Antistripping Additive	1.7
II. TYPE OF BINDER	
MC 3000	13.73
RC-3000R	13.69
III. TYPE OF AGGREGATE	
Quartzite	29.99
Pea Rock	6.68
Blotter Gravel	4.45

To examine whether a significant difference among treatments is present, a statistical technique commonly used in data analysis, analysis of variance (ANOVA), was used. Past experience with the SDT test has shown that most specimens exhibit no significant chip loss after five cycles (10 days), therefore, the cumulative loss at 10 days for all specimens was analyzed. When the *t*-test of logarithmic series distribution (LSD) was applied, it was evident that the three treatments were significantly different from each other, with Treatment 1 reporting the highest cumulative loss (with a mean value of 32.4 percent), followed by Treatments 2 and 3 (with cumulative losses of 7.1 and 1.7 percent, respectively).

The type of binder had no influence on cumulative chip losses. ANOVA revealed that all specimens made with an MC binder and those made with an RC binder had mean cumulative chip losses of 13.73 and 13.69 percent, respectively; such a difference is insignificant.

Aggregate type, however, proved to have a significant influence on cumulative chip loss. Test results revealed that quartzite, pea rock, and blotter gravel experienced mean cumulative chip losses of 29.99, 6.68, and 4.45 percent, respectively. The *t*-test showed a significant difference among the three types of aggregate. Table 5 summarizes test results, and Table 6 presents ANOVA statistics.

CONCLUSIONS

The following were the major findings from the study:

- Quartzite chips, which are considered hydrophilic aggregate, were the most susceptible to moisture in Treatment 1, where quartzite chips were taken as is from the stockpile with about 2.1 percent field moisture.
- Quartzite aggregate, when used with antistripping agent–treated asphalt binder, had the most chip retention.
- The amount of chip retention was improved significantly from Treatment 1 to Treatment 2, in which the aggregates were oven-dried.
- The moisture susceptibility of all aggregates was reduced dramatically when antistripping was added to the asphalt binders.
- Without antistripping additives, polymer-modified RC-3000R cutback did not have any significant effect on the amount of chip retention compared with plain MC-3000 for all three aggregates. Figure 2 shows that binder type has no significant effect on chip loss or retention. Figure 3, however, shows that when antistripping additives were used with both binders, chip loss was significantly reduced.

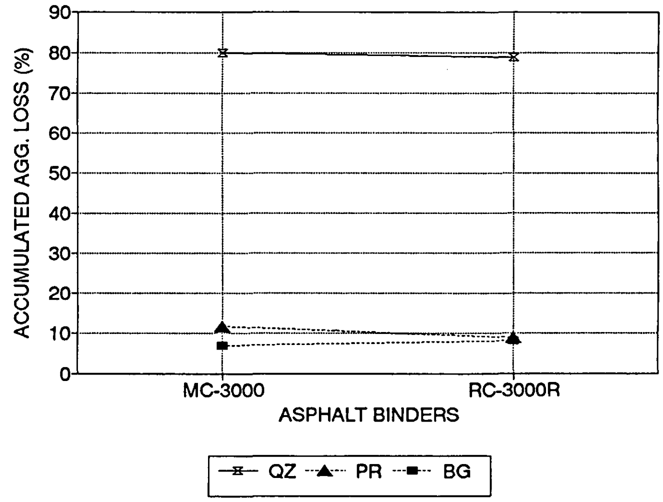

FIGURE 2 Effect of binder type on aggregate loss, Treatment 1.

TABLE 6 ANOVA Results

SOURCE	DF	F Value	Pr > F
Treatment	2	4590	0.0001
Aggregate	2	3418	0.0001
Treatment * Aggregate	4	3050	0.0001
Asphalt	1	0.02	0.8849←
Treatment * Asphalt	2	1.99	0.1509←
Aggregate * Asphalt	2	4.87	0.0134←
Treatment * Aggregate * Asphalt	4	10.07	0.0001

← Insignificant

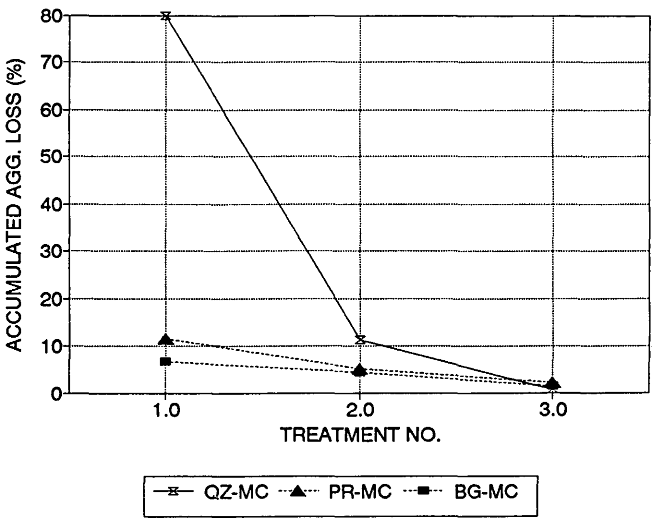

FIGURE 3 Effect of treatment type on aggregate loss.

• Among the three aggregates, blotter gravel exhibited the highest chip retention despite its low cost and uncleanliness. It should be pointed out that past experience with the field performance of seal coat sections made with blotter gravel showed that it has the lowest skid resistance and often bleeds under weather and traffic action. Therefore, although the selection of blotter gravel as seal coat chips might be justified from the economical and laboratory retention point of view, its field performance must be considered before it is used in any job.

• Treatments 2 and 3 reduced chip loss significantly; however, Treatment 3 scored ahead of Treatment 2. In a practical sense, the treatment that yields a lower life-cycle cost should be considered. Life-cycle cost analysis should be performed before deciding on the appropriate treatment.

The amount of chip retention in this study dealt with moisture susceptibility only as it relates to material characteristics. Other factors influencing chip retention, such as traffic volume and loading and environmental conditions such as temperatures, must be examined in a comprehensive study for the chip retention of seal coats to be fully understood.

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