Enhancing the Bond of Emulsion-Based Seal Coats with Antistripping Agents

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Seal coats are highly regarded as a pavement maintenance tool because, among other functions, they enhance the friction value of existing road surfaces. Asphalt emulsions are commonly used in seal coat construction for their adaptability to environmental and handling conditions, and the better the bond between emulsion and aggregate, the better the friction value of the seal coat. This study seeks to find out whether antistripping agents enhance the bond between aggregate and emulsion, consequently improving the friction value of the seal coat; to determine the best way of including the antistripping agent in the seal coat; and to establish a mathematical model to predict friction value of a particular seal coat at any time after construction. To those ends, several seal-coat test sections were prepared, subjected to traffic for several months, and then evaluated. The outcome of the research reveals that (a) including the antistripping agent in a seal coat improves the bond between aggregate and asphalt and reduces the tendency of aggregate particles to rotate under horizontal drag forces, both of which led to higher friction values; (b) mixing the antistripping agent with the emulsion instead of applying it to the aggregate surface improved the total bond and led to higher frictional values; and (c) quadratic models were better than exponential models at predicting friction values of seal coats at any time after construction.

Maintenance officials consider seal coats to be a reliable method of preserving the integrity of road surfaces. One of the cardinal functions of seal coats is to restore the friction value of the road surface to its original construction level.

The success of any seal coat depends on the type of aggregate used, the type of binder, the compatibility of aggregate and binder (how well the two materials bond), and quality control during construction. In this research, crushed quartzite, which exists in abundance in the southeastern part of South Dakota and the southwestern part of Minnesota, was used. The asphalt emulsion CRS-2 was chosen for this study because of its suitability to the type of aggregate used and to the ambient temperature at the time of construction. Two different types of antistripping agents were also used to prevent debonding between the aggregate and the emulsion.

A review of the literature on asphalt pavement debonding revealed that most of the research was geared toward hot mixes; virtually no work addressed cold mixes or seal coats, except for a study by Selim (*1*) on a new testing method for evaluating seal coat debonding when asphalt emulsion is used as a binder.

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To enhance the bond between the aggregate and the binder in a seal coat, antistripping additives are sometimes used. The chemical industry has introduced several antistripping agents designed to be added to the asphalt mix at a dose of 0.5 to 1.5 percent of the weight of residual asphalt. Adding antistripping agents to asphalt hot mixes has been well documented, but no well-recognized method exists for including the antistripping agent in cold applications, such as seal coats made with asphalt emulsions. In this study two types of antistripping agents were employed. The first type, REDICOTE 82-S, is 100 percent active, heat stable, and when added to the mix produces a water-resistant film of asphalt. The second type, HIB7178, is also heat stable, fluid at ambient summer temperature, and recommended for use in all seasons. It makes the aggregate surface wettable and allows the asphalt to deposit an intact coat on the aggregate surface.

Seal coats are more vulnerable to debonding than hot mixes because

- All uncoated aggregate surface is exposed to moisture.
- The relatively thin layer of seal coat mass (aggregate and binder) is subjected to the abuses of weather and traffic.
- Once debonding at any aggregate particle begins, it can accelerate when the particle rotates under traffic load, braking action, or both.

Clearly, seal coats have as much need for antistripping additives as some hot mixes do.

The term *total bond* will be used throughout this paper to mean the original bond between the aggregate and binder (without the use of any antistripping agents) plus the additional bond produced when the antistripping agent was added. The term *friction value* will also be cited frequently instead of other terms such as *skid resistance*, *friction resistance*, and so on.

RESEARCH OBJECTIVES

This research was carried out to shed some light on the total bond of seal coats made with asphalt emulsion as the binder. The objectives of the research were threefold:

- To determine whether the antistripping agents produced added bonding between the aggregate and the emulsion's residual asphalt.

- To find out whether antistripping agents, if they are helpful, should be mixed with the emulsion first or should be used to coat the aggregate surface before the construction of the seal coat.
- To examine the trend of friction value loss over time with a reliable mathematical model.

