Correlation Between Field and Laboratory Performance of Liquid Asphalt–Based Seal Coats

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The success of any seal coat depends not only on the quality of the binder and the aggregate (chips) but also on the compatibility of the two materials. Compatible binder-aggregate combinations will result in a long-lasting seal coat, and incompatible combinations will result in chip loss, bleeding, and so on. The use of additives in seal coats, whether applied to the binder or to the aggregate, has proved very useful in prolonging the life of a seal coat and improving its field performance. Polymer modified cutback (RC-3000R) and plain cutback (MC-3000) were used along with three different types of aggregate chips [blotter gravel (BG), pea rock (PR), and quartzite (Q)] to determine the best binder-aggregate combination. Also, seal coats made with liquid asphalt were examined closely in terms of laboratory performance (using modified Vialit test) and field performance (using an evaluation technique developed in South Dakota). The RC-3000R and quartzite combination performed the best in the field and the MC-3000/BG combination was the worst. The field performance of test sections that were subjected to traffic for over 2 years resulted in a ranking of all test sections from 1 to 6, with 1 being the best in performance. Two parameters extracted from the Vialit test were found to have an excellent correlation with field performance—initial retention and the additional chip loss due to impact.

Seal coats are made out of a binder and an aggregate. Popular binders are emulsions, liquid asphalts, and sometimes paving-grade asphalt cements. Successful seal coats can last between 3 and 7 years before another seal coat or other type of surface treatment needs to be considered. The success of any seal coat depends largely on the compatibility between the binder and the aggregate. It also depends on the quality of each individual material and a host of other reasons relevant to traffic and weather conditions.

Asphalt modifiers have been used since the early 1930s. There are several reasons why a fresh asphalt needs to be modified: for instance, to prevent stripping, to make asphalt less brittle in cold temperatures and more viscous in hot temperatures, and occasionally to rejuvenate it. Of all the available binders for seal-coat construction, liquid asphalt (cutback) was examined in this study. Two different types of liquid asphalt—a medium-curing grade (MC-3000) and a polymer-modified, rapid-curing grade (RC-3000R)—were utilized in this research work. The study also employed three different types of aggregate chips: blotter gravel, pea rock, and quartzite. These three aggregates are commonly used for chip seals in the eastern part of South Dakota owing to their easy availability.

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To evaluate how seal coats perform in the field as well as in the laboratory, two different techniques were used. The field performance of seal-coat test sections was evaluated by using a technique developed in South Dakota in the mid-1960s (*1*). The technique was slightly modified to accommodate the circumstances of this study. After seal-coat test sections were constructed, they were evaluated periodically for over 2 years. The periodic evaluation revealed consistency in the performance of the six test sections. The evaluation technique consequently resulted in ranking all test sections from 1 to 6, with 1 being the best in performance and 6 being the worst. The Vialit test was used to evaluate the laboratory performance of test specimens that were constructed in a very similar manner to those that were built in the field. The original Vialit test was developed in France (*2*), where limited types of aggregates are used for chip seals. There was a need to modify the test to make it more suitable to the large variety of aggregates available in the United States, particularly the Midwest. The modified Vialit test used in this study will be referred to as the Vialit-SD test.

To see whether there is any trend between laboratory and field performance of seal-coat test sections, a correlation study was made by using both Spearman's and Pearson's correlation techniques. The results revealed that excellent correlation exists between field ranking and laboratory ranking of two parameters, namely, initial retention (R_1) and additional aggregate loss due to impact (Diff = $R_1 - R_2$). When the various laboratory specimens (treatments) were ranked according to either of the two previously mentioned parameters, the ranking was highly correlated to that obtained during field evaluation of the same treatments.

OBJECTIVES

The main objectives sought in this study are

1. To examine whether polymer-modified cutbacks have any advantage over regular cutbacks when used in seal coats,
2. To determine which of the two types of cutbacks and the commonly used three types of aggregate chips performed the best as a seal coat, and
3. To determine whether there is any correlation between laboratory and field performance of seal coats.

MATERIAL SELECTION

To examine whether polymer-modified cutbacks have any advantage over plain cutbacks, an RC-3000R (latex modified) and an MC-3000 were used. An MC-3000 had been specified for a Lincoln County, S. Dak., sealing job on Highway 111, some sections of which were incorporated into this study. Quartzite chips were specified for the same job. It would be logical to have used a polymer-modified MC-3000R so a fair comparison could have been made of plain end-modified products; however, the asphalt industry does not produce MC-3000R but manufactures an RC-3000R instead. It was also appropriate to use more than one type of aggregate in this study to see which binder-aggregate combination yielded the best results either in the field or in the laboratory.

