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Nataraj V. Banihatti, Miller C. Ford, Jr.

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Miller C. Ford, Jr., PhD, PE

Nataraj V. Banihatti, MSCE

Arkansas State Highway and Transportation Research Center
Department of Civil Engineering
University of Arkansas
Fayetteville, Arkansas 72701

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by

Nataraj V. Banihatti, MSCE
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CONDUCTED BY

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16. Abstract

This report on design of asphalt chip seals is based on testing of the in-place seal coat and its emulsion and aggregate components. The samples were obtained from four seal coat projects constructed by the AHTD district maintenance sealing crews during the 1990 and 1991 sealing season. The seal coat test sections studied were constructed using CRS-2, CRS-2P and CRS-2L asphalt emulsions. The performance or relative durability of each seal coat test section was determined by use of an accelerated wear track and field condition ratings. Seal coats constructed with CRS-2P and CRS-2L emulsion performed better than CRS-2 jobs. The chip seals constructed with Class 1 (-3/4") or Class 2 (-1/2") aggregate performed better than did the chip seals constructed using Class 3 (-3/8") aggregate. Also, chip seal samples taken from projects constructed using pneumatic and steel wheel rollers indicated greater durability than samples taken from projects using only a pneumatic roller.

Based upon the continuing investigation of the 1981 chip seal sections of TRC-65, a fairly good relationship between the accelerated wear track results and chip seal service was determined by regression analysis.

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ABSTRACT

This report on design of asphalt chip seals is based on testing of the inplace seal coat and its emulsion and aggregate components. The samples were obtained from four seal coat projects constructed by the Arkansas State Highway and Transportation Department District maintenance sealing crews during the 1990 and 1991 construction season. The seal coat test sections studied were constructed using CRS-2, CRS-2P and CRS-2L asphalt emulsion. The mineral aggregate used in the seal coats represented two types and three sizes of aggregates available for seal construction in Arkansas. The performance or relative durability of each seal coat test section sample was determined by use of an accelerated wear device and field condition ratings. Seal coats constructed with CRS-2P and CRS-2L emulsion performed better than CRS-2 jobs. The seal coat projects constructed using Class 1 (minus 3/4") or Class 2 (minus 1/2") aggregate provided a more durable pavement surface than did the seal coat projects constructed using the Class 3 (minus 3/8") aggregate. Further, seal coat samples taken from projects constructed using pneumatic and steel wheel rollers indicated greater durability than samples taken from projects using only pneumatic rollers.

Based upon the continuing 1981 investigation (TRC-65), a fairly good relationship between the accelerated wear track results and seal coat service life was determined.

GAINS, FINDINGS, AND CONCLUSIONS

The circular wear track method of evaluating the performance of chip seals in the laboratory was confirmed. New types of binders and aggregates may be evaluated in the laboratory to determine their potential for use as chip seal materials.

The seal coat pavements constructed using Class 1 (minus 3/4") or Class 2 (minus 1/2") mineral aggregate provided a more durable laboratory sample than did the seal coat pavements constructed using Class 3 (minus 3/8") mineral aggregate. A fairly good correlation was established between chip seal service life and weight loss using the accelerated wear device test.

Chip seal samples had a greater resistance to wear when the aggregate was embedded in the pavement using steel wheel rollers in conjunction with pneumatic tire rollers in the construction process. The pavement sections constructed using both pneumatic and steel wheel rollers also indicated higher condition ratings than pavement sections constructed using only a pneumatic roller for compaction.

Field observations after about 1 year of service indicate that seal coat sections constructed with CRS 2P and CRS 2L emulsion were performing better than seal coat sections constructed with regular CRS 2 emulsion. No economic analysis to select the better of the CRS-2P, CRS-2L or CRS-2 emulsions may be performed until the service life of the test section's are determined.

