Chip Seals for High Traffic Pavements

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Chip seals have been successfully used on highways with traffic volumes in excess of 5,000 vehicles per day. The performance life of those chip seals averages 6 to 7 years, with some applications lasting much longer. Unfortunately, a significant number of chip seals have not performed adequately. Some agencies refuse to use this potentially cost effective approach to pavement rehabilitation and maintenance as a consequence. By developing a more fundamental understanding of the causes of chip seal failures on high traffic volume facilities, improved design methods, construction materials and methods, equipment, and specifications can be developed. These improved procedures will form the basis of implementation packages that will encourage state highway administrations and other public agencies to utilize chip seals on high-volume pavements. Reasons for chip seal failure on high traffic volume facilities and methods that have been used to overcome these difficulties are described. In addition, methods are described for predicting potential adhesive qualities of chip seal binders by using a modification of the Vialit procedure. Also, techniques are described for producing pressure distributor nozzles that can be effectively calibrated, resulting in known binder distribution transverse to the centerline. These nozzles, which have been used on one experimental project, were produced to provide higher binder volume outside the wheelpaths.

Chip seal coats are used to extend pavement service life by reducing water and air infiltration and improving frictional characteristics. Application of chip seals is usually limited to low traffic volume facilities. Reasons for this are several:

- Unknown cost effectiveness,
- Vehicle damage by flying stones,
- Poor performance because of inattention to proper principles, and
- Traffic disruption during construction.

If chip seal coats were suitable for use on roadways with high traffic volumes (20,000 vehicles per day on four-lane facilities), their use would increase. Postponement of overlays on these facilities by use of chip seal coats would represent a great cost advantage.

The causes of the problems that discourage use of chip seal coats on high traffic volume pavements and methods to overcome these will be discussed so that wider use of this potentially cost effective construction process may be further developed.

OBJECTIVE

The objective of this paper is to describe problems associated with applying chip seal coats to high-traffic-volume asphalt concrete pavements and potential systems for solving these problems. To accomplish this objective, this paper has been divided into three parts as follows:

- Problems and Suggested Solutions,
- Desirable Equipment, and
- Alternative Techniques.

Facilities with traffic in excess of 7,500 vehicles per day in one direction on four lanes will be considered as high traffic for purposes of this paper.

PROBLEMS AND SUGGESTED SOLUTIONS

Chip seals are not used frequently in the United States and Canada on high traffic volume facilities. In fact, the author has determined in a recent survey that use of chip seals on high traffic facilities appears to be practiced in only 10 of the 50 states and 5 Canadian provinces. Some of the reasons for lack of use are: (a) vehicular damage, (b) short-term aggregate loss, (c) short life expectancy (long-term aggregate loss), (d) tire noise, and (e) prolonged traffic control.

These reasons, however, seem to disappear in areas of the country where chip seals are used effectively on high traffic volume facilities. Many of the apparent obstacles are interrelated and, therefore, some redundancy is unavoidable during this discussion.

Vehicular Damage

The most significant impediment to construction of chip seals on high traffic volume facilities is the potential liability due to stone damage. This damage occurs primarily to windshields, headlights, and radiators, but claims are reported for paint damage as well.

Procedures that can be followed to limit or eliminate this difficulty have been followed by several states with success.

There are two major reasons why this type of damage occurs: loose or excess chips and limited traffic control.

Problem 1: Loose or Excess Chips

The most common deviation from proper practice during chip seal construction appears to be application of excessive chip quantities. There is a tendency to apply excess chips to avoid chips being picked up or tracked by rollers. In doing so, materials are wasted, and excess chips may be thrown by rapidly moving traffic. An incorrect assumption often made regarding application of excess chips is that excess chips can simply be swept off the surface, leaving the correct application

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quantity in place. However, when this practice is exercised at least two major forms of distress result: vehicular distress, as discussed, and pavement distress.

The second form of distress occurs when more than one aggregate thickness is present and additional chips on the surface are pushed into those below. This action causes dislodgement of the first layer, causing loss of aggregate and changes in grading. Crushing of aggregate can also occur and be offset somewhat by hard, durable particles, but dislodgement still occurs, creating early aggregate loss and the potential for flushing.

Alternative Solution: One-Aggregate Thickness The obvious solution to this problem is to reduce aggregate quantities to a level that produces a layer one aggregate thick. However, there is reluctance on the part of many field personnel to do this because of the risk of roller pick up. In many cases, the only way to assure proper chip quantities is to recognize what the chip seal should look like immediately after chip application and before rolling. Many have described the appearance as being somewhat low on aggregate, with some holidays in the surface. These holidays, where some asphalt shows through, will be filled in after rolling when aggregates are reoriented.

Alternative Solution: "Choke" Stone Choke stone is a second application of stone to a single application chip seal. Sometimes called a double aggregate seal, or armor coat, the second application of aggregate is usually smaller than the first aggregate layer. The first layer of aggregate is applied at a rate somewhat lower than a conventional single application chip seal. This results in a first layer with more voids or holidays in the surface than would normally occur for a single seal. The intent of the second application of aggregate is to fill in these voids in the surface. These smaller, second application aggregates become lodged between the first stone layer, and locking or choking occurs. This choke stone prevents the larger first layer aggregates from rocking, or rolling over, which could lead to disembedment.

Alternative Solution: Double Application Chip Seal A double application chip seal is similar to a single with choke stone application, but the first stone layer is applied so that few, if any, voids are present; and the second layer, often a smaller size, is applied by using a second application of binder. Because the second aggregate application often consists of smaller stone and fills the rough surface texture created by the first stone layer, there is less tendency for the second application of stone to become dislodged. This second layer, technically, creates a "choke" for the first layer as well, and, therefore, there is little chance of the first application becoming dislodged.

