Criteria for Selecting Desirable Quantities of Coal Tar Emulsion Seal Coat Components

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The use of coal tar seal coats often creates difficulties in the field. In the research described by this paper, tests were developed or modified to measure workability (Brookfield viscosity), cure time (scuff resistance), skid resistance (scuff resistance), cracking (cyclic freeze-thaw conditioning), debonding (adhesion), and fuel resistance. Guidelines were established for determining the preliminary optimum quantities of additive, additional water, and sand for a given set of materials. These procedures are applicable to a wide variety of coal tar sources and types of additives. The procedure may also be used to refine optimum quantities after the preliminary analysis by reducing the range of variables. The reliability of these procedures will be tested on various field sections at the general aviation airport in Stead, Nevada.

Coal tar emulsion sealers have historically been used to protect asphalt concrete pavements from fuel, oil, water intrusion, and weathering. Because of the sealers' ability to resist fuel, they have been used extensively on airport taxiways and fueling areas. They are also used on automobile parking lots to resist motor oil drippage, which can soften asphalt concrete pavement. The sealers provide an impermeable surface to prevent water intrusion which can lead to raveling and stripping of the pavement. They also prevent weathering by protecting the pavement from sunlight and oxidation.

Sand is used with coal tar emulsions to enhance skid resistance. The level of skid resistance is influenced by the gradation and shape of the sand; therefore, a large, coarse sand is typically used. Sand loadings (i.e., quantities) have been increased in recent years in an attempt to provide an even rougher surface. However, the higher quantities of sand are difficult to keep suspended in the coal tar emulsions. Also, the sand-sealer interface has provided a path for petroleum products to penetrate the sealer.

Previous experimentation has shown that the use of latex polymeric additives in the coal tar emulsion can increase its ability to hold the sand in suspension (*1*). The latex also increases the sealer's flexibility. This flexibility allows the sealer to move with the underlying pavement as it contracts and expands due to thermal changes and traffic loads.

Although coal tar sealers have been used for many years, they have created some difficulties. Interviews with manufacturers, suppliers, contractors, and owners have identified several problems, including

- Workability (the ability to place the material),
- Cure time (when to open a new surface to traffic),
- Skid resistance,
- Cracking of the surface,
- Debonding of the sealer with the underlying pavement, and
- Fuel resistance.

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METHODOLOGY

A review of the literature revealed a limited amount of research on the testing of coal tar emulsions used as seal coats on asphalt concrete pavements. The objective of this research was to evaluate and develop test procedures to define desirable properties of coal tar emulsions. This was accomplished by

- Identifying industries that use test methods relating to seal coat performance,
- Developing or modifying the identified test methods, and
- Evaluating the potential of the selected tests to define desirable properties of coal tar seal coats.

In addition to the coal tar industry, the paint, asphalt cement, asphalt concrete, and slurry seal industries were identified as having applicable or adaptable test methods. Tests chosen for evaluation or modification from these industries were

- Brookfield viscosity,
- Thomas-Stormer viscosity,
- Scuff resistance (ASTM D3910–84 and International Slurry Seal Association (ISSA) TB139 (*2*)),
- Cyclic freeze-thaw (*3*),
- Flexibility (ASTM D2939–78),
- Wet flow (shrinkage) (ASTM D2939–78),
- Measuring adhesion by tape test, Method A (ASTM D3359–83),
- Kerosene resistance (ASTM D3320–79), and
- Fuel drip followed by the wet track abrasion procedure (*4*).

INITIAL FIELD TEST SECTIONS

Before starting the laboratory testing program, major coal tar suppliers were invited to place field test sections on the University of Nevada-Reno (UNR) campus. The test sections were placed on a parking lot that experienced low traffic

TABLE 1 FIELD TEST SECTION FORMULATIONS

Section	Prime Coat	No. of Base Coats	Top Coat w/out Sand	Quant. Coal Tar, gal.	Quant. Additive, gal.	Quant. Water, gal.	Quant. Sand, lb/g CT*
1	No	2	Yes	100	8.2	80	13
2	No	1	Yes	100	8.2	80	13
3	Poly oil & water	2	Yes	100	8.2	80	13
4	Yes	2	No	80	--	20	4
5	No	2	No	asphalt emulsion (20% cut)			
6	No	2	No	15% coal tar, 85% asphalt emulsion			
7	No	2&3	No	Fass - Dri			5.4
8	No	2	Yes	100	25	25	10
			Top Coat	100	10	25	---
9	Water	2	Yes	100	10	20	5
			Top Coat	100	10	25	---
10	J220	2	No	100	10	20	5
11	No	2	No	100	10	20	5
12	No	2	Yes	100	4	40	2
13	No	2	Yes	100	6	50	6
14	No	2	Yes	100	5	40	4
15	No	2	Yes	100	7	50	8
16	Yes	2	No	100	15	45	7
17	Yes	2	No	100	10	90	6.2

* - Coal Tar Emulsion

volume so that weathering effects could be monitored without the influence of traffic loads. The parking lot, which was approximately 8 mo old, provided a large, uniform surface for the application of the test sections.

Field samples were collected for laboratory cyclic freeze-thaw analysis by taping asphalt roofing shingles to the pavement prior to test section application. The samples were removed and returned to the laboratory after 24 hr of field curing.

Seventeen field test sections of varying sizes were placed by four suppliers between September 9th and 30th, 1986. The mix formulations of these test sections can be found in Table 1.

The test sections were visually monitored once a month for crack development. The following scale was developed to rate cracking:

0 = No cracking,

1 = Hairline cracking,

2 = Slight cracking,

3 = Moderate cracking, and

4 = Severe cracking.

Examples of these ratings are shown in Figure 1. This was the only testing performed at the field test site.

LABORATORY TESTING

Laboratory testing was conducted in two phases. Phase 1 included preliminary test method evaluation, while phase 2 consisted of modifying or refining the test procedures.

Phase 1

Phase 1 included the following three test stages:

1. Coal tar emulsion;
2. Coal tar emulsion, water, and additive; and
3. Coal tar emulsion, water, additive, and sand.

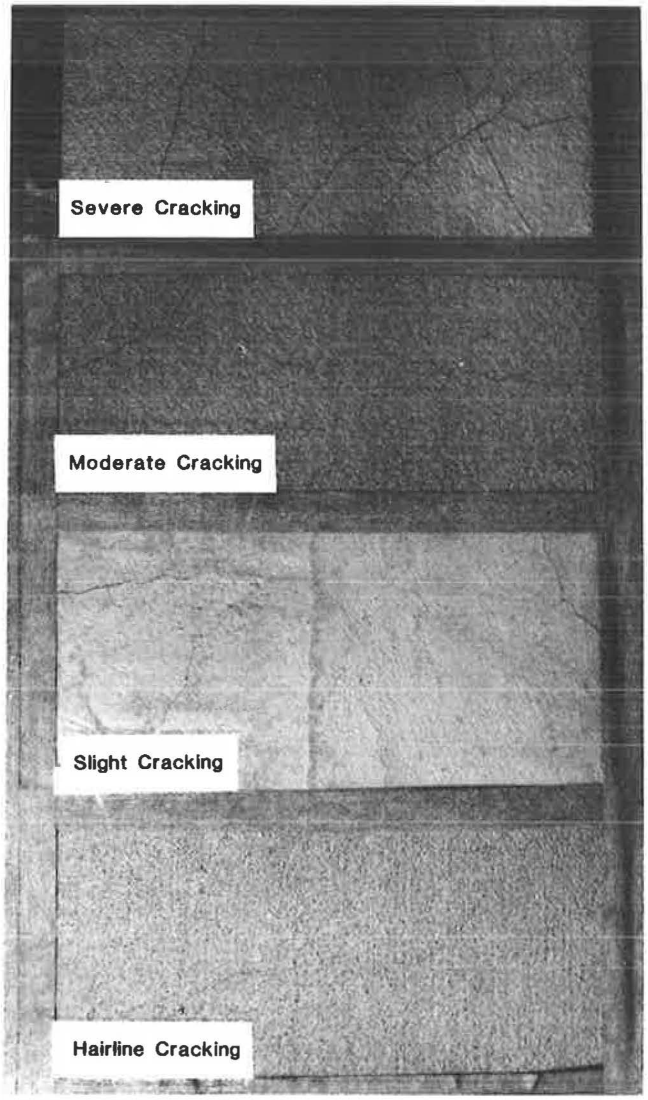


FIGURE 1 Crack rating scale developed for cyclic freeze-thaw conditioning test.

The variables considered during testing were

- Coal tar source,
- Additive content,
- Water content,
- Sand content,
- Sand gradation, and
- Sand shape.

In stage 1 testing, coal tar source was the only variable considered. The tests performed in this stage are shown in Figure 2.

The testing in stages 2 and 3 was performed according to designed experimental plans. The plan used in stage 2 was a three-factor, full factorial experiment with three levels for each factor. Source, additive quantity, and water quantity were the three factors investigated. Each factor consisted of low, medium, and high levels. The low and high limits were determined from the absolute lowest and highest manufacturer-recommended limits on the variables. The medium limit was the average between the low and high limits. Due to the large number of formulations that would result if the testing

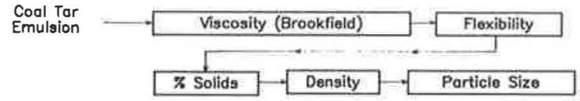


FIGURE 2 Test sequence for stage 1 of phase 1 testing.

of stage 3 were conducted from a full factorial design, this plan was reduced to a partial factorial experiment with two levels for each factor. Sand gradation, sand shape, additive content, water content, and sand content were the variables considered. The two levels considered were low and high, and they were selected as described above.

The tests performed in stages 2 and 3 are shown in Figure 3.

Phase 2

Phase 2 was conducted by following a four-factor, full factorial experiment with three levels for each factor except sand loading, which had two levels (see Table 2). The variables, or factors, that were considered included

- Coal tar source,
- Additive content,
- Water content, and
- Sand content.

The tests performed in this phase are shown in Figure 4.

Several tests were eliminated after the phase 2 results were reviewed. The wet track abrasion procedure was dropped because it did not provide reliable results and did not indicate mix component changes. The Thomas-Stormer Viscometer, which was used to indicate settling, was also rejected. Because of the higher sand loadings, the results from the settling test were limited. After addition of the large quantity of sand, the Thomas-Stormer paddle, which is driven by weights, was unable to rotate in the mixture with the maximum weight applied. In addition, the tile fuel resistance test was eliminated. Test results indicated that, although this method could possibly discern overall fuel resistant mixtures, it was not sensitive to changes in the components of the mixtures. If this method is included in further testing, it should only be used as a final pass/fail step.

TEST METHODS AND RESULTS

All of the test methods used coal tar emulsion with sand, which is referred to as the composite system in this paper. Only the viscosity test was used for both the composite system and the coal tar emulsion, additive, and addition water (total liquids), combination. Desirable limits were established for each test method on the basis of a review of the results and extensive visual observation.

Viscosity

Test Method

Viscosity was measured using the Brookfield Viscometer DV II (see Figure 5). The Brookfield was chosen because of its

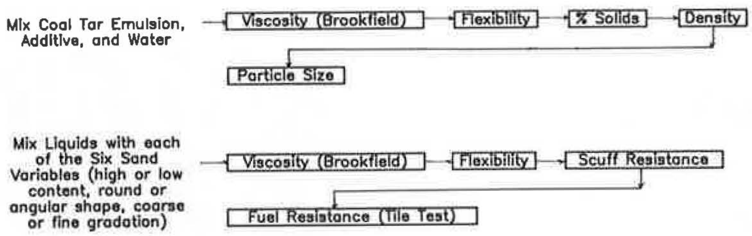


FIGURE 3 Test sequence for stages 2 and 3 of phase 1 testing.

TABLE 2 VARIABLE LEVELS USED IN EXPERIMENT

Variable	Code	Quantity or Description
Additive	L	4.0 g/100 g coal tar emulsion
	M	14.5 g/100 g coal tar emulsion
	H	25.0 g/100 g coal tar emulsion
Water	L	20.0 g/100 g coal tar emulsion
	M	55.0 g/100 g coal tar emulsion
	H	90.0 g/100 g coal tar emulsion
Sand	L	2 lbs/g coal tar emulsion
	H	13 lbs/g coal tar emulsion

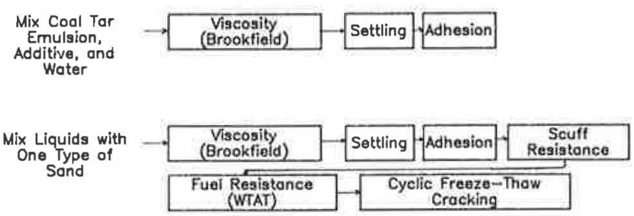


FIGURE 4 Test sequence for phase 2 testing.

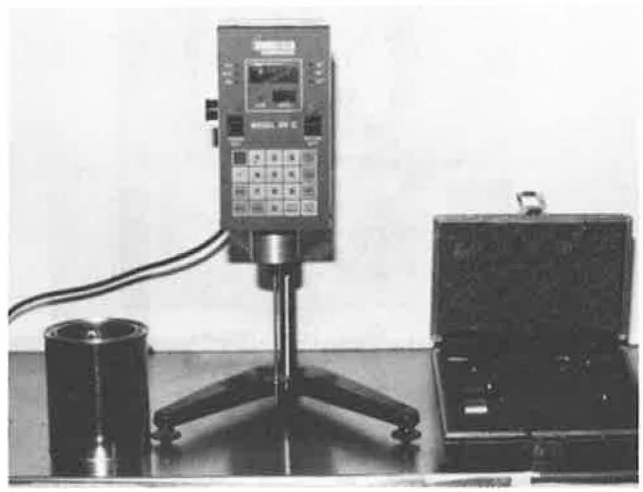


FIGURE 5 Brookfield Viscometer.

ease of use and wide range of measuring capabilities. After initial testing, it was found that coal tar emulsion mixtures exhibited shear thinning characteristics (*5*). Therefore, the testing procedure was controlled as follows.

The coal tar emulsion and water were mixed with 50 strokes of a large laboratory mixing spoon. A Brookfield spindle was then inserted into the material and allowed to rotate for 5 sec at a shear rate of 50 r/min before a viscosity measurement was taken. The additive was then introduced and stirred with an additional 50 strokes, and the viscosity was measured as before. This procedure was repeated for the addition of sand.

Repeatability

An examination of the standard deviations versus the viscosity in poises indicated a nonlinear relationship. Therefore, the coefficient of variation (CV) was chosen to represent repeatability. This statistical parameter is actually an expression of the standard deviation as a percentage of the mean viscosity. Three replicates of six materials were used to determine the CV for both the total liquids and the composite system. The CV was 3.7 percent for the total liquids and 8.0 percent for the composite system.

To find the standard deviation for any viscosity, the viscosity is multiplied by the CV (with the percentage expressed in decimal form). For example, if the testing of three samples of total liquids yields an average viscosity of 50.0 poises, then the standard deviation is $50.0 \times .037 = 1.9$ poises.

Desirable Test Limits

Desirable viscosity limits were established by evaluating the laboratory tests, a visual observation of ease of mixing, the consistency of the material, and the ability of a technician to prepare samples (*5*). When preparing samples, materials with viscosities of less than 10 poises were found to be too fluid; sands rarely stayed in suspension. These materials would tend to run off the pavement if used in the field. On the other hand, viscosities of greater than 90 poises were accompanied by one or more of the following:

- Obvious coagulation,
- Lumping,
- Inability to spread material, and
- A thick layer at the bottom of the container, indicating that the additive or the sand was thickening or settling out.

Thus, these materials would cause an uneven surface texture if squeegied and would clog spray nozzles.

Scuff Test

Test Method

The procedures and equipment for the scuff test were developed from the asphalt concrete and slurry seal industries (ASTM

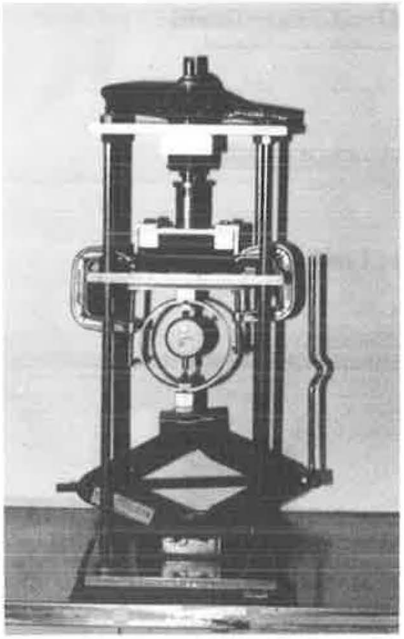


FIGURE 6 Scuff test apparatus.

D3910–84 and (*2*)). The equipment applied a constant pressure to the test specimen, then rotated a rubber abrasion foot on the specimen. The torque required to turn the foot was then measured (see Figure 6).

The sample medium used was asphalt roofing shingles, cut into 6-in. × 6-in. squares; three samples were needed for each test. A uniform film thickness of the composite system was applied using a 16-gauge sheet metal mask: a 6-in. × 6-in. square with a 4-in. × 4-in. section removed from the center. A straightedge was used to apply the material evenly within the cut-out section.

All prepared samples were allowed to cure at ambient temperature (77°F) until they were tested. One sample was tested at 4 hr, the second at 8 hr, and the last at 24 hr.

During testing, samples were held in place on the platen with "C" clamps. The platen was raised upward to the rubber abrasion head, and a normal load of 28 psi was applied. The torque wrench was then pulled through an arc of 180°, and a torque reading was taken in inch-pounds. A torque wrench with a capacity of 300 in.-lb provided an adequate range for all testing.

Repeatability

Testing to determine the repeatability of this method indicated that the standard deviation between any two tests was 13.1 in.-lb. This value was rounded up to 15 in.-lb because the torque wrench measured in increments of 5 in.-lb. The standard deviation was consistent for any test time or range of torque values.

Desirable Test Limits

Torque readings below 50 in.-lb caused material to be pushed in front of the rubber abrasion head. Values of 80 in.-lb or

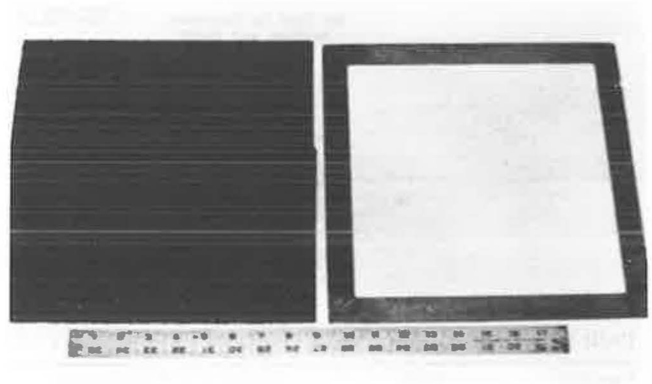


FIGURE 7 Asphalt roofing shingle and mask for cyclic freeze-thaw conditioning test.

greater at 4 hr with a reduction in values at 8 hr also indicated that the material was moving on the shingle. The high initial readings were the result of testing the shingle and not the seal coat; as the material set (8 hr), the test began to evaluate the seal coat instead of the shingle.

Torque readings between 50 and 100 in.-lb were equated with material shearing under the abrasion head. Some of the seal coat remained adhered to the shingle, but the surface of the seal coat tended to push in front of the abrasion head.

On the basis of these observations, 8- and 24-hr limits were set as follows:

- A torque of a minimum of 100 in.-lb at 8 hr, and
- A torque greater than the 8-hr reading at 24 hr.

The limit on the 24-hr reading ensured that the 8-hr reading was actually measuring the seal coat and not the shingle.

Cracking Tendencies

Test Method

The temperatures used for the freeze-thaw cycles were derived from typical asphalt concrete testing procedures. This testing was based on typical northern pavement temperatures of 140°F or above during the summer and 10°F during the winter.

Composite systems were applied to a 12-in. × 12-in. section of asphalt roofing shingles. One layer of sealer was applied in a uniform film thickness using a 16-gauge sheet metal mask, which was 12-in. × 12-in. with a 10-in. × 10-in. section removed from the center (see Figure 7). After the sample was prepared, it was cured at 77°F and at a relative humidity of less than 20 percent for 24 hr. Samples were then exposed to a 140°F oven for 24 hr and a 10°F freezer for 24 hr. Samples were conditioned for 10 cycles, each consisting of one treatment of both temperatures. Cracking was monitored after the completion of each cycle. The same scale was used for these evaluations as for the field test sections (see Figure 1).

Repeatability

Various materials with diverse cracking tendencies were evaluated to determine the repeatability of this test. In all but a

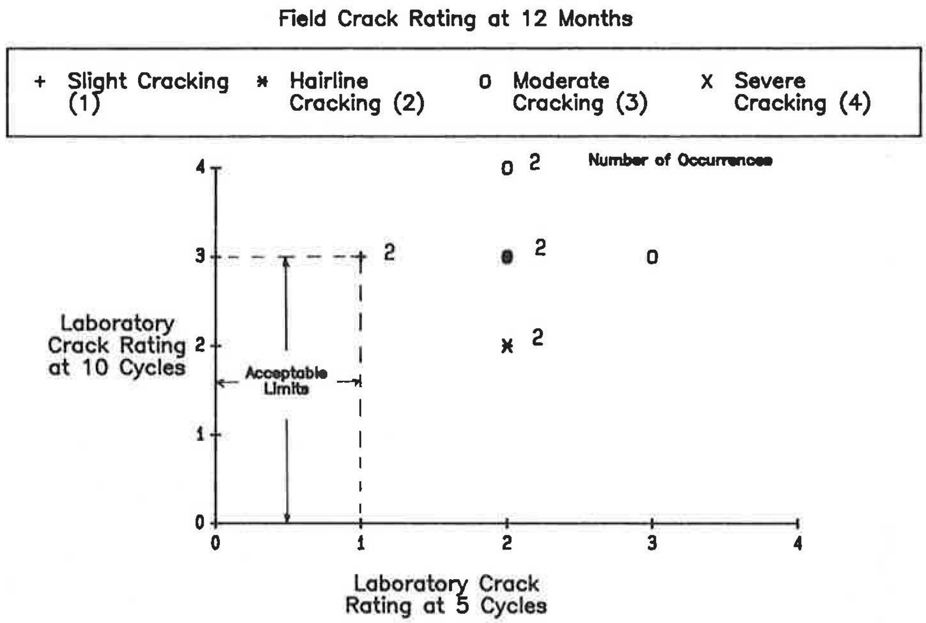


FIGURE 8 Relationship between laboratory freeze-thaw cracking and field test section cracking.

few cases, the ratings for replicates of the same material were identical. A calculation of the standard deviation for this test method was 0.29.

Desirable Test Limits

Using a comparison between field cracking of test sections and freeze-thaw cracking of laboratory samples as a basis, rating limits were chosen as follows:

- A rating of 1 or less at the end of 5 cycles, and
- A rating of 3 or less at the end of 10 cycles.

The relationship used to select these ratings is shown in Figure 8. This figure shows laboratory cracking at 10 cycles versus laboratory cracking at 5 cycles, with the symbols indicating the results of the field crack rating at 12 mo for each sample. These limits were based on field evaluations to date and have produced a crack rating of 1 or less after 1 yr in the field. Comparisons of 11 test sections comprising a wide range of coal tar sources, additives, and sand gradations and shapes were the basis for these ratings. Typical relationships between field cracking and laboratory conditioning are shown in Figures 9 and 10. It should be noted that the same crack rating system was used for both the laboratory and the field evaluations.

Adhesion

Test Method

ASTM D3359–83 describes the detailed use of the adhesion test procedure. Basically, one thickness of the composite system was placed on an aluminum panel, and the sample was cured at 77°F for 24 hr. After curing, an "X" was cut in the seal coat so that the panel was visible. A length of pressure-sensitive tape was applied so that the center of the X was covered, the tape was peeled back, and the adhesion between the sealer and the panel was rated. The ASTM rating scale, was modified for this research as follows:

5A = No peeling,
4A = Trace peeling or removal along the incision,
3A = Jagged removal along most of the incision up to 1/16 in. on either side,
2A = Jagged removal along most of the incision up to 1/8 in. on either side,
1A = Removal from most of the area of the X under tape, and
0A = Removal beyond the area of the X.

A plus sign (+) was added to indicate that sand was retained on the tape.

Repeatability

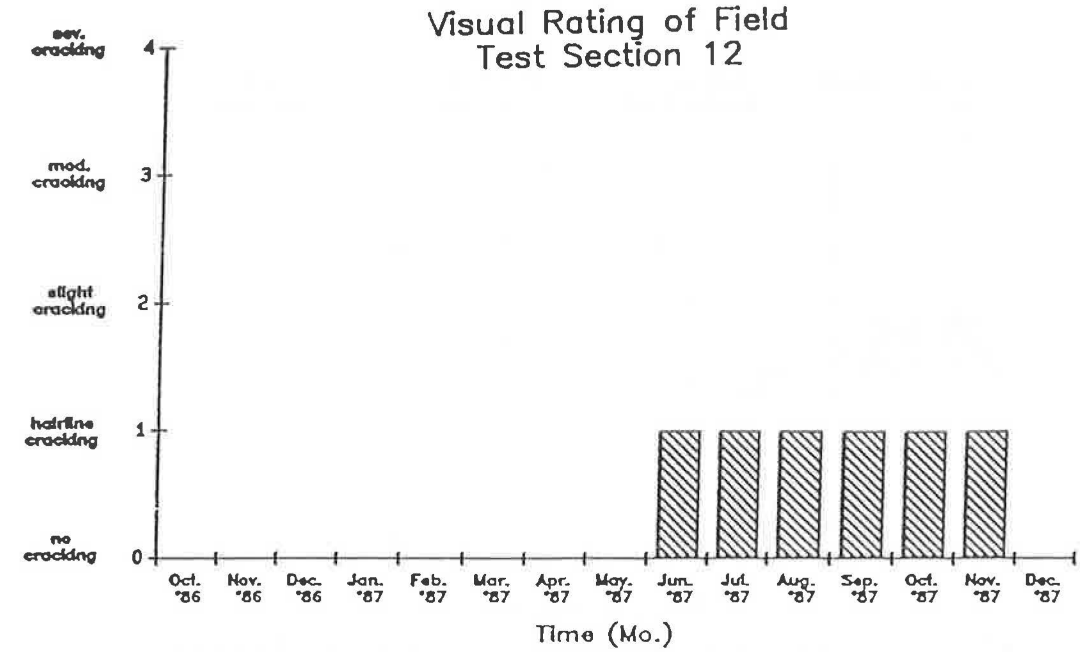
Repeatability was not established for this test method.

Desirable Test Limits

Most products tested indicated no peeling; however, at the higher sand contents, most samples demonstrated a loss of sand retention. Therefore, limits were set at a rating of 5A with no sand being retained on the tape.

USE OF DESIRABLE PROPERTIES TO DEFINE OPTIMUM COMPONENT QUANTITIES

Preliminary optimum component quantities were defined by a process of elimination based on the limits set for each test



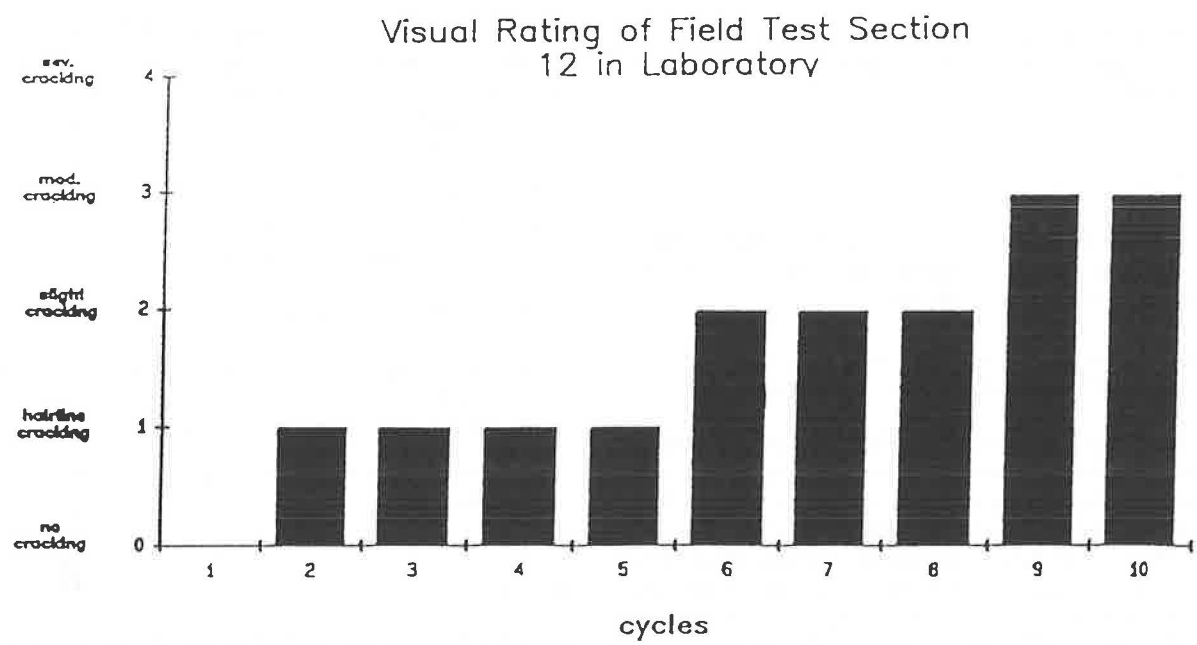


FIGURE 9 Typical relationship for field cracking versus laboratory cracking (test section 12).

(see Table 3). An example for coal tar source 2 is shown in Figure 11. Five steps were used for this process of elimination.

Step 1

In this step, incompatibilities were identified between the components making up the liquid portion of the sealers. The following criterion was considered:

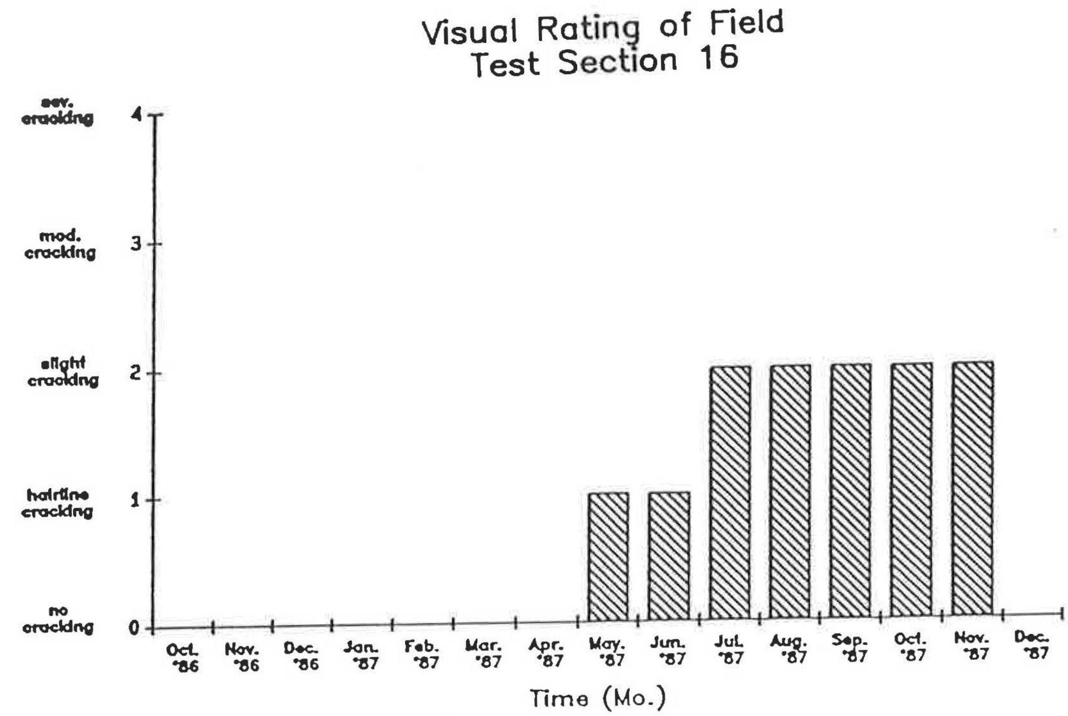
- Viscosities between 10 and 90 poises are acceptable.

Any mixtures not meeting this requirement were eliminated from the matrix for the next step. Figure 11 shows that all mixtures except the low water/low additive and low water/medium additive were eliminated.

Step 2

This step checked the workability of the mix by identifying any new incompatibilities created by the introduction of sand. The composite material could neither run off the pavement nor clog spray bars. The following limit was used:

- Viscosities between 10 and 90 poises are acceptable.