TOTAL BOND AND FRICTION VALUE IN A SEAL COAT

Because the original bond between aggregate and residual asphalt and the bond added when an antistripping agent is present are difficult to measure, this research uses total friction value to indicate effective bonding. It should be pointed out that friction value is indirectly affected by the presence of antistripping agents in the residual asphalt. Although tires and the asphalt matrix do not make direct contact (unless bleeding occurs), the friction value will be affected by how much rotation the aggregate particles yield under drag forces. Aggregate rotation is vulnerable to residual asphalt stiffness and the degree of bond between aggregate and residual asphalt. Hence, the presence of antistripping agents in the residual asphalt matrix should enhance the bond and reduce aggregate particle rotation, which would consequently improve the friction value as measured by a device such as the British Pendulum Tester (BPT).

Seal coats do not exhibit their friction value characteristics in the same way as some heterogeneous solid material, such as asphalt hot mixes used for wearing courses. In a hot-mix wearing course, friction value depends highly on the type of aggregate and its surface texture. Aggregate particles are totally embedded in the asphalt matrix. When steel rollers are used during compaction, aggregate particles in the soft hot mix have a good chance to rotate and lay flat. Those aggregate particles at or near the surface are well situated and totally surrounded by other aggregate particles; the binder will ultimately provide the friction value of the wearing course surface. Pneumatic rollers are used only to seal the surface and make it tight.

In seal coats, pneumatic tire rollers are the recommended compaction device for embedding aggregate particles into the very thin layer of asphalt binder. Aggregate particles cannot rotate freely and lay flat because the aggregate on the surface of the seal coat interlocks, as shown in Figure 1. The extra, loose aggregate is usually shoved away to the side by traffic or removed with power brooms a few days after the seal coat is constructed. This extra aggregate is in excess of what the board test recommends (*2*); its purpose is to ensure sufficient cover over the embedded aggregate and to prevent possible tracking of asphalt binder by the pneumatic roller tires.

Total friction value is the total resistance force encountered by an object sliding over a pavement surface. This object can be a locked wheel tire or the rubber unit of the BPT. Two factors go into friction:

1. The surface texture and roughness of the exposed portion of embedded aggregate, as well as the conditions of the wheel tire (drag force); and

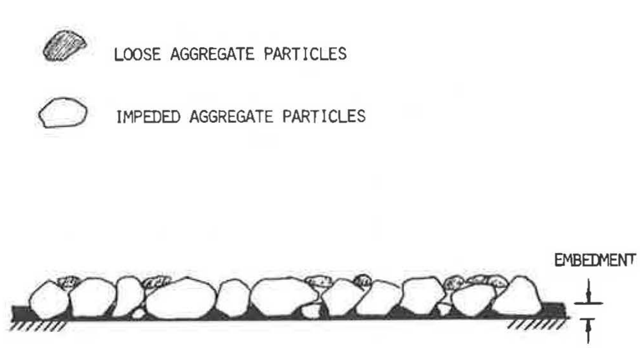

FIGURE 1 Arrangement of aggregate particles after compaction of a newly constructed seal coat.

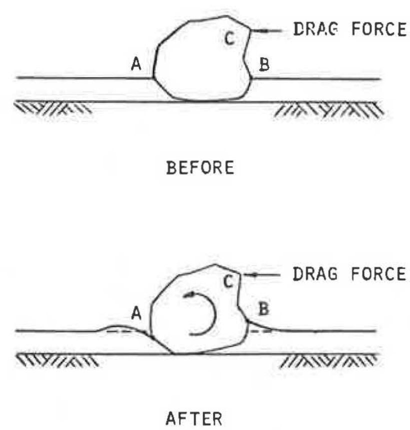

FIGURE 2 Rotation of aggregate particles due to drag force during service.

2. The ability of asphalt binder to prevent the aggregate particle from rotating under the horizontal drag forces produced by braking tires (see Figure 2). Resistance to rotation depends on the binder's consistency and the degree of bond between the binder and the aggregate. Rotation depends greatly on the residual asphalt stiffness and its ability to resist deformation—the less the rotation, the higher the friction value, and the more the rotation, the less the friction value. Tension zones, as depicted in Figure 2, can foster the separation of aggregate and asphalt binder once debonding begins.

For a seal coat to do the job it should, the second element—ensuring no particle rotation—must exist before the first element—appropriate surface texture and aggregate surface roughness—can contribute fully to total friction value.

When only one type of aggregate is used (for instance, crushed quartzite, as in this study), any improvement in total friction value should be attributed to the additional bond between quartzite and residual asphalt that was prompted by the antistripping agent. This additional bond hinders aggregate particle rotation, which leads to higher friction value.