Alternative Solution: Sweeping Sweeping is often desirable after rolling to remove any loose chips. Theoretically, sweeping should not be necessary if the aggregate and binder rates are correct. But field adjustment of these quantities is often not as precise as it could be, and sweeping becomes necessary before traffic is allowed. However, sweeping of an emulsified asphalt chip seal too early in the life of the seal can cause chips to be dislodged and must be accomplished with care or the sweeping will be counterproductive.

Alternative Solution: Traffic Control Allowing slow moving traffic on a new seal coat after final rolling and sweeping is often one of the best means to reduce chip loss. Slowly moving vehicles seem to provide a level of chip orientation not achievable by conventional pneumatic rollers. The only method that assures the traffic will move slowly, however, is to use pilot vehicles. This process may be required for several hours after construction, especially for emulsion binders, depending on weather conditions. This practice is often not followed because of the inconvenience to motorists on high-volume facilities. To avoid this problem, some agencies have tried chip seal operations on high-volume facilities at night. This, in turn, creates an additional problem: when emulsions are used, breaking time is greatly increased, which increases the time before traffic can be allowed.

Alternative Solution: Reduce Aggregate Size Many agencies have begun to limit the maximum size of chips to ⅜ in. Although the maximum amount of binder available for sealing purposes is reduced by this practice, the potential for vehicular damage is concurrently reduced, producing very acceptable short-term cost effectiveness for many agencies.

Alternative Solution: Lightweight Aggregate Lightweight aggregates from synthetic or natural sources offer significant insurance against vehicular damage. These materials are typically one-third to one-half the specific gravity of conventional mineral aggregates and, therefore, have less ability to damage vehicles. Disadvantages include selective availability and higher asphalt demand. However, a modified version of the Kearby chip seal design procedure adopted by the state of Texas accounts for differences in binder demand when using lightweight aggregates.

Problem 2: Limited Traffic Control

In the presence of inadequate traffic control, chip loss will occur even when proper quantities have been applied. This is especially true for chip seals constructed with unmodified, emulsified binders.

Alternative Solution: Increase Traffic Control The obvious solution to this problem is to provide adequate traffic control. Posted low speed limits, generally, are not an effective means to accomplish this task. Instead, pilot vehicles are required.

Because of the beneficial effects that slow moving traffic can have on a new chip seal, pilot vehicles may be one of the most significant factors in assuring success on high-volume facilities. For this reason, traffic control is one of the variables studied in the full-scale evaluation of chip seal performance in this research.

However, it is understood that pilot vehicles are not always practical. Therefore, other solutions may be effective in reducing early chip loss due to a lack of traffic control.

Alternative Solution: Modified Binders This research effort does not advocate use of modified binders in place of proper traffic control. However, experience indicates that certain modifiers possess improved adhesive properties and, if properly applied, can significantly improve chances for success when pilot vehicles are absent or used to a limited extent.

Alternative Solution: Hot Asphalt Cement Binders Certain areas of the country apply chip seals using hot-applied penetration or viscosity graded asphalt cements. Success of these systems depends to a large extent on weather conditions, aggregate quality, and the proximity of the aggregate spreader to the asphalt distributor. In warm weather, however, with precoated aggregate applied immediately after binder application, these chip seals provide one of the best alternatives to lack of traffic control. Special equipment and contractors familiar with hot-applied chip seals are absolutely necessary to achieve success. In addition, construction in cooler climates is usually not recommended because of loss of adhesion and cohesion of asphalt cement binders to aggregates during cold temperatures.

Alternative Solution: Hot Asphalt-Rubber Binders A variation of the method described is the use of asphalt cement binders modified with ground tire rubber, which is called asphalt-rubber. These systems may provide the highest quality chip seal available to date. The application temperatures are usually 375°F, chips should be precoated to eliminate any dust, and chips must be embedded immediately after binder application. Experience indicates that asphalt-rubber binders can be used effectively to reduce the hazard of flying chips even with limited traffic control.

Certain disadvantages are associated with hot asphalt cement and asphalt-rubber seals, however. Because of the highly specialized nature of the construction, only select contractors have the ability to skillfully build them. Therefore, availability is usually limited to out-of-state contractors. In addition, the initial cost is high, approaching that of an asphalt concrete overlay.

Short-Term Aggregate Loss

This impediment refers to chip loss within hours or days after construction. Short-term aggregate loss is usually related to vehicular damage and, of course, is also associated with pavement distress. Some of the causes for short-term aggregate loss have been discussed and relate to excessive chip quantities and inadequate traffic control. However, if the loss occurs over a period of days, or perhaps weeks, the causes may be due to other sources. There are several causes for this type of chip loss.

Problem 1: Inadequate Binder Quantity

If the binder quantity is too low, aggregate embedment in the binder will be inadequate. Therefore, aggregate loss will occur over a wide range of times related to the optimum binder rate.

Alternative Solution: Adjust Design/Shot Rate in Field Often, the binder quantity recommended by design requires adjustment in the field. This adjustment may require estimation of new quantities based on visual observation. However, measurements of approximate chip embedment can be made in the field, and adjustments should be made if initial embedment is below desired levels.

Problem 2: Binder Too Cold

Asphalt cement binders used for chip seal construction are capable of producing the best chip seal performance available. However, chips must be applied to the binder while it is hot and viscosity is low or proper coating of the chips will not occur, and a lack of adhesion will result. The rate at which chips become dislodged is related to how cold the binder was during construction. Heated, precoated, or heated and precoated chips help alleviate this problem by providing the contractor more allowable time to embed chips.

Alternative Solution: Raise Asphalt Temperature This problem can be solved by two methods. If the binder temperature is already adequate, then chip loss may be related to rapid cooling of the binder upon application. If chips are placed in the binder after it becomes too viscous, improper adhesion will result upon cooling. Therefore, the chip spreader must be within proximity of the asphalt distributor when the chips are applied. In some cases, this may represent a maximum of 6 to 10 ft.

Problem 3: Substrate Too Cold

Primarily related to emulsified binders, if the existing pavement to be sealed is too cold, then proper adhesion of the emulsion to the existing pavement will not occur.

Alternative Solution: Wait For Proper Temperature In most cases, the *minimum* temperature for the substrate pavement prior to emulsion application is 50°F. Optimum temperature may be somewhat higher.

Problem 4: Cool or Cold Weather Immediately After Construction

Much early chip loss is associated with construction during the late fall season. Temperatures of the pavement and air can be adequate, even optimum during construction. However, when nighttime temperatures drop below optimum conditions, proper curing of the binder may not have occurred to the point where adequate tensile strength is developed. If traffic is allowed without pilot vehicles, then the result will be early chip loss.

Alternative Solution: Wait For Proper Conditions This may seem like a simple solution, but it may be very undesirable or even unacceptable. Often chip seals are programmed late in the year to provide waterproofing prior to winter. Application of the seal may provide added pavement life if successful construction can be accomplished. Therefore, if construction must take place, then the special procedures outlined earlier will be necessary to assure that early chip loss is minimized.

Alternative Solution: Increase Initial Chip Embedment If cool or cold weather is anticipated after construction, then a slightly higher binder application rate may be used to provide higher initial aggregate embedment. Care must be taken to avoid too high an application rate, however, to prevent flushing distress from occurring during subsequent hot seasons.

Alternative Solution: Fog Seal If cool or cold weather was not anticipated after construction and a higher than usual binder application rate was not used during construction, a fog seal can be an effective means of retaining aggregate in the short term.

Techniques for Predicting Short-Term Aggregate Loss

Early chip retention may be the most important criterion for establishing the success or failure of a chip seal on high-traffic pavements. This criteria is directly related to level of inconvenience forced on motorists. This inconvenience can be measured by vehicular damage, construction delays, and detours. A laboratory test that could identify the length of time required before traffic could be allowed to return to the chip seal would be a useful tool.

Vialit Test

Attempts to measure early adhesive strength of chip seal binders has been done by using variations of the French Vialit test. Unfortunately, variability of the test can be very high. It appears that reasons for this variability are related to the use of actual project aggregate in the test. Therefore, a modification of the Vialit test as devised by Brossel is under development to eliminate some of the repeatability problems experienced when natural mineral aggregates are used as the adherent.

Modified Vialit Test

Glass marbles were acquired as a substitute for the mineral aggegates in the Vialit test. The marbles consist of high sodium content glass spheres that pass the ⅝ in. sieve and are retained on the ½ in. sieve.

A rough surface texture was generated by sandblasting each of the marbles to create a more representative "aggregate" surface for bonding to the emulsion. A flat area was then ground on each marble approximately 7/16 in. in diameter to create a better surface for bonding to the emulsion.

The Vialit test was then conducted by using the new aggregates for each of the emulsions used in the field. Certain variations of the test procedure include placing a 3,800 g constant weight on the marbles for embedment for 30 sec instead of using the steel roller, curing the emulsion on the impact plate at 140°F with the 100 marbles in place, and removing the plate from the oven for 5 min and testing. Each of the marbles used in the test was weighed and numbered prior to testing. The average weight of the test marbles was 2.91 g with a standard deviation of 0.27 g. Therefore, the average weight ranges between 2.86 and 2.96 g with 95 percent confidence.

The results by using this modified Vialit test procedure for three emulsions is shown in Table 1 and Figure 1. These results are for emulsion evaluated after various periods of oven curing at 140°F with 5 min at room temperature (74°F) prior to testing.

The average weight loss of marbles is presented in Table 1. These results are more consistent than those obtained from field tests, as might be expected, but are not as consistent as originally hoped.

The increase in adhesion loss with time observed in the field for the HFRS-2(P4) was apparently reversed in the laboratory, the material developing more adhesion with time than either the HFE-90 or 100S. This may indicate the initial 10 min curing period at 140°F used in the laboratory provides more curing than the 75 min period at 84°F used in the field. To help explain these differences, a preliminary correlation between field and laboratory results has been prepared in Figure 2 by superimposing laboratory results on those from the field. The correlation was approximated by using the HFE-100S test results, which appear to show the most consistent trend of the three materials tested.

Results from Figure 2 indicate the laboratory test, where curing is by forced draft oven at 140°F, causes curing at a much higher rate than the field, as would be expected. The approximate equivalent adhesion between field and laboratory begins at approximately 110 to 115 min (field) compared

TABLE 1 AVERAGE WEIGHT LOSS OF MARBLES

Matrl	Cure, min	Wt. Loss, %	Average Wt Loss, %	s, %
HFE-90	10	8.0		
		8.4	8.2	0.27
	15	28.9		
		32.8	30.9	2.76
	25	8.0		
		21.0	14.5	9.19
HFE-100S	10	25.6		
		32.3	29.0	4.74
	15	19.9		
		30.0	25.0	7.14
	25	9.0		
		11.0	10.0	1.41
HFRS-2P(4)	10	14.0		
		13.0	13.5	0.71
	15	9.0		
		16.9	13.0	5.59
	25	4.0		
		6.0	5.0	1.41

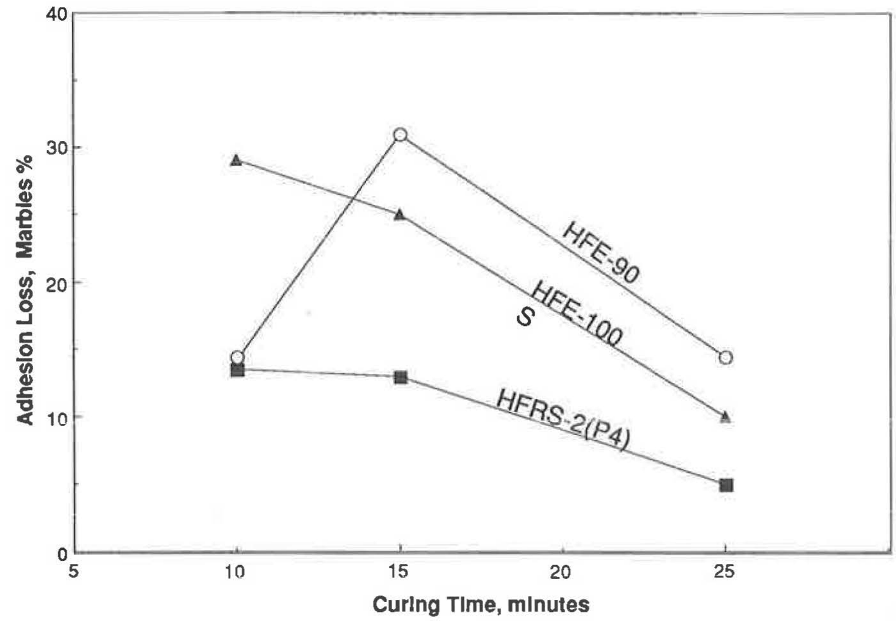

FIGURE 1 Results of modified Vialit (marbles) test in laboratory.

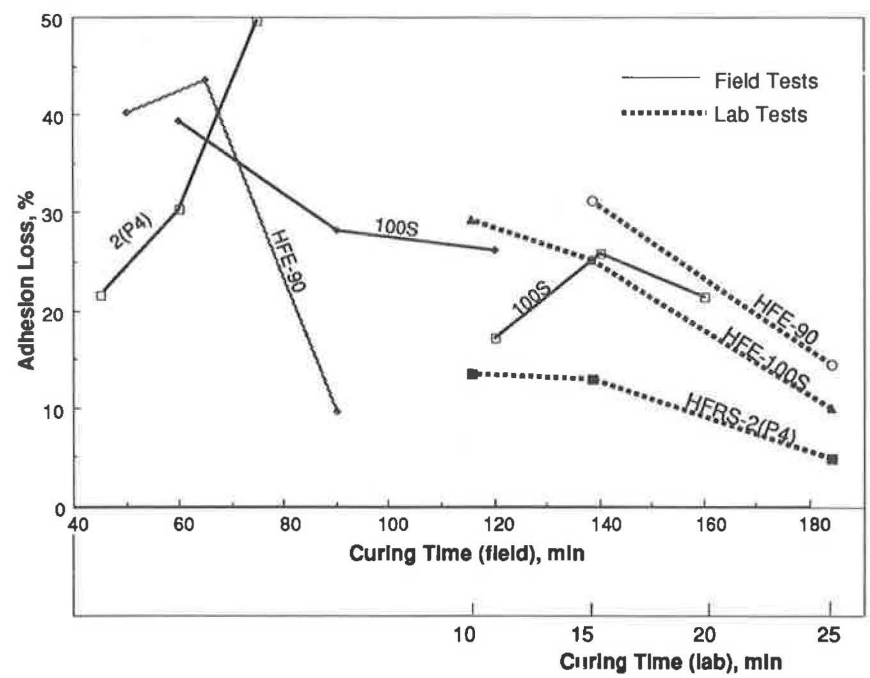

FIGURE 2 Preliminary correlation between Vialit field and lab results.

with 10 min (laboratory) and continues to approximately 160 min in the field compared with 20 min in the laboratory. Correlations for the HFE-90 and HFRS-2(P4) are not very encouraging from these limited data, but additional work could prove that better relationships are possible.

Short Life Expectancy (Long-Term Effective Aggregate Loss)

One of the reasons for avoiding use of chip seals on high traffic volume pavements is related to the short life expectancy of the application. Expected chip seal life varies depending on conditions, but a recent survey of practitioners around the country indicates that 5 to 7 years should be the possible goal. This goal may not be possible with current chip seal practice, especially if proper construction techniques are not followed. However, use of special binders has reduced the chances of long-term failure, and certain new concepts in chip seal practice may provide additional help in this area. Some of the reasons for loss of effective aggregate are discussed next with some of the possible methods available for solving short life expectancy.

Problem 5: Loss of Binder Adhesion or Cohesion

Chip loss that occurs over a period of several years can be attributed to a loss of adhesion between the asphalt binder and the aggregate and to decreased cohesion within the binder. This loss of adhesion and cohesion is associated with at least three factors:

- Increased brittleness of asphalt due to oxidative hardening,
- Decreased resilience of binder, and
- Stripping.

As the asphalt film hardens due to oxidation, strain energy required to cause failure decreases. Therefore, smaller movements of the aggregate owing to traffic may result in fracture of the asphalt film surrounding aggregate particles and a resulting loss of chips.

As the level of strain required to cause fracture of the binder film decreases so does the chance that aggregate particles will be removed by the action of traffic. Therefore, increases in failure strain should improve chip retention. However, these increases in strain should be accompanied by increases in strength as well so that large displacements in the aggregate do not occur.

Stripping may occur early in the life of the chip seal or over many years during service. Obviously, if the asphalt film is displaced by water, then a loss of aggregate will be the result.

Alternative Solution: Reduce Asphalt Hardening Work done by Dickinson (*1*) to document the hardening of binders in service and Oliver (*2*) indicates that asphalt hardening can be attributed to chip seal distress. Certain antioxidative additives are available which can significantly reduce the changes occurring to asphalt due to oxidation. Additional work by Oliver (*3*) indicates that oxidation can be slowed significantly by use of LDADC-type antioxidant additives. Research in the United States has just begun to look at antioxidative additives in chip seal binders, but the promise of better adhesion at relatively low initial cost should interest agencies building chip seals on high as well as low-volume facilities.

Increased binder film thickness on aggregates also helps reduce long-term aging. Work by Traxler (*4*) indicates that oxidation occurs within the very upper portion of the surface film of asphalt. Therefore, thicker asphalt films are more resistant to this form of damage. However, if the film of asphalt is too thick, then other forms of distress may be manifested that are more serious than oxidative hardening. One method of achieving thick asphalt films on chip seal aggregates without necessarily causing flushing distress has been by the use of "high-float" emulsified asphalts (ASTM D977).

Alternative Solution: Improve Long-Term Resiliency of Binders The most popular method of improving the resiliency of asphalt binders has been by addition of various polymer modifiers. These additives have recently come into routine use in many parts of the country primarily because of their ability to allow early sweeping to reduce traffic control and to allow traffic earlier than most conventional binders. Although most agencies cite early life performance as the chief reason for using polymer modified binders, evidence is beginning to be collected that suggests long-term benefits as well. Little objective research has been done regarding the long-term resiliency of polymer modified binders. Although most of these modified materials demonstrate dramatic increases in resiliency during early life, little is known about the effects of oxidative hardening, ultraviolet radiation, or other environmental effects during their long-term use.

Alternative Solution: Reduce Water Susceptibility Stripping has been studied as a major failure mechanism in asphalt concrete for many years. However, this same mechanism persists for chip seal construction as well. Reduction of water sensitivity has traditionally been achieved by adding liquid antistripping agents to asphalts and hydrated lime to aggregates. However, chip seal practice precludes the use of lime. Therefore, liquid agents added to cements prior to emulsification has been the means of reducing water susceptibility. Recently, however, laboratory evidence suggests that certain polymer modified asphalts are effective in reducing stripping. Although not intended as simply antistripping agents, these materials may offer more than one benefit when used for chip seal construction.

Problem 6: Submergence of Chips in Substrate Pavement

Loss of effective aggregate can mean that aggregate has become submerged in a soft substrate pavement surface and is no longer available to provide frictional resistance. This situation is generally worse than loss of effective aggregate due to ejection by mechanisms just described because methods to prevent this distress mode are costlier and reasons for application of these methods may not be obvious prior to construction.

Alternative Solution: Removal of Soft Substrate Layer If a highly flushed or soft surface layer is present prior to construction, then it should be removed by milling or other suitable technique until a hard surface is available to place the chip seal.

Alternative Solution: Light Binder Application Rate Without removing the soft surface layer, success of other alternatives is questionable. However, if removal is not feasible, then binder application at a lighter rate than would be used on a hard substrate can result in an adequate alternative. Care must be taken to keep traffic off as long as possible to avoid early chip loss.

Tire Noise

One objective of chip seal construction is improved friction characteristics. However, if improved friction is achieved by using larger aggregates in chip seals, the result often generates complaints from motorists. One reason open-graded friction course applications have become popular with motorists, and

often are used as an alternative to chip seals, is because noise levels are lower.

Problem 7: Large One-Sized Aggregate

The best chip seals are effective as sealing mechanisms that also provide a high-friction riding surface. One of the best ways to achieve these two objectives is by using large, one-sized aggregates, generally of ½ in. or greater dimension. Larger aggregates require greater asphalt shot rates to bind the chips, producing more sealing capabilities while providing necessary friction. However, because of other constraints discussed earlier, these relatively large aggregates may not be desirable.

See the second, third, and sixth alternatives under Vehicular Damage. These alternatives relate to use of "choke" aggregate, double application seals, and smaller size aggregate. Each of these techniques will result in an effectively smaller aggregate coming into contact with vehicular tires. The result will be less tire noise. However, because choke stone and double seals can also result in a denser surface, care must be taken to provide aggregate with high microtexture so that frictional characteristics are not sacrificed.

Prolonged Traffic Control

Primarily a difficulty associated with emulsified asphalt binders, increased traffic control is often necessary until the emulsion has had time to "break" and develop tensile strength.

Alternative Solution: Avoid Construction During Hottest Part of Day Construction during very hot, sunny weather can cause certain emulsified asphalts to break at the surface, creating a "skin" of residue. This skin is highly impervious and consequently will not allow free evaporation of water within the emulsion. This causes the binder to remain tender for a period longer than would be expected on less warm or sunny days.

Alternative Solution: Polymer Modified Binders Many modified binders achieve a higher level of adhesion than corresponding conventional binders. Therefore, chip retention is better during the early life of the chip seal, and often the rigid levels of traffic control required for conventional chip seals are not as significant when polymer modified binders are used. However, high chip retention cannot be guaranteed for any type of binder. Therefore, wholesale elimination of traffic control requirements should not be expected.

DESIRABLE EQUIPMENT

Spray Nozzles

Special spray nozzles were fabricated by the research team for use during construction of experimental field test sections. Three sizes of nozzles were supplied for installation in the pressure distributors to be used. These were standard Rosco No. 2 nozzles and standard nozzles machined to provide 20 and 30 percent increase in volume. Machining was accomplished so spray width remained equal for all nozzles. These nozzles were placed in the spray bar so that the higher volume was applied outside and between the wheelpaths. Machining was accomplished in Brownwood, Texas, with the help of the Texas Highway Department. The Brownwood district provides nozzles of the type fabricated for this experiment to contractors during construction of chip seals and feels that this practice is largely responsible for the success of the chip seal program in this part of Texas. Details regarding the fabrication of the special nozzles are discussed in a recent paper by Martin (*5*). What follows is a summary of how the nozzles were fabricated for this study.

A group of Roscoe No. 2 nozzles was purchased as a set. The nozzles were grouped according to spray width and then checked for volume output by using the apparatus shown in Figure 3. Ten nozzles from the same spray width group were placed in the apparatus, and volume output was measured and averaged. A single nozzle was selected closest to the average volume output of the group of 10 nozzles and used as a reference nozzle. It was desired to create a set of 45 nozzles with known characteristics to produce a potential spraying capability of 15 ft. Each of 45 nozzles with the same spray width was then compared with the reference nozzle for volume output. Any nozzle deviating more than ±10 percent from the average volume of the 45 nozzles was discarded. After the set of 45 nozzles with equal spray volume was obtained, 25 of this group were selected for volume modification.

These modified nozzles would be placed in the spray bar for use outside the wheelpath areas. Nozzle modification must be done so that a spray volume increase occurs without a change in spray width. This is done by cutting the vee-shaped groove in the nozzle deeper. This process must be done by trial and error until the amount of cutting can be related to the change in volume output of the nozzle.

The volume output of water was compared for each nozzle in the manner described to verify that the machined nozzles produced 20 to 30 percent more output than the standard nozzles. Results of this laboratory evaluation were used to determine which nozzles provided accurate enough volume output for use in field tests. Results of this analysis are shown in Figure 4.

Uniformity of spray width was measured for each nozzle. This information is important so that difficulties such as

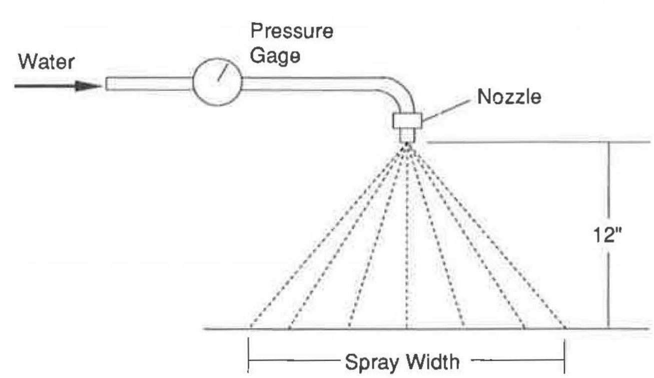

FIGURE 3 Spray nozzle calibration apparatus.

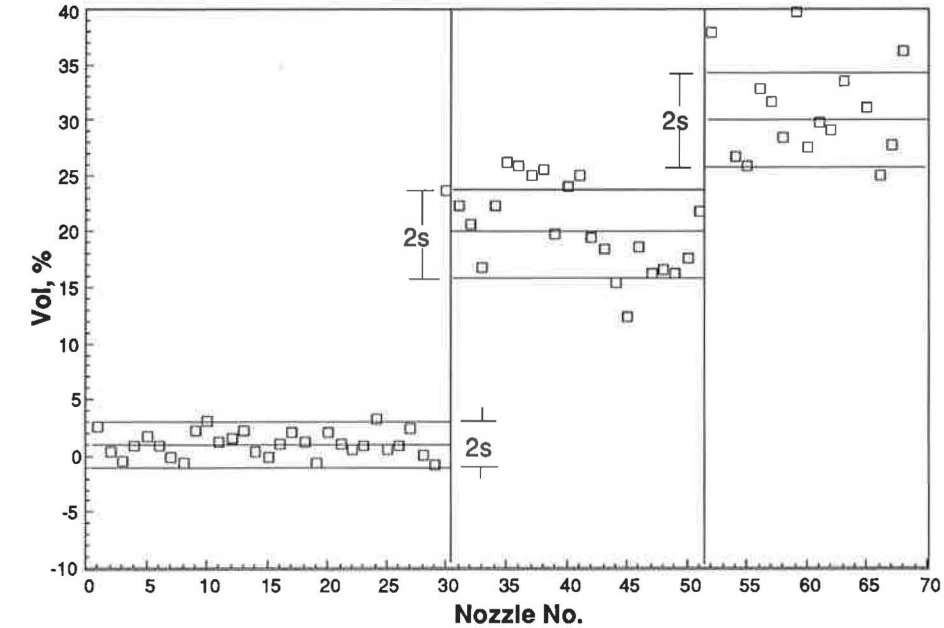

FIGURE 4 Variation in water volume from nozzles.

streaking or drilling during spray application are reduced. Also, the spray width obtained during calibration can be used to determine correct spray bar height in the field. Spray bar height should be adjusted to produce a minimum of three overlaps from adjacent nozzles.

The equation for determining spray bar height based on laboratory calibration is as follows:

$$H_q = \frac{q \cdot C \cdot N}{W \cos \theta}$$

where

H_q = spray bar height for q overlaps (in.),
C = nozzle calibration height (in.),
N = nozzle spacing in distributor (in.),
W = spray width during calibration (in.), and
θ = nozzle angle in distributor.

This relationship has been used to generate a convenient graph for checking spray bar height given various calibration spray widths, desired overlaps, and two nozzle angles as shown in Figure 5.

The calibration procedure used to derive the relationship for spray bar height and generate Figure 5 is based on laboratory calibration using water as the spray medium. Water should be less viscous than asphalt materials used in chip seal

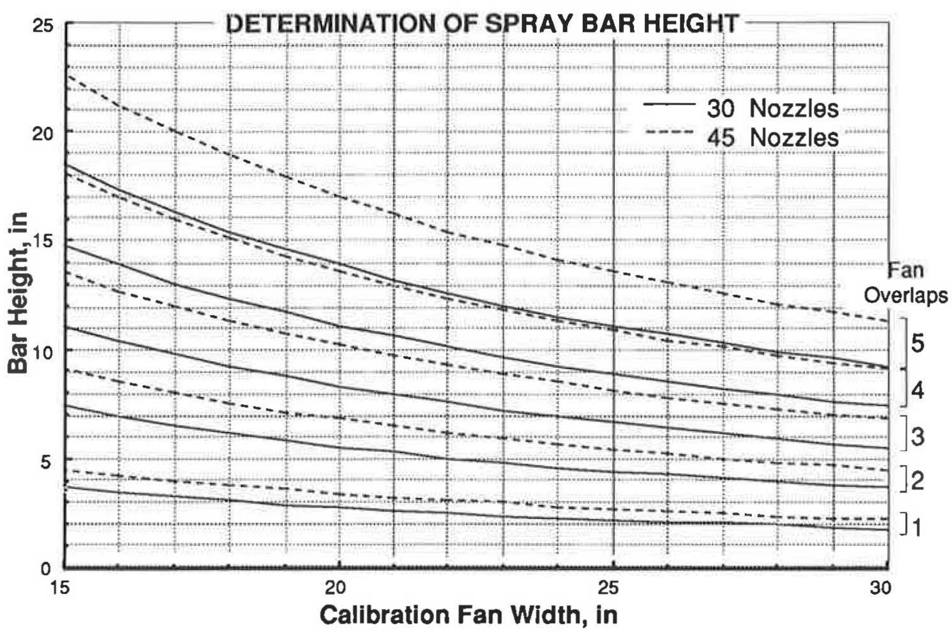

FIGURE 5 Distributor spray bar heignt determination.

construction. This may affect volumetric output of the nozzles but has little, if any, effect on spray width.

The nozzles were positioned in the spray bar of the pressure distributor so that the 20 and 30 percent oversize nozzles were located in areas outside the wheelpaths of the pavement lane to be sprayed. Distribution of traffic across a typical two-lane pavement has been measured, and these data were used to determine positioning of the special oversize nozzles in the spray bar. The distribution of traffic and the corresponding nozzle positions are shown in Figure 6.

The spray bar was positioned at a height to produce three overlaps of the spray pattern as shown in Figure 6. Because of the overlapping pattern a transition between 20 and 30 percent oversize and standard nozzles occurs in conjunction with the transition of traffic within the lane.

Pressure Distributor Output

The pressure distributor was calibrated prior to construction to determine volumetric output of asphalt from each of the spray bar nozzles. Nozzles were selected for use in the distributors based on volumetric accuracy as discussed earlier.

Determination of asphalt volume output from each spray nozzle for each pressure distributor was as follows: sample containers were placed under each spray nozzle to collect asphalt during discharge from the spray bar. Asphalt was sprayed into the containers, and each was weighed. Results of this testing are shown in Figure 7.

According to District 23 Texas Highway Department personnel, variation in volume of ±10 percent from the target volume desired for each nozzle group is satisfactory to achieve desired results. Results of testing shown in Figure 7 indicate this variation was exceeded for two nozzles on the left and one nozzle on the right side of the bar. However, it was believed that upon heating the bar during spray operations these nozzles would be within the tolerances suggested. Note the trend to lower volume output in the nozzles located at the edges of the bar.

Aggregate Spreader Adjustment

Two weeks prior to construction of the test sections, the aggregate spreader was inspected and adjusted for lateral spread uniformity. This operation consisted of accompanying the maintenance personnel during routine chip seal construction and observing the appearance of the chips after spreading. Adjustments were made to gate openings on the spreader until a uniform appearance was achieved laterally across the pavement. After construction was completed and spread uniformity had been accomplished, the spreader was parked until it was needed for construction of the test sections.

ALTERNATIVE TECHNIQUES

The difficulties discussed for constructing chip seals on high-traffic volume pavements can be remedied by various means. Some conventional techniques that have been used successfully in the past have been discussed. However, the high demand placed on chip seals by high-traffic volumes, which often include high truck traffic, and high speeds may require extraordinary measures to assure success.

Two new techniques have recently been tried on an experimental basis by various highway agencies. A brief description of each is now presented.

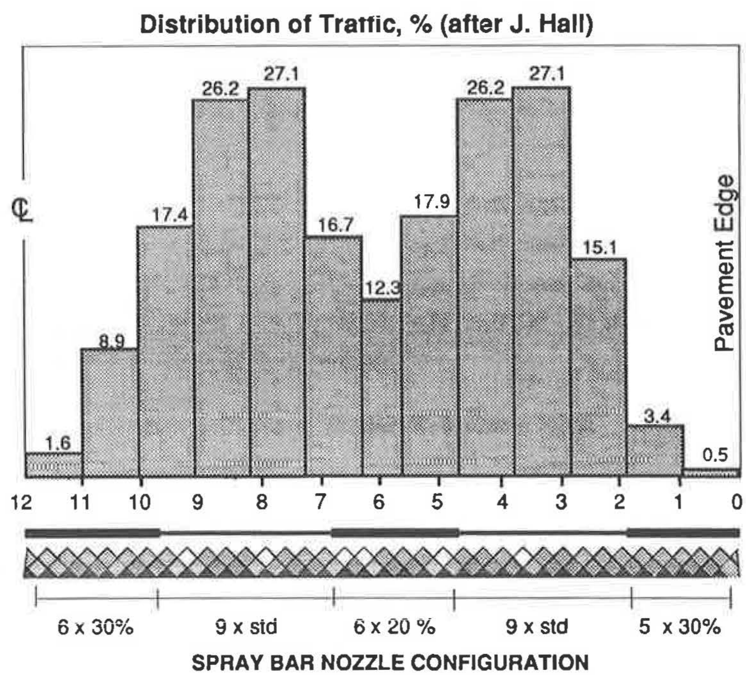

FIGURE 6 Spray bar nozzle positions in full-scale field test.

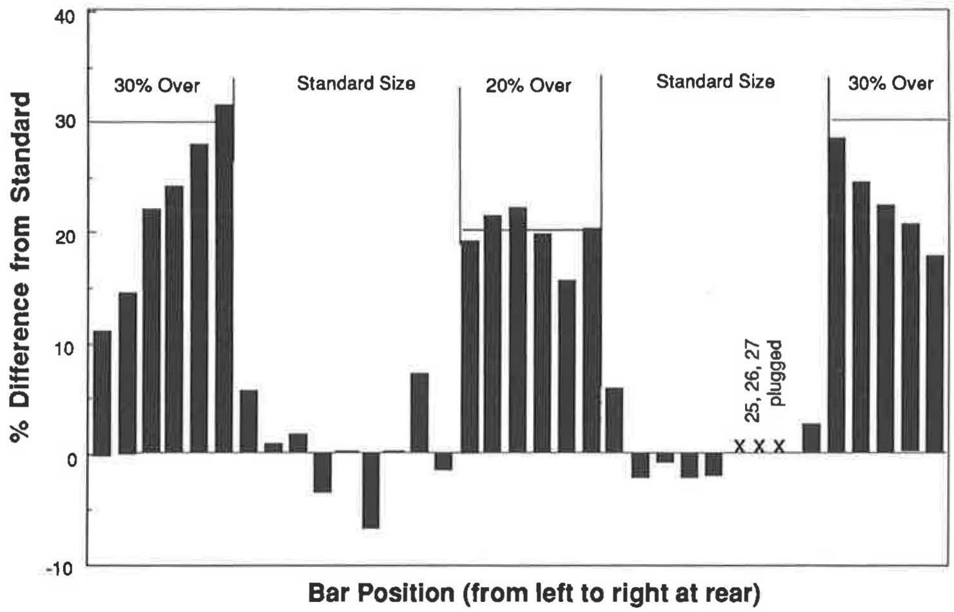

FIGURE 7 Asphalt output from pressure distributor.

Sandwich Seal (French Dressing)

The sandwich seal or "French Dressing" is a double application chip seal constructed by using only one application of asphalt binder. The process that has been recently introduced by the French Highway Department (LCPC) was developed as a means of sealing high traffic pavements and flushed pavements. In summary, the process involves the following steps:

1. Apply first application of chips to clean, dry pavement surface.
Materials: One-sized (3/8 to 1/4 in.) washed chips.
Rate: Determine application rate to provide coverage at one stone thickness. Use method described by Epps, et al. (*6*). Reduce actual spread rate to approximately 80 percent of this amount.
2. Roll chips with lightweight steel-wheel roller. (The recommended procedure includes use of a lightweight steel roller to "seat" the first chip application. However, the author is not convinced this step is necessary or desirable.)
3. Determine emulsion application rate in accordance with traffic, surface conditions, climate, and so forth, for conventional single course treatment. Apply from 1.2 to 1.5 times this amount as the target application rate. This rate may require adjustment after the second course of chips is applied.
4. Apply second course of chips to emulsion.
Materials: One-sized (1/4 to 1/8 in) washed chips.
Rate: Determine application rate to provide coverage at one stone thickness by using previous method described.
5. Slow moving pneumatic rollers should be applied to second chip application as soon as the surface will allow.

A sandwich seal was constructed as part of a larger experiment on US 169 in Tulsa, Oklahoma, during early winter 1989 by using the just described technique. Although the application was generally successful, setting time for the emulsion was significantly higher than for conventional double application chip seals placed at the same time. In addition, the first application of aggregate was somewhat higher than optimum at the beginning of the application. This resulted in the emulsion's coating the aggregates and not penetrating and adhering to the substrate pavement as desired. The result was a layer of chips that could be easily removed from the pavement surface.

Chemical Breaking Agents

Two of the major problems with construction of chip seals on high traffic volume pavements involve the potential for vehicular damage and prolonged traffic control. Therefore, when emulsion binders are used an advantage could be gained if the time required for the emulsion to break could be reduced, thereby reducing the time required for traffic control. In addition, if the break time could be accelerated, then the tensile strength of the binder would be increased sooner, providing less potential for chips to become dislodged.

The concept involves spraying a light application (0.05 to 0.10 g/yd^2) of a chemical breaking agent on the chip seal to promote early setting. Three application methods were used:

1. Spraying the chip seal after chips had been applied but before rolling,
2. Spraying the chips after rolling, and
3. Spraying the pavement *before* emulsion, chips, and rolling.

Results of this preliminary technique were favorable. Application Methods 1 and 2 appeared to cause "skinning" of the emulsion and a less rapid break. However, Method 3 worked to cause a more rapid break and equal to better chip retention than the control section. No loss of adhesion to the substrate

pavement was observed, as might have been expected. A secondary benefit of the treatment was a lack of dust during or after sweeping or after opening to traffic.

CONCLUSIONS

- Chip seal construction on high traffic volume pavements is avoided by most state highway departments in the United States.
- The major reasons for avoiding this construction technique are (a) vehicular damage, (b) short-term aggregate loss, (c) short life expectancy, (d) tire noise, and (e) prolonged traffic control.
- Construction procedures exist that can produce successful chip seals on high traffic volume pavements.
- Besides conventional techniques that can be used, two new techniques have demonstrated promise for use in high traffic volume chip seals. These include emulsion breaking agents and the sandwich seal treatment.

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