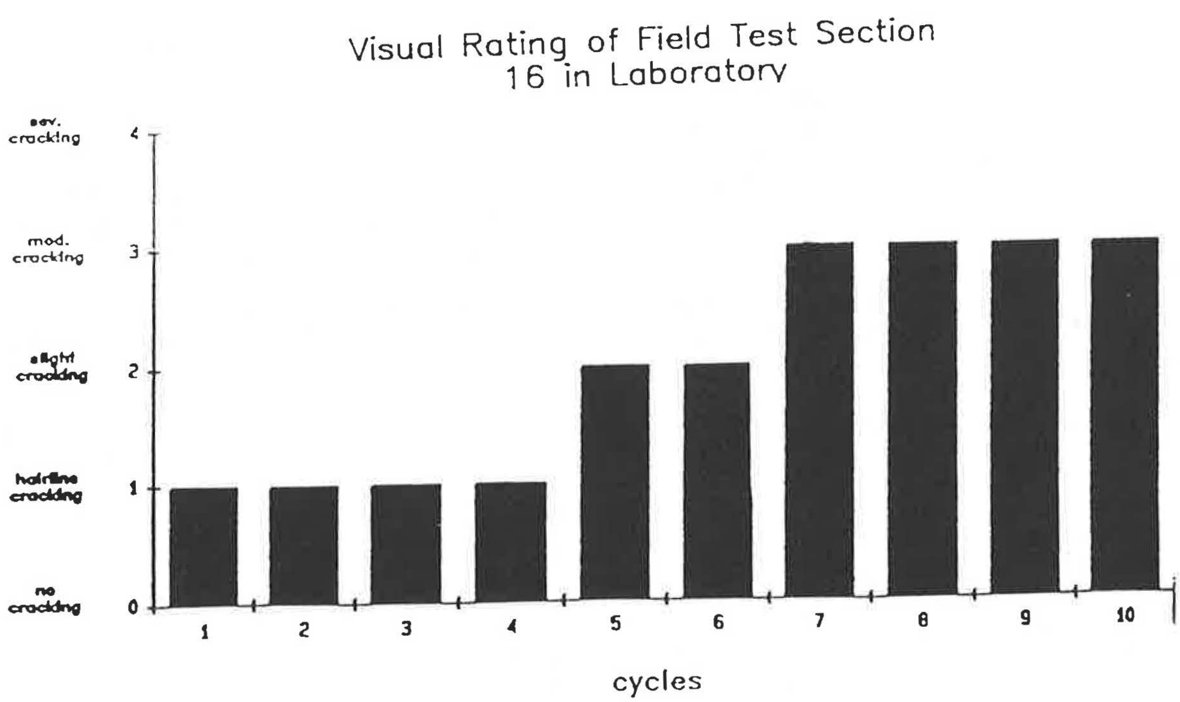


FIGURE 10 Typical relationship for field cracking versus laboratory cracking (test section 16).

TABLE 3 DEVELOPMENT OF PRELIMINARY OPTIMUM COMPONENT QUANTITIES

Step	Test Method	Performance Item	Criterion	Repeatability
1	Brookfield Viscosity @ 77°F	Incompatibility between additive and coal tar	Viscosity between 10 and 90 poises	CV = 3.7%
2	Brookfield Viscosity @ 77°F	Workability of mix	Viscosity between 10 and 90 poises	CV = 8.0%
3	Scuff Resistance	Rate of set	8 hour torque ≥100 in-lbs	Std Dev = 15 in-lbs
		Final scuff resistance	24 hour torque ≥8 hour torque	Std Dev = 15 in-lbs
4	Cyclic Freeze-Thaw Conditioning	Cracking	Rating ≤1 @ 5 cycles Rating ≤ 3 @ 10 cycles	Std Dev = 0.29
5	Tape Test	Adhesion	Rating = 5A No sand loss	N/A

Any mixtures not meeting this requirement were eliminated in the step 3 matrix.

Step 3

In this step, the initial set and final scuff resistance were checked. The seal coat was allowed to set for a maximum of 8 hr. The torque value was checked at 24 hr to ensure the best final scuff resistance for the materials used. The limits for this step were as follows:

- Torque ≥ 100 in.-lb at 8 hr, and
- Torque ≥ the 8-hr value at 24 hr (a small difference in numbers was tolerated as long as it remained within the realm of repeatability error).

The results from this step usually narrowed the acceptable combinations of components to approximately four to six mixtures. Those not meeting the requirements were eliminated from the step 4 matrix.

Figure 11 shows the 8-hr torque value in the upper left-hand corner of the cell and the 24-hr cure in the lower right-hand corner. It should be noted that the 8-hr torque value (85 in.-lb) for the medium additive, low water, and low sand mixture was left in the test matrix. Any scuff test result that was within the repeatability error was given a chance to pass the remainder of the requirements.

Step 4

The purpose of step 4 was to optimize long-term performance by limiting both the 5- and 10-cycle cracking. The following criteria were used:

- A rating of 1 or less at 5 cycles, and
- A rating of 3 or less at 10 cycles.

Figure 11 shows that only the medium additive, low water, and high sand mixture met these criteria.

Step 5

This step was used as a pass/fail test for adhesion and sand retention. Sand had to be retained by the seal coat after curing. The following limits were considered:

- No sand can adhere to the tape, and
- No debonding of the seal coat and the test medium is allowed (adhesion rating of 5A).

The only selection that met the freeze-thaw requirement also met the adhesion/sand retention check.

In general, this methodology indicated that the optimum combination of the variables investigated was coal tar source 2: a medium additive with low additional water and a high sand loading.