What follows are brief descriptions of all materials used.

MC-3000. MC-3000 is a highly viscous grade of medium-curing liquid asphalt. This grade of cutback is commonly used during the hot summer months. Table 1 shows the basic characteristics of the binder.

RC-3000R. Rapid-curing liquid asphalt is more receptive to polymer modification than the MC grade. Specifications and properties of this binder grade are also shown in Table 1.

Quartzite (Q). This crushed material exists in abundance where this study was performed. Previous studies (*3*) showed that quartzite, despite its higher cost, is more economical to use during the life cycle of either a seal coat or a hot mix mat. The chip size specified for Highway 106/111, which was also used in this study, is ⅜ in.

Pea rock (PR). This rounded gravel is obtained from various gravel pits around the study area. It has a very smooth surface but contains a small amount of crushed particles. The maximum size is ⅜ in.

Blotter gravel (BG). This type of low-quality aggregate is often used by local governments owing to its relatively cheaper cost per ton. It is not clean nor does it have a narrow gradation range as required for aggregates to be used in seal coats. This type of chip was used in this study because of its popularity in some localities that are having maintenance budget problems, and also to examine its performance in comparison with that of the other two types of chips. Maximum size for this type of aggregate is ⅜ in. Few aggregate particles over ⅜ in. were observed. Figure 1 shows the three different types of aggregate.

It was necessary to examine six different binder-aggregate combinations. Each combination includes one of two different types of cutbacks and one of three different types of chips.

FIELD TEST SECTION CONSTRUCTION AND EVALUATION

In summer 1986, Lincoln County, South Dakota, let a seal coat job 2.5 mi long. The project called for quartzite aggregate chips and MC-3000 for a binder. This binder-aggregate combination (MC 3000/Q) formed one of the six treatments, and

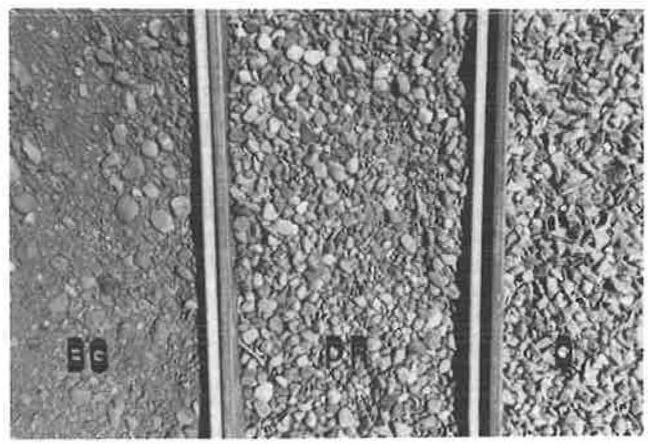

FIGURE 1 Aggregate chips used in the study.

TABLE 1 PROPERTIES OF LIQUID ASPHALTS

PROPERTY	MC-3000	(RC-3000R)
AASHTO	M82-75	M81-75
Specific Gravity at 60°F	1.005	0.992
lbs./gallon at 60°F	8.37	8.264
Kinematic viscosity at 140°F, CS.	4460 (3000-6000)	4598 (3000-6000)
Flash point (Tag open up)F	150+ (150 min)	80+ (80 min)
Distillation Test		
Distillate, % by vol of total - Distillate at 680°F		
Total to 500°F	0% (0-15%)	53% (25% min)
Total to 600°F	53% (15-75%)	83% (70% min)
Residue from distillation to 680°F	91% (80% min)	84% (80% min)
Test on Residue From Distillation		
Penetration at 77°F	140 (120-150)	104
Abs. viscosity at 140°F poises	743 (300-1200)	1160

( ) Specifications

an additional five treatments were constructed. The treatments are identified as follows:

Treatment	*Binder*	*Aggregate Chips*
A	MC-3000	BG
B	MC-3000	PR
C	MC-3000	Q
D	RC-3000R	BG
E	RC-3000R	PR
F	RC-3000R	Q

Each of the five additional treatments was about 700 ft long and 13 ft wide. Chips were applied at the rate of 20 lb/yd^2 for both quartzite and pea rock chips, and 25 lb/yd^2 for the blotter gravel chips. Binder, whether MC-3000 or RC-3000R, was applied at the rate of 0.26 gm/yd^2. These quantities were recommended by the office of the Lincoln County Highway Superintendent, where the original seal coat project was being constructed. These same quantities were also used when laboratory specimens were made during the second phase of this study.

In the mid 1960s, researchers at the South Dakota Department of Transportation developed an evaluation technique for the field performance of seal coats. The technique is qualitative in nature and depends on assessing five categories associated with the seal coat. Each category is worth 20 points, with a total of 100 points for an ideal seal-coat section. The five different categories follow:

Category	*Score*
Chip retention	20
Skid resistance	20
Uniformity of application	20
Cracking	20
Bleeding	20
Total	100

The methodology, when originally developed, was used to evaluate a seal coat after 1 year of service. The evaluation is recommended to be done by only one evaluator, who gives the section surface a score between 0 and 20 for each category according to descriptive guidelines that help the evaluator choose the proper numerical values (*1*).

Once the visual rating of all five categories of a 1-mi section is completed, an average of all 1-mi sections within the project is calculated and used as the rating value for the entire project. The original methodology also suggests that rating should not be done on sections of seal coats that have been patched so extensively that much of the seal coat has been covered. The methodology also suggests that when the rating drops to 50, some sort of maintenance is necessary. The type of maintenance will depend on the type and extent of damage the section encountered while in service.

To expand the use of this methodology and make it applicable to comparisons of various seal coats instead of only one seal coat at a time, it was necessary to modify the methodology slightly. After a review of the original five categories, it was decided that the category "Uniformity of Application" is of no value when test sections are compared that were constructed within a few hours of each other by using the same rate of material application and the same equipment. Quality control measures were observed to ensure that asphalt spray bars and aggregate spreaders were delivering the prescribed amount of material. This category was eliminated and replaced by a category called "Traffic Volume," which was necessary because some test treatments (A and B) were subjected to lower traffic volumes than the other four treatments. To keep the simplicity of the methodology, the new category also received a 20-point weight. On a scale of 0 to 20, it is suggested that the following tabulation be observed when numerical values are assigned to the traffic volume category.

Traffic Volume (VPD)	*Score*
>4,000	20
3,250–3,999	18
2,500–3,249	16
1,750–2,499	14
1,000–1,749	12
<1,000	10

Field test sections (treatments) were evaluated periodically by using the modified methodology. There was consistency in the performance of the six test treatments, and Table 2 shows the evaluation summary after about 2.5 years of service.

The results shown in Table 2 reveal some interesting facts. The top performer was the RC-3000R/Q combination, and second in rank was the MC-3000/Q combination. When pea rock was used with RC-3000R under a high traffic volume, it performed in fashion similar to that when it was used with MC-3000 under a lower traffic volume. This suggests that higher-quality binder can tolerate higher-volume traffic. The two treatments involving pea rock, therefore, received a tie ranking for third and fourth place (3.5 for an average). The worst combination was MC-3000/BG, which received sixth rank; RC-3000R/BG took fifth place.

LABORATORY EVALUATION

Very few laboratory techniques are available to assess seal coats. Selim recently developed a laboratory technique to quantify chip loss in emulsion-based seal coats caused by moisture (*4*). Unfortunately, the methodology is not applicable to liquid asphalt–based seal coats, and therefore it could not be used in this study. The Vialit test offered good potential for evaluation of laboratory samples of seal coats made in similar quantity to those constructed in the field. The original Vialit test was developed to test the binder-aggregate compatibility through the amount of chip retention after application of an impact to separate the chips from the binder. The original method involved embedding 100 aggregate chips (through the use of a grid to distribute them equally) into an asphalt binder applied to a steel plate at a rate identical to the field application rate of the binder. After a specified curing time, the plate is inverted in the Vialit machine, and a steel ball weighing 500 g is dropped from a given height three times within 10 sec. The percent retention of chips is determined by the number of chips that remain intact in the binder. This method is very limited in its application owing to the limited number of aggregate chips available in France where this test was originally developed. It was inevitable that the methodology would be modified to broaden the application of the test to accommodate the variety of aggregates available in North America and to improve the meaning of retention, which should be based on the original amount of aggregate chips utilized (by weight) instead of the number of chips retained. Some research institutions in the United States and Canada took part in the modification attempt. However, no final

TABLE 2 FIELD EVALUATION FORM, APRIL 16, 1989

Traffic	MEDIUM 1200-1500 VPD			HIGH >3500 VPD		
Binder	MC - 3000			RC-3000R		
Aggregate	BG	PR	Q	BG	PR	Q
Section	A	B	C	D	E	F
CATEGORY						
Chip Retention	13	17	14	13	15	16
Skid Resistance	10	14	17	10	13	17
Traffic Volume	12	12	18	18	18	18
Cracking	12	12	13	12	12	13
Bleeding	13	16	14	10	13	14
Total	60	71	76	63	71	78
Rank	6	3-4	2	5	3-4	1

agreement has been reached as to how much and in what area the modification needs to take place. A detailed description of a modified method has been given by Selim (*5*). The modified methodology is tentatively named Vialit-SD until an accepted ASTM or AASHTO modified test can be adopted.

Modified Vialit Test

The highlights of the Vialit-SD test are as follows:

1. The chip application box was modified to allow a representative sample of the chips to be evenly distributed over the binder.
2. Two different aggregate losses were observed and documented twice, and the data were used to calculate the percent retention. The first observation was made after the plate was initially inverted, shaken gently, returned face up, brushed gently with a brush, then reinverted and shaken again very gently. This should take place within 10 sec. The percent retention (R_1) was then calculated by the following equation:

$$R_1 = \frac{D - A - C}{B} \times 100 \quad (1)$$

where

R_1 = initial percent retention immediately after initial 10-sec inversions and brushing,
A = weight of stainless steel test plate (g),
B = weight of aggregate chips (g),
C = weight of binder (g), and
D = weight of plate, aggregate chips, and binder after the initial 10-sec inversions and brushing (g).

The second observation was made after the plate was placed in the Vialit apparatus in an inverted position and the 500-g steel ball was allowed to drop on the bottom of the steel plate three times in 10 sec. An additional number of aggregate chips was always separated owing to the impact force. The final percent retention was calculated by the following equation:

$$R_2 = \frac{E - A - C}{B} \times 100 \quad (2)$$

where R_2 is the final percent retention after the initial 10-sec inversions and brushing and the impact force and E is the weight of plate, aggregate chips, and binder after initial 10-sec inversions and brushing and impact force (g).

3. The percent retention was expressed in terms of the weight of the aggregate chips that remained intact with the binder versus the original weight of the aggregate chips.

It should be noted here that the term (100 − R_1) represents the percent of loose aggregate that never had a chance to become imbedded in the binder, and the term (Diff = $R_1 - R_2$) represents the percent of chip loss due to the impact force exerted by the steel ball.

The Vialit-SD test was performed on the six different treatments A–F, and the number of binder and chips was identical to the application rate used in the field construction of the seal-coat sections. Table 3 gives a summary of the test results, and Table 4 shows the ranking of the various treatments for each parameter of the curing period. It should be pointed out that for R_1 and R_2 the ranking was higher if the percent retention was higher and, in the case of loss due to impact (Diff = $R_1 - R_2$), the lower the loss, the higher the ranking.

4. Compaction of test plates was achieved through mechanical means instead of as proposed in the original method. After the test plate was prepared according to a prescribed method, it was then taken to a compaction machine with a special compaction head covered with ¾-in. tire rubber tile, and a force of 2,880 lb. was applied. A compression force of 45 psi was applied four times to the test plate specimen; the load was lifted and the plate rotated 90 degrees before the load was applied again. The compaction process was completed within 2 min of preparing the test plate (*5*).

CORRELATION STUDIES

To find out whether any similar trend in both field and laboratory behavior of various treatments exists, a correlation analysis was done. Because the nature of field evaluation methodology is qualitative and the laboratory evaluation methodology is quantitative, it was decided to use a nonparametric statistic to perform the correlation (*6*). Spearman's approach was followed, where treatments are ranked both in the field and in the laboratory. In the field, when a treatment received high scores it meant that it performed well when compared with a treatment with a lower score. In the laboratory, the higher the percent retention (R_1 and R_2) the better it is for the seal coat and, thus, the higher the ranking. It was also determined whether there was any correlation between the term "loss due to impact" (Diff = $R_1 - R_2$) at various curing times and the field behavior of different treatments. The higher the loss due to impact is, the lower the ranking will be, and the lower the loss, the higher the ranking. The

TABLE 3 SUMMARY OF VIALIT TEST RESULTS

BINDER	MC-3000			RC-3000R		
AGG.	BG	PR	Q	BG	PR	Q
TREATMENT	A	B	C	D	E	F
CURING TIME						
10 MINUTES						
Initial Retention (R_1%)	77.3	75.9	51.0	79.0	64.1	50.0
Final Retention (R_2%)	60.5	73.4	50.2	60.7	62.1	48.8
Loss Due to Impact %	16.8	2.5	0.8	18.3	2.0	1.2
30 MINUTES						
Initial Retention (R_1%)	81.6	78.4	55.4	81.7	67.8	54.2
Final Retention (R_2%)	60.9	77.1	54.0	64.3	66.5	52.9
Loss Due to Impact %	20.7	1.3	1.4	17.4	1.3	1.3
2 HOURS						
Initial Retention (R_1%)	82.4	79.4	56.3	86.6	79.2	55.6
Final Retention (R_1%)	61.7	78.0	55.3	66.8	76.2	54.2
Loss Due to Impact %	20.7	1.4	1.0	19.6	3.0	1.4
5 HOURS						
Initial Retention (R_1%)	86.9	81.8	58.8	91.2	81.9	58.3
Final Retention (R_2%)	67.4	80.3	57.6	72.8	78.7	57.4
Loss Due to Impact %	19.5	1.5	1.2	18.4	3.2	0.9
24 HOURS						
Initial Retention (R_1%)	86.9	84.8	59.8	91.5	82.9	61.4
Final Retention (R_2%)	68.9	82.2	58.5	74.0	81.0	59.5
Loss Due to Impact %	18.0	2.6	1.3	17.5	1.9	1.9

TABLE 4 SUMMARY OF VIALIT TEST RESULTS: RANKING OF TREATMENTS

BINDER	MC-3000			RC-3000R		
AGG.	BG	PR	Q	BG	PR	Q
TREATMENT	A	B	C	D	E	F
CURING TIME						
10 MINUTES						
Initial Retention (R_1%)	2	3	5	1	4	6
Final Retention (R_2%)	4	1	5	3	2	6
Loss Due to Impact %	5	4	1	6	3	2
30 MINUTES						
Initial Retention (R_1%)	1	3	5	2	4	6
Final Retention (R_2%)	4	1	5	3	2	6
Loss Due to Impact %	6	2	4	5	1	2
2 HOURS						
Initial Retention (R_1%)	2	3	5	1	4	6
Final Retention (R_1%)	4	1	5	3	2	6
Loss Due to Impact %	6	2.5	1	5	4	2.5
5 HOURS						
Initial Retention (R_1%)	2	4	5	1	3	6
Final Retention (R_2%)	4	1	5	3	2	6
Loss Due to Impact %	6	3	2	5	4	1
24 HOURS						
Initial Retention (R_1%)	2	3	6	1	4	5
Final Retention (R_2%)	4	1	5	3	2	6
Loss Due to Impact %	6	4	1	5	3	2

TABLE 5 SUMMARY OF CORRELATION BETWEEN FIELD QUALITATIVE EVALUATION AND LABORATORY QUANTITATIVE EVALUATION USING SPEARMAN'S ANALYSIS

CATEGORY	r	Prob > lrl Ho: Rho=0
R_1 (10 min.)	**-0.9276**	**0.0077**
R_2 (10 min.)	-0.4638	0.3542
Diff (10 min.)	**0.8697**	**0.0244**
R_1 (30 min.)	**-0.9856**	**0.0003**
R_2 (30 min.)	-0.4638	0.3542
Diff (30 min.)	0.6029	0.2052
R_1 (2 hrs.)	**-0.9276**	**0.0077**
R_2 (2 hrs.)	-0.4638	0.3542
Diff (2 hrs.)	**0.8677**	**0.0251**
R_1 (5 hrs.)	**-0.9276**	**0.0077**
R_2 (5 hrs.)	-0.4638	0.3542
Diff (5 hrs.)	**0.9856**	**0.0003**
R_1 (24 hrs.)	**-0.8697**	**0.0244**
R_2 (24 hrs.)	-0.4638	0.3542
Diff (24 hrs)	**0.9276**	**0.0077**

correlation analysis was conducted between the field ranking and the laboratory ranking of the six various treatments. The results in Table 5 suggest that only the parameters R_1 and loss due to impact have an excellent correlation with field performance. In the case of R_1 a negative coefficient means that a treatment that performed well in the field with a high ranking would have the opposite performance in the laboratory (i.e., lower percent retention and consequently lower ranking). The level of significance was consistently above 96 percent. The second laboratory parameter that positively correlated with field ranking was the loss due to impact (Diff = $R_1 - R_2$). Correlation coefficients were even higher with a level of significance exceeding 99 percent. In the latter case, it was evident that the lower the losses due to the impact force of the Vialit-SD test, the higher the performance of the corresponding treatment in the field.

Figures 2–6 show a graphical presentation of the ranking of various treatments both in the field and in the laboratory.

CONCLUSIONS

The two major aims of this study were to find out (a) whether polymer modification of liquid asphalt contributed to a better performance of seal-coat test sections and (b) whether the field performance of different treatments of liquid asphalt-based seal coats could be correlated with the laboratory performance of similar specimens of seal coat. In the process of testing this hypothesis, the following conclusions were reached:

1. Of the three different types of aggregate chips, quartzite (Q) performed best, pea rock (PR) performed second best, and blotter gravel (BG) performed worst. Blotter gravel should not be used for seal coats at all because of the large amount of dirt and fines.
2. After the necessary modifications to the Vialit test, it proved to be a reasonable tool to access and compare the performance of seal-coat specimens in the laboratory.
3. Because of the qualitative nature of the field performance technique and the quantitative nature of the laboratory evaluation technique, it was necessary to use a nonparametric approach to conduct the correlation study. The ranking of treatments both in the field and in the laboratory was achieved by using Spearman's analysis.
4. The correlation study between field and laboratory peformance of various seal-coat treatments showed excellent agreement. Two parameters from the modified Vialit-SD test were found to have high correlation with field performance. The first parameter was initial percentage of retention (R_1) of chips, regardless of curing time. It should be noted that the term "initial loss = 100 − percent initial retention R_1" could have been used instead of initial retention (R_1), in this study; and, in this case, the ranking of treatments would have been reversed because higher retention means lower losses. If initial loss were included in the correlation analysis instead of initial retention (R_1), then the correlation coefficients would have the same numerical values but carry a positive sign instead of a negative sign. This would mean that the higher the initial losses, the better the performance in the field of the same

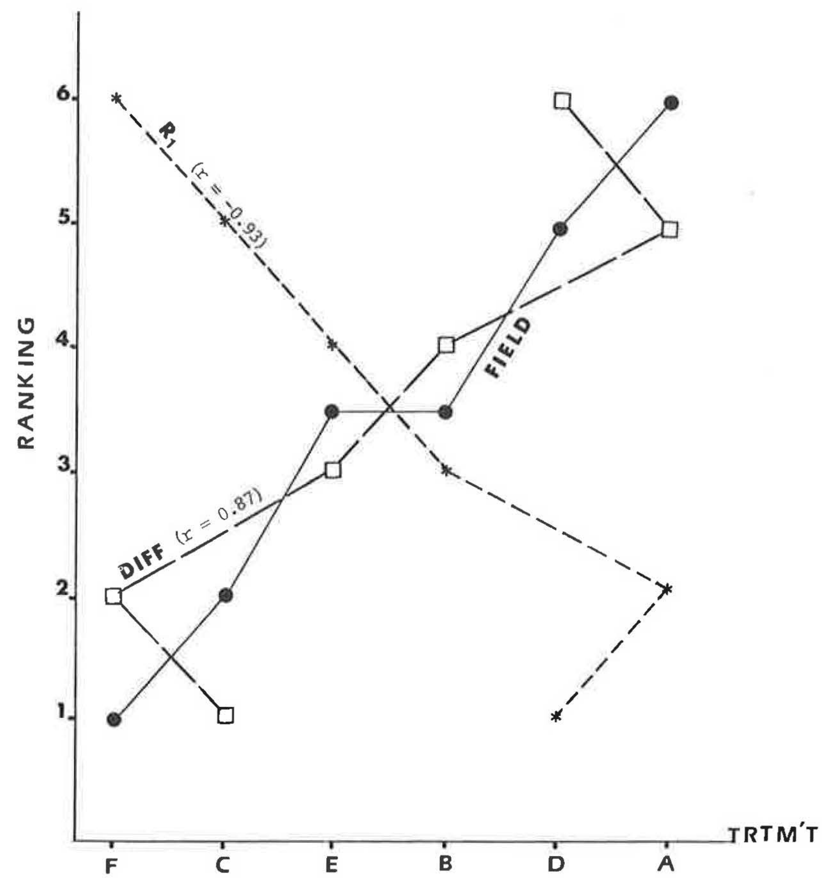

FIGURE 2 Ranking of various treatments for the 10-min curing time.