PREPARATION OF MATERIALS

Although CRS-2 emulsion is known to contain an antistripping chemical (diamene salt), this research investigated the

TABLE 1 TREATMENT IDENTIFICATION

TREATMENT	DESIGNATION	DESCRIPTION
A	Q + E	Quartzite and Emulsion
B	Q + (E * 82-S)	Quartzite and Treated Emulsion with REDICOTE-82S
C	Q + (E * HIB-7187)	Quartzite and Treated Emulsion with HIB-7178
D	(Q * 82-S) + E	Treated Quartzite with REDICOTE 82S and Emulsion
E	(Q * HIB-7178) + E	Treated Quartzite with HIB-7178 and Emulsion

benefits of using a commercial antistripping agent to further improve the bonding between quartzite aggregate and CRS-2 emulsion. Quartzite is a hydrophilic rock known to have stripping problems. Two commercial antistripping agents were chosen, REDICOTE 82-S and HIB-7178. Either antistripping agent must be added to the seal coat by mixing it with the emulsion or spraying it over the aggregate in a thin coat. Because available literature did not stipulate the appropriate way of including antistripping agents in seal coats, both methods were used. A professional laboratory mixed a predetermined amount of the antistripping agent with the emulsion during the asphalt phase of the project; for the coating method, the antistripping agent was diluted and sprayed so that a predetermined amount of the agent was deposited on the quartzite surface. The predetermined amount was about 1 percent of the amount of base asphalt in the emulsion (*1*).

Enough quantities of the following materials were prepared to construct the field seal-coat strips:

- Untreated quartzite
- Untreated CRS-2 emulsion
- Treated quartzite with REDICOTE 82-S
- Treated quartzite with HIB-7178
- Treated emulsion with REDICOTE 82-S
- Treated emulsion with HIB-7178

FIGURE 3 Spreading emulsion on test strip.

CONSTRUCTION OF TEST SECTIONS

To meet the objectives of this research, a total of five treatments were chosen (see Table 1); for each treatment, two identical seal-coat strips were constructed across a traffic lane. Each strip measured 3 ft in width and 11 ft in length (the width of a traffic lane).

Test sections were constructed in the following steps.

1. The road surface was cleaned and a strip 3-ft wide was chalked on the pavement.
2. The emulsion (plain or treated) was kept at 110°F for 2 hr before it was spread by hand and leveled by a special tool, as shown in Figure 3. The rate of application was controlled at 0.3 gal/yd^2 (the residual asphalt rate was about 0.22 gal/yd^2).
3. When the emulsion started turning black from its original brownish color, aggregate was added manually at a rate of 30 lb/yd^2 and spread evenly over the emulsion.
4. A pneumatic tire roller with 50 psi tire pressure provided the required compaction through four passes.

All 10 test strips were constructed about 25 to 30 ft apart on the right lane of a major arterial (10,000 vehicles per day). Having all test strips within one very long block ensured that each strip was exposed to the same traffic.

DATA COLLECTION

Test strips were cured for about 6 hr before traffic was allowed on them. Test strips also received additional compaction by traffic for one more week, which allowed aggregate particles to get situated in the seal coat under traffic and weather action. The portable British skid tester was used to measure friction values (friction number) for the test strips (treatments). Tests were taken along the wheel path near the middle of the strip, about 3 ft away from the right pavement edge.

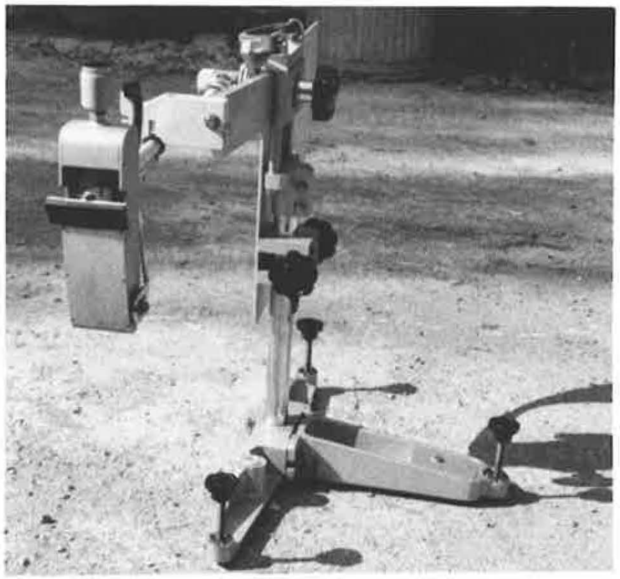

FIGURE 4 The British Pendulum Tester used for measuring friction values.

To guarantee that the exact same spot was used to measure the friction value at different times, paint markers were put on the pavement where the BPT's legs were placed when readings were taken. Figure 4 shows the BPT. Three friction values were obtained for each test spot, according to the recommended methodology established in ASTM E-303, and values modified to compensate for temperature variation were recorded. Friction values could not be measured every 2 or 3 months, as they would have to be to observe a significant decline in friction values due to traffic action, because weather conditions in South Dakota are too severe for data collection between November and March.

Final construction of all test strips was completed in the middle of August and the first set of readings was taken a week later. Further data were collected in August and October 1986 and in April, July, and October 1987. Table 2 summarizes all the data collected.

DATA ANALYSIS

To examine the rate at which friction values declined with time, several models were tried, but it soon became evident that the quadratic model and the exponential model were superior to the others for this research. Only the results from these two models are presented here in detail. The Statistical Analysis System package was employed for data analysis and model development.

Quadratic Model

Table 3 and Figure 5 are self-explanatory; they represent the results of the quadratic equation.

TABLE 2 FRICTION VALUES

Treatment \ Date	Aug. 86	Oct. 86	Apr. 87	July 87	Oct. 87
A-1	65,65,67	65,64,64	54,56,54	53,52,52	51,51,51
A-2	58,58,59	58,58,57	53,52,52	54,53,53	50,52,51
B-1	70,72,74	71,68,68	59,59,57	54,55,54	55,54,54
B-2	71,72,72	71,69,69	55,55,55	55,54,54	55,54,54
C-1	70,70,71	67,66,66	57,56,56	56,56,56	56,56,56
C-2	74,74,72	69,65,68	59,57,59	58,60,58	58,56,57
D-1	70,70,70	66,66,66	60,59,59	58,57,57	58,56,55
D-2	67,68,68	62,61,60	57,57,58	57,57,56	56,56,56
E-1	66,66,67	67,67,64	54,53,52	54,54,52	52,52,52
E-2	69,69,68	65,66,65	56,54,54	56,55,54	52,52,53

TABLE 3 QUADRATIC EQUATION MODELS

TREATMENT	R^2	MODEL*
A	0.75	$S = 63.9 - 1.39\ T + 0.035\ T^2$
B	0.96	$S = 75.8 - 2.97\ T + 0.101\ T^2$
C	0.95	$S = 74.4 - 2.83\ T + 0.110\ T^2$
D	0.89	$S = 69.9 - 1.97\ T + 0.071\ T^2$
E	0.94	$S = 70.8 - 2.45\ T + 0.082\ T^2$

*S = $a + a_1T + a_2T^2$, where

S = Predicted Friction Value

a = Intercept

a_1, a_2 = Coefficients

T = time in months from construction date

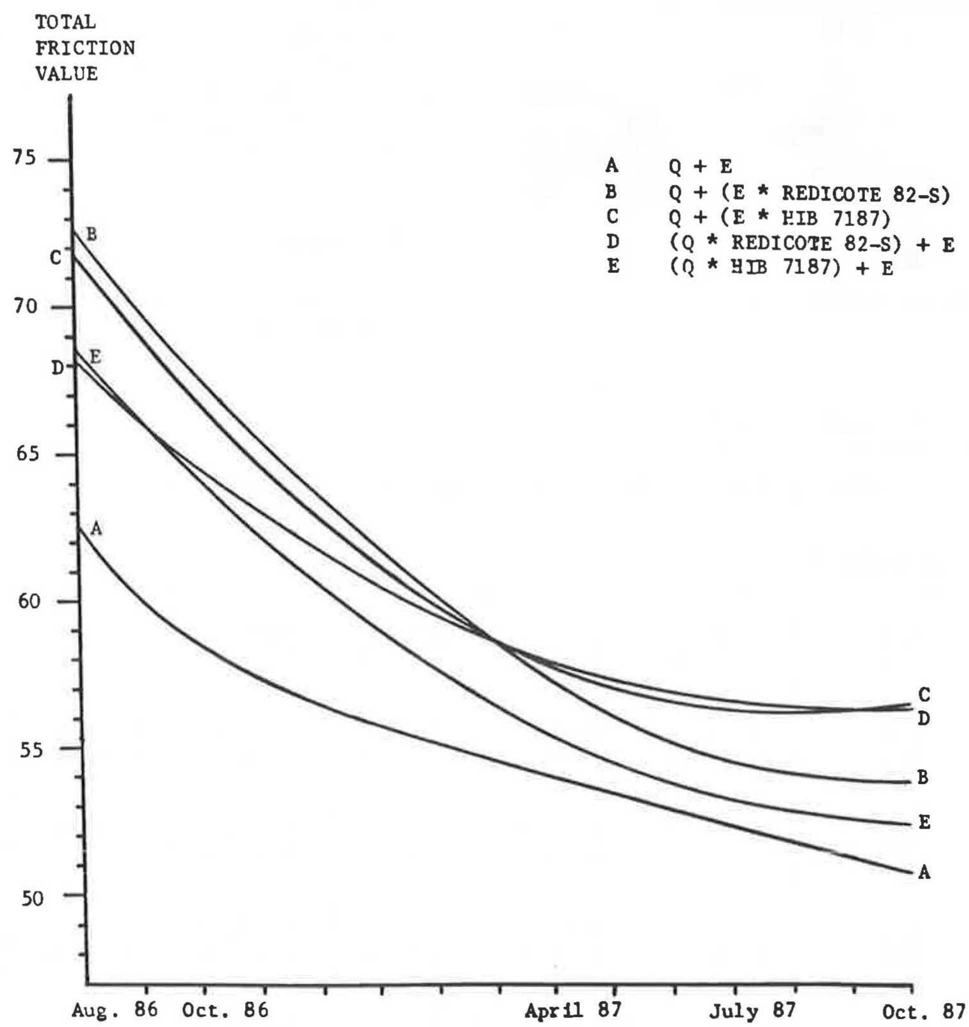

FIGURE 5 Friction values as predicted by the quadratic equation.

TABLE 4 EXPONENTIAL EQUATION MODELS

TREATMENT	R^2	MODEL*
A	0.84	$S = 50 + 14.98e^{-0.160\ T}$
B	0.86	$S = 54 + 25\ e^{-0.249\ T}$
C	0.81	$S = 56 + 17.55\ e^{-0.188\ T}$
D	0.81	$S = 56 + 13.5\ e^{-0.195\ T}$
E	0.85	$S = 52 + 20.05\ e^{-0.200\ T}$

*S = S_{min} + be $^{-cT}$

S = Predicted Friction Value

S_{min} = Minimum friction value as predicted by the quadratic model

b,c = coefficients

T = Time in months from construction date

Exponential Model

The analysis outlined below led to the exponential model.

The general form of the model is

$$S = S_{min} + be^{cT} \quad (1)$$

where

S = friction value at any time T;
S_{min} = stabilized value of friction;
b, c = coefficients; and
T = time in months from construction date.

To determine the value of S_{min}, it was necessary to use the quadratic model, which reads

$$S = a + a_1T + a_2T^2 \quad (2)$$

where

S = friction value at any time T;
a = intercept;
a_1, a_2 = coefficients; and
T = time in months from construction date.

By taking the first derivative and equating it to zero, the time it takes the treatment to stabilize can be determined (T'). The term T' can be substituted in the model to solve for the lowest friction value (S_{min}), as follows:

$$dS/dT = a_1 + 2a_2T = 0 \quad (3)$$

$$T' = -a_1/2a_2 \quad (4)$$

$$S_{min} = a + a_1(-a_1/2a_2) + a_2(-a_1/2a_2)^2 \quad (5)$$

$$S_{min} = a - a_1^2/4a_2$$

Now that the stabilized value of friction is known (S_{min}) for each treatment at time T', the following analysis can complement the development of the exponential model. From Equation 1,

$$S - S_{min} = be^{cT}$$

$$\ln(S - S_{min}) = \ln b + cT \quad (6)$$

This equation actually represents a linear model with intercept equal to ($\ln b$) and slope equal to c. Once the linear model is developed, the values of b and c can be determined, and finally the exponential model will read

$$S = S_{min} + be^{cT} \quad (7)$$

Table 4 and Figure 6 summarize the models for each treatment and the correlation coefficients.

CONCLUSIONS AND RECOMMENDATIONS

The use of antistripping additives should not be limited to hot mixes. This research demonstrates that antistripping additives can also improve the field performance of seal coats by improving the coat's total bond and friction value. Friction value is determined by both aggregate surface texture and aggregate particles' resistance to rotation when a horizontal drag force is applied. The main conclusions drawn from this research are as follows:

1. Antistripping additives, whether added to the aggregate or to the emulsion, can enhance the total friction value of a seal coat. The following observations arise from examination of the total friction values in Table 2.