COMPARISON OF DESIRABLE LIMITS FOR TEST RESULTS AND SUPPLIERS' SUGGESTED OPTIMUM MIXTURES

Table 4 provides a comparison of the optimum component quantities as defined by desirable test results, before and after the sand retention check, and the corresponding suppliers' suggestions. The quantities were compared before and after the sand retention check because of the wide range between the high and low sand loadings. In other words, a mix might

TOTAL LIQUIDS

Step 1 - Check mix for incompatibility between coal tar and additive

		Additive Low	Additive Med.	Additive High
Water	Low	29.1	30.4	4.9
Water	Med.	7.3	3.2	2.7
Water	High	2.2	2.0	low

LIMITS: Viscosity between 10 and 90 poises

COMPOSITE MIX

Step 2 - Check workability of mix

		Additive								
		Low			Medium			High		
		Water			Water			Water		
		L	M	H	L	M	H	L	M	H
Sand	L	35.1	X	X	35.6	X	X	X	X	X
Sand	H	60.6	X	X	43.4	X	X	X	X	X

Viscosity between 10 and 90 poises

Step 3 - Check initial set and final scuff resistance

		Additive								
		Low			Medium			High		
		Water			Water			Water		
		L	M	H	L	M	H	L	M	H
Sand	L	150 110	X	X	85 120	X	X	X	X	X
Sand	H	150 125	X	X	100 115	X	X	X	X	X

8 hour torque ≥ 100 in-lbs.

24 hour torque > 8 hour torque

Step 4 - Limit crack development

		Additive								
		Low			Medium			High		
		Water			Water			Water		
		L	M	H	L	M	H	L	M	H
Sand	L	X	X	X	3 4	X	X	X	X	X
Sand	H	X	X	X	0 1	X	X	X	X	X

Rating ≤ 1 @ 5 cycles

Rating ≤ 3 @ 10 cycles

Step 5 - Check adhesion, between mix and substrate and between sand and binder

		Additive								
		Low			Medium			High		
		Water			Water			Water		
		L	M	H	L	M	H	L	M	H
Sand	L	X	X	X	X	X	X	X	X	X
Sand	H	X	X	X	5A,N	X	X	X	X	X

Adhesion rating = 5A

Loss of sand (Y/N)

FIGURE 11 Selection of desirable properties for coal tar source 2.

perform well in all of the tests but fail to retain sand because of the high sand loading.

Table 4 shows that the procedure developed in this research raised the additive content compared with the suppliers' recommendations for all sources. The water content remained constant for two sources, was increased for one source, and was decreased for one source. In general, the sand content was increased before the sand retention check and decreased afterward.

It should be noted that UNR component quantities were chosen from the limits used to define desirable test results. No interpolation was made between low, medium, and high component quantities.

The process developed is only a preliminary estimation of component quantities based on a wide range of component levels. After the preliminary quantities have been found, another estimate of component quantities should be performed to refine the optimum quantities. This process would be identical to the preliminary analysis but would consider a narrower range of variables. Due to limited time and money, only the general practicality of this methodology was assessed in this study.

SUMMARY

On the basis of previous difficulties experienced with coal tar seal coats, tests were developed or modified to measure

- Workability (Brookfield viscosity),
- Cure time (scuff resistance),
- Skid resistance (scuff resistance),
- Cracking (cyclic freeze-thaw conditioning),
- Debonding (adhesion), and
- Fuel resistance.

Viscosity was selected to detect two initial problems. The first was an incompatibility between the components, which causes coagulation and an inordinate amount of thickening of the emulsion. Both of these create an increase in viscosity. Second, viscosity was used to measure the ease with which the material could be squeegied or sprayed.

A scuff test, adapted from the slurry seal and asphalt concrete industry, was designed by the University of Nevada-Reno. Limits for scuff values were set at 8 hr to provide a substantially scuff-resistant surface 8 hr after placing mate-

TABLE 4 COMPARISON OF OPTIMUM QUANTITIES DETERMINED FROM LABORATORY TESTING AND SUPPLIERS' RECOMMENDATIONS

Source/Components	Before Sand Retention Check (Steps 1-4)	After Sand Retention Check (Steps 1-5)	Supplier's Recommended Quantities
Source 1:			
Water*	55	20	80
Additive*	14.5	14.5	8.2
Sand**	13	2	13
Source 2:			
Water	20	20	20
Additive	14.5	14.5	10
Sand	13	13	5
Source 3:			
Water	20	20	50
Additive	25	25	6
Sand	13	13	6
Source 4:			
Water	90	90	90
Additive	25	25	6
Sand	13	2	6.2
Source 6:			
Water	90	90	60
Additive	4	4	3
Sand	2	2	8

* - Quantity measured in gal/100 gal coal tar emulsion
** - Quantity measured in lbs/gal coal tar emulsion

rials. A minimum scuff value was established at 24 hr to indicate optimum scuff resistance for any given set of components.

Cracking was evaluated by applying coal tar emulsions to roofing shingles, then subjecting the prepared samples to multiple cycles of freezing and thawing. Limits on cracking were set for this testing at 5 and 10 cycles of freeze-thaw. These limits were linked to field performance.

The cross-hatch test was used to identify debonding of the sealer from the test medium as well as loss of sand retention by the sealer.

Guidelines were established for determining the preliminary optimum quantities of additive, additional water, and sand for a given set of materials. These procedures are applicable to a wide variety of coal tar sources and types of additives. The procedure may also be used to refine optimum quantities after the preliminary analysis by reducing the range of variables.

FUTURE RESEARCH

The tests and limits developed in this study will be used to define the quantities of composite system components for field test sections at the general aviation airport in Stead, Nevada, which is located several miles outside Reno city limits. The materials used for these test sections will be similar to those supplied for the original field test on the UNR parking lot. Because the test methods and limits were refined with these specific materials, continuity between the initial field work, preliminary and final laboratory testing, and the final test sections will be maintained. Materials will include

- Six sources of coal tar emulsions;
- Various additives, including acrylonitrile-butadiene latex and proprietary products; and
- One sand source and gradation.

Sand source and gradation were held constant to reduce the variables in the laboratory portion of this research. Because the optimization steps did not account for various sand sources and gradations, the field mixtures will also be restricted to this sand and gradation.

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