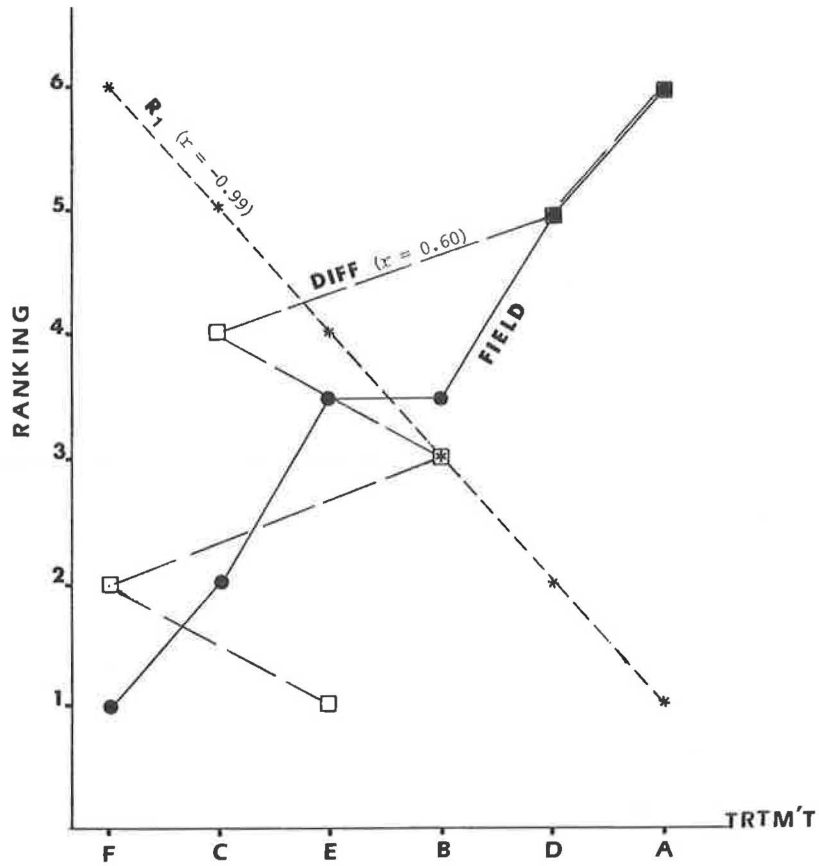

FIGURE 3 Ranking of various treatments for the 30-min curing time.

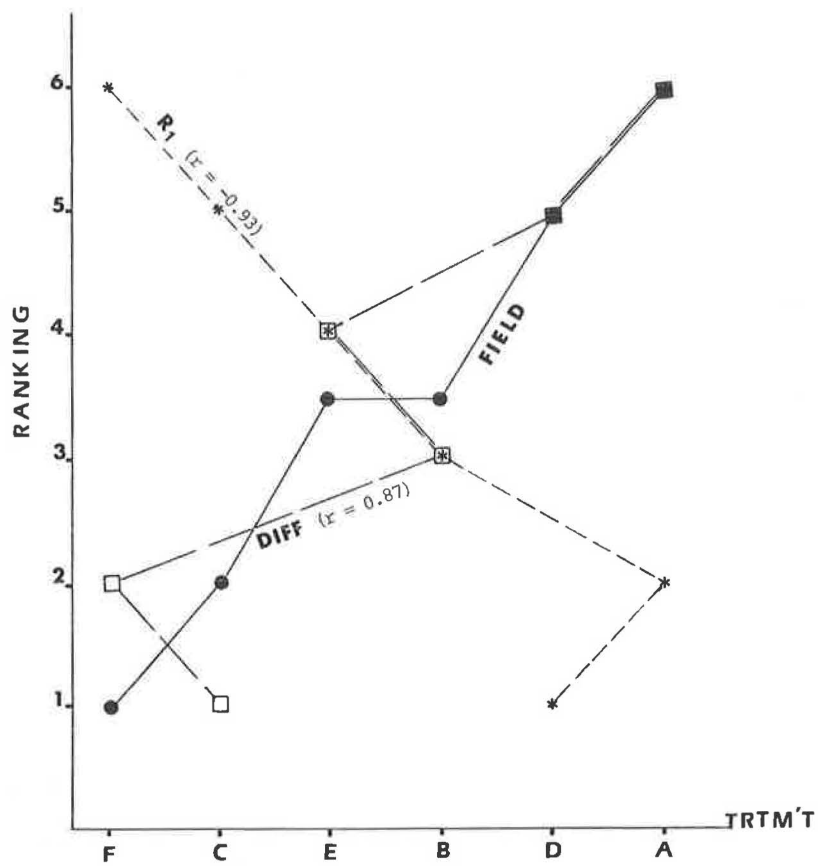

FIGURE 4 Ranking of various treatments for the 2-hr curing time.

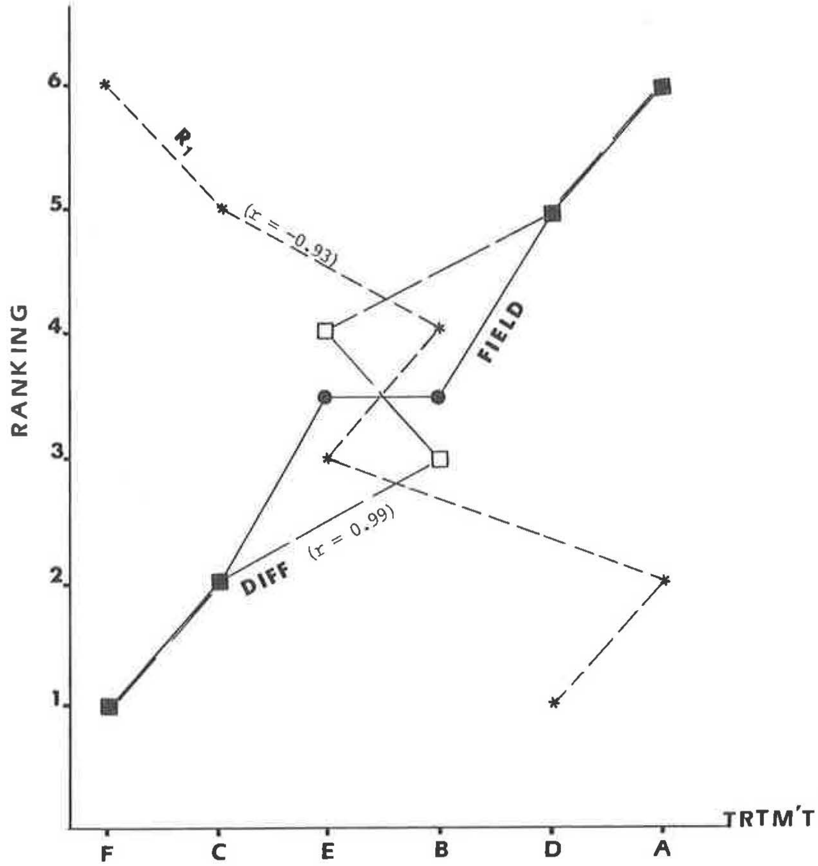

FIGURE 5 Ranking of various treatments for the 5-hr curing time.

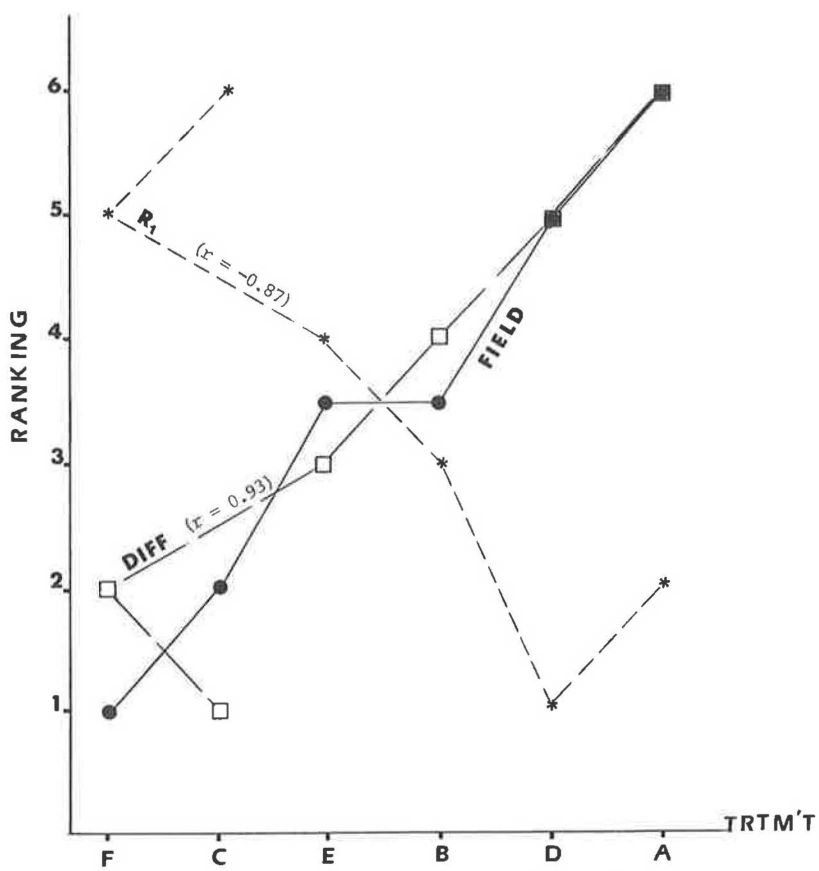

FIGURE 6 Ranking of various treatments for the 24-hr curing time.

treatment. The second parameter was the additional loss of chips caused by impact force (Diff = $R_1 - R_2$). Coefficients for this parameter were positive, which meant that the fewer the losses, the better the performance of the same treatment in the field. Correlation coefficients for both parameters ranged between 0.87 and 0.99 with a confidence level between 97 and 99 percent.

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