- Treatments B, C, D, and E, where quartzite and antistripping agents were part of the seal coat, yielded higher total friction values than the control Treatment A, which contained quartzite but no antistripping agent. The average gain was about 8.6 percent in total friction value.
- When the emulsion was treated with the antistripping

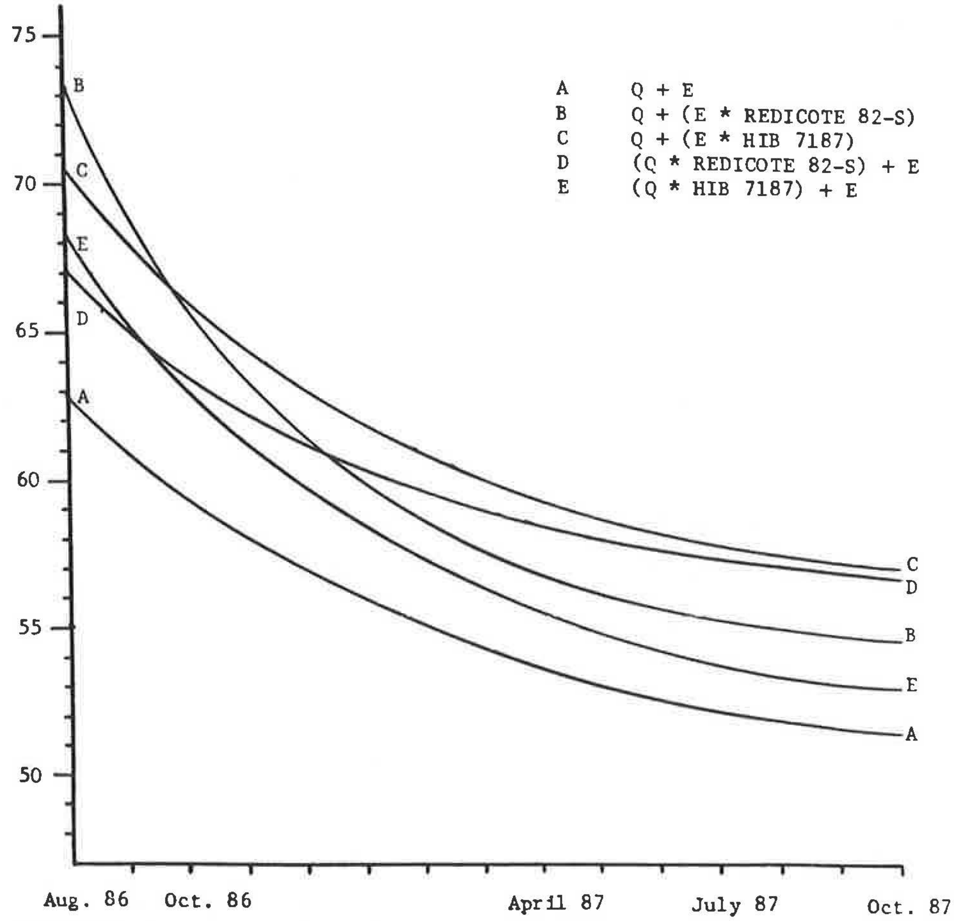

FIGURE 6 Friction values as predicted by the exponential equation.

agent (Treatments B and C), the average gain in total friction value over that of control Treatment A was about 10.3 percent.

- When quartzite was treated with the antistripping agent (Treatments D and E), the average gain in total friction value over that of control Treatment A was only 6.9 percent.

2. Antistripping agents should be added to the emulsion instead of applied to the aggregate surface for the following reasons.

- The treated emulsion (Treatments B and C) yielded higher friction values.
- In a massive production of seal coats where either emulsion or aggregate need to be treated with an antistripping agent, it is much easier to add the agent when the emulsion is manufactured (during the asphalt phase). Doing so ensures better disbursement of the agent with a minimum amount of work. Moreover, if the agent is added to the aggregate, special equipment is needed to dilute the agent and apply it to the aggregate surface, a relatively complex and expensive operation.

3. Quadratic models can successfully predict the friction value of seal coats. Correlation coefficients for quadratic models were generally higher than their counterparts for exponential models.

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