IMPLEMENTATION STATEMENT

The results of this research work may be used to design longer lasting and more economical seal coat pavements. The SEALIT methodology presented may be used in evaluating the proper application rate of asphalt and aggregate in relation to the aggregate gradation, traffic and pavement conditions. A continued effort is needed to monitor the seal coat projects investigated in this research work to determine their relative performance and service life. At that time the most economical emulsion, either CRS-2, CRS-2P or CRS-2L, may be determined.

Steps should be taken in construction to insure the initial embedment of the mineral aggregates into the liquid asphalt. This embedment was accomplished by the Arkansas Highway and Transportation Department sealing crews by coordinating the speed of the distributor truck, chip spreader and rollers. The aggregate that was placed and rolled as soon as possible after the application of the emulsion provided the more durable seal coat samples. The use of pneumatic wheel rollers and steel wheel rollers with as high a contact pressure as the aggregate can withstand without crushing would contribute greatly to obtaining a good seal coat.

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CHAPTER I

INTRODUCTION

The use of polymer modified emulsions for the purpose of seal coat construction is gaining popularity because these binders have apparent good initial chip retention. However, the polymer modified emulsions are more expensive than the regular emulsions, and not enough research has been done to assess the cost-effectiveness of these binders.

Many state highway agencies have been facing problems in consistently obtaining good quality seal coats in spite of using the best materials. A good quality seal coat is expected to last about ten years. However, in many cases, seal coats have been known to fail within a couple of years after construction. Such failures have left the Highway personnel wondering where they went wrong. The quality and life of a seal coat depends upon various factors such as quality of materials used, quality of construction, the environment and traffic. However, a significant number of seal coat failures can be attributable to inferior construction practices. Nevertheless, there have been some concerns about the accuracy of design procedures used. The Arkansas State Highway and Transportation Department (AHTD) follows the Asphalt Institute's design procedure (1) using the average least dimension in their calculations. However, the seal coats thus designed are not performing as well as expected. Moreover, questions remain about the use of a somewhat different shot rate when polymer modified emulsions are used in construction. Hence, there was a need to assess the accuracy of the design procedures.

Research Objectives

The research project had four major objectives. Study the existing seal coat design procedures and recommend or develop a rational design procedure for the AHTD. Determine the actual performance of chip seals whose physical characteristics were evaluated under TRC-65. Evaluate the cost effectiveness of using polymer modified emulsions in seal coat construction in the Arkansas. This required the accelerated wear track testing in the laboratory of chip seal specimens of polymer modified emulsion and conventional CRS-2 seal coats. Develop an user-friendly computer program for the design procedure to be used.

Scheme of Study

The research project was commenced during Fall 1990. The following was the scheme of study. The literature review was an important part of the research. Special emphasis was given to literature on seal coats using polymer modified emulsions. Even though not much material was available on this topic, whatever was available was useful in comparing the various findings.

The seal coat samples were collected by and with the help of AHTD research personnel. The sampling and condition survey work was recorded on video for subsequent use in comparing chip seal performance during the life of the seal coat. Asphalt and aggregate samples were also collected from four different seal coat jobs. The samples included various combinations of aggregate and asphalt. All testing was performed at the asphalt laboratory located at the University of Arkansas Engineering Research Center. The seal coat samples were tested for durability on the accelerated wear track.

A relationship between chip seal durability in years with the results of the accelerated wear track was determined. Based on the findings of this and other research, a seal coat design procedure was recommended and the use of polymer modified emulsions was evaluated. A user friendly computer program was developed for the design procedure recommended which will make seal coat designing more efficient for the AHTD Design Engineer.

CHAPTER II

LITERATURE REVIEW

An asphalt seal coat is an application of asphalt followed with an aggregate cover. The cover aggregate is seated into the asphalt by rolling. The terms seal coat and surface treatment are sometimes used interchangeably; however, a surface treatment is usually applied over a base course or some specified material, sometimes in multiple layers, whereas a seal coat is applied over an existing asphalt surface in one application. Seal coating is constructed to produce an initial pavement or maintain an existing asphalt pavement. Seal coating improves the skid resistance, waterproofs the pavement surface, seals minor cracks, improves the appearance of the pavement, makes the surface dust free, protects the pavement from weathering, and thus indirectly helps in maintaining structural stability of the pavement (2).

Major factors which affect the performance of a seal coat are application rates, aggregate characteristics, emulsion characteristics, construction techniques, traffic and environment. The basic criteria for obtaining a good seal coat are to use the right kind of materials at correct application rates with proper construction techniques.

Many design methods give reasonably accurate application rates. However, the main idea behind all of these procedures is the same - to arrive at an asphalt emulsion shot rate which is sufficient to embed the aggregate layer to approximately 70 percent of its depth and to arrive at an aggregate spread rate which will form a single layer on the pavement surface with voids as minimum as possible (3).

Durability and Performance of Seal Coats

Factors Related to Binder

The life and performance of a seal coat depends on how well the binder holds the aggregate particles and adheres to the road surface. In other words, adhesion is the most important quality of the binder. Loss of cover aggregate, the degree of stone whip-off depends on the adhesion characteristics of the binder. The adhesion characteristics depend on the type, grade and the amount of binder applied. Three different kinds of binders are used for seal coat construction. They are asphalt cement, cutback asphalt and emulsified asphalt.

Asphalt cement is a pure form of asphalt without any chemicals added. Cutbacks are obtained by liquefying asphalt with petroleum solvents. Emulsified asphalt, which are commonly used for seal coats nowadays, are made by combining asphalt, water and an emulsifying agent. The kind of emulsifying agent determines whether the resulting asphalt emulsion is cationic or anionic. Different types of emulsions include cationic, anionic, and polymer or latex modified emulsions. A comparison of different asphalt product types is given in Table I (4,5).

Quantity. The quantity of binder applied plays an

Table I : A Comparison between Asphalt Cement, Asphalt Emulsion and Cut-Back Asphalt (Ref.4,5)

Asphalt Type	Advantages	Potential Problem Areas
Asphalt Cement	1. Few cure problems: road surface will usually accept traffic without shelling when rolling is completed	1. High spraying temperatures required: a.May reduce durability of asphalt if overheated b. Introduces operator safety and discomfort problems c. Demands careful control to obtain uniform asphalt distribution d. Is influenced by atmospheric and road surface temperatures. 2. Sensitivity to aggregate surface moisture. 3. Aggregate must be spread and rolled soon after asphalt is distributed
Asphalt Emulsion (Anionic)	1. Can be applied at or above ambient temperature. 2. Water dilution can be used except for rapid setting emulsions	1. Separation of asphalt and water on long storage or after freezing. 2. Asphalt stripping with high silica aggregates 3. Emulsion may run off if road surface temperature is too high. 4. Cure time problems: traffic control required until cure is completed. 5. Will separate if mixed with cationic emulsions.
Asphalt Emulsion (Cationic)	1. Can be applied at or above ambient temperature. 2. Good adhesion with all aggregate types. 3. Good adhesion with moist aggregates. 4. Can be used in cool weather. 5. Resistant to wash-off if rain occurs soon.	1. Separation of asphalt and water on long storage or after freezing. 2. Emulsion may run off if road surface temperature is too high. 3. Water dilution may cause premature break. 4. Cure time problems: traffic control required until cure is completed. 5. Will break if mixed with anionic emulsion.
Cut-Back Asphalt	1. Convenient to use: uniform distribution 2. Requires lower spraying temperature than asphalt cement. 3. Can be used in cool weather. 4. Residue will not be brittle in cold weather.	1. Cure time problems. 2. Cut-back solvent creates air quality problems. 3. Waste of energy in cut back solvent. 4. Solvents have low flash and fire points,thus a workman safety hazard. 5. Flushing problems.

important role on the performance of a seal coat. There is a minimum quantity which is required to hold the aggregate particles in place and bind it to the underlying surface. On the other hand, there is also a maximum amount which, if exceeded, causes bleeding and results in low skid resistance, not to mention the wastage.

The optimum quantity of binder is influenced by factors such as voids in the aggregate layer, condition of the existing pavement surface, and absorption characteristics of the aggregate. All these factors should be taken into account while designing a seal coat (3).

Uniformity of Application. The uniformity of the binder application is also an important factor in the performance of a seal coat. Streaking is the most common problem caused by non-uniform application of the binder (2). The causes for non-uniformity may be an under asphalted mixture, an excess of binder, a faulty distributor or careless operation of the distributor. Another cause of streaking is low spraying temperature so that the binder is not fluid enough to fan out properly from the nozzles on the spray bars. The Asphalt Institute recommends a temperature of 125 F to 185 F for spraying rapid-setting emulsions.

Viscosity. Asphalt is highly susceptible to temperature. The viscosity of the asphalt is inversely proportional to the temperature. The viscosity and the aggregate retention characteristics of the binder depend upon the temperature of the pavement surface. When the binder is in a near-fluid state, which is caused by very hot pavements, it fails to retain the aggregate under the traffic. Hank and Brown (6) stated that the temperature of the road surface, not the distribution application temperature, has more effect on the temperature of the asphalt film and therefore on its properties related to its bonding and retaining aggregate. However, proper spraying temperatures are also important to obtain correct shot rates.

With temperatures at or below 140 F, the application and subsequent performance are generally good. Applications at pavement temperatures in the range of 160 F to 190 F, cause a number of problems (7).

Most of the literature indicates that the base asphalt should have a penetration range of 100 to 300 (8). Softer asphalt permit higher percentage of aggregate embedment initially, whereas, harder asphalt retain the embedded aggregate better. Softer asphalt have other advantages such as higher resilience, lower temperature susceptibility and long term of effective resistance to the action of the elements (9).

Cohesive Strength and Adhesion. Before the new seal coat is opened to traffic the binder must have developed enough cohesive strength so that aggregate is not dislodged by the traffic. Much initial damage can be done to the new surface if the needed cohesion has not been developed to a sufficient degree. Adhesion characteristics of the binder, in many respects, determine the service life and performance of the seal coat (10).

Polymer Modified Emulsions

Even though Cationic Rapid Setting Emulsions (CRS 2) are still widely used for seal coat constructions, polymer-modified emulsions (CRS 2P) are becoming very popular. The polymer modified emulsions seem to have qualities more desirable in chip seal construction than do the regular CRS 2 emulsions. Many highway departments have been experiencing better results when polymer modified emulsions were used for seal coat construction.

Oklahoma Department of Transportation, Pennsylvania Department of Transportation and the Arkansas Highway and Transportation Department have reported success when the polymer modified emulsions were used for slurry seals (11). Polymer-modified asphalt are found to be more flexible when cold and tougher when hot. Polymers increase adhesion and cohesion, reduce temperature susceptibility, increase resistance to fatigue cracking and may, thus, increase durability.

Polymers improve the quality of emulsion by increasing their resistance to flushing or bleeding. Also, due to improved adhesion characteristics there will be more resistance to rock loss in cold weather and whip-off under initial traffic. A few polymers with their respective characteristics are listed in Table II (12).

The use of polymer-modified emulsions for chip seals

Table II : Polymer Modifiers and their Characteristics (Ref. 12)

Modifier Type	Trade Name	Attributes
Ethylene Vinyl Acetate	Elvax	Increases durability,toughness,tenacity and resistance to cracking
Styrene-Butadiene Binder	Styrelf	Arrives at jobsite ready to use,needs no incorporation equipment
Styrene Butadiene reclaimed Rubber	Overflex	Improves durability,decreases fatigue; protects asphalt from ultraviolet light
Polyethylene	Novophalt	Made available on site, ready to use; prolongs pavement life
Thermoplastic polymers	Rosphalt 50	Densifier mix,extends high and low temperature ranges,adds skid resistance
Styrenic Block Co-Polymer	Kraton D Kraton G	Reduces permanent deformation and thermal and fatigue cracking
Polychloroprene	Neoprene	Increases elasticity,toughness and tenacity
Styrene Butadiene Rubber	Latex	Increases elastcity,toughness,tenacity and adhesion
Styrene Butadiene Rubber Latex	Ultrapave	Makes asphalt less susceptible to temperature changes and cracking
	Latex 275	Improves resistance to cracking

means a higher initial cost. There has not been much research done to assess the cost-effectiveness of these emulsions in the long run.

Factors Related to Aggregate

The characteristics of the aggregate used in seal coat construction play a crucial role in the performance of the seal coat. The aggregate layer, partially held by the binder is directly exposed to the traffic. This demands high resistance to abrasion caused by traffic and also sufficient strength not to crush under rolling and traffic forces (2).

Particle size. Particle size is of utmost importance in seal coat construction. If the particles are too small, they will eventually disappear into the binder under traffic load and, thus, serve no practical purpose. On the other hand, very large particles that are not adequately held will be easily dislodged by the traffic. Fine aggregates have a blotting action on the asphalt because of more surface area thereby decreasing the efficient use of the binder. Also, finer aggregates are more sensitive to small variations in asphalt application (3).

Generally the ratio of maximum to minimum sizes of aggregate should be 2:1 with a reasonable tolerance for oversize and undersize particles to allow for economical production (13). If the variation between the sizes of the individual particles is too great, the tire noise or rumble will also be high. Nevitt (14) states that stone particles between the 1/4" and 3/8" screens are most desirable.

Small size stones offer more resistance to degradation than the larger stones of the same type and quality. However, smaller particles are affected by minute variations in asphalt application. Thus, the possibility of applying too much binder is increased and the result can eventually be bleeding of the surface. Particles which do not project more than 20% of their height above the binder are supposed to have little or no functional value (15).

Gradation. Seal coats constructed with one size aggregates perform best. Herrin et al. (9) stated that the use of one-size aggregate offers maximum contact between the tire and the surface. This contact increases the frictional area which, in turn, increases skid-resistance when the correct quantity of binder is used. Also, one-size aggregate usually develops interlocking qualities that are better than those developed with nonuniform aggregates. This interlocking of aggregates is needed to prevent aggregate displacement under traffic. It has been the experience of many highway agencies that seal coats constructed with graded cover aggregate have a shorter life span than those built with one-size aggregate.

However, the use of one-size cover aggregate is expensive compared to graded aggregate. Hence, for economical reasons, a small tolerance in aggregate gradation becomes inevitable.

Aggregate application rate depends upon the average particle size, and the way in which the size of the aggregate is defined differs with different design methods. One method involves obtaining the size at a predetermined percentage on the aggregate gradation chart. Another method involves the determination of average least dimension (ALD). The ALD is found by plotting the mean aggregate size against the flakiness index which will be illustrated later in this chapter (3).

However, when graded aggregate is used for seal coat construction, the method for calculating the mean particle diameter is different. This is because the use of the average least dimension by direct measurement is not feasible with smaller particle sizes. For graded aggregate, the mean particle diameter is calculated by taking the weighted average of the mean size of the largest 20 percent, the middle 60 percent and the smallest 20 percent. The resulting mean particle diameter is called the "Spread Modulus" (16).

Quantity. The optimum quantity of aggregate is the amount of aggregate which will form a layer one stone deep with as few voids as possible (16). More aggregate causes double layer formation which not only causes wastage of aggregate but also encourages other phenomena such as ravelling, pot holing and the formation of corrugations. Also, excess aggregate might get crushed under traffic and thus form fines which will blot the surface of the asphalt. On the other hand, less aggregate leaves voids in the seal coat and is also undesirable. However, Marais (17) stated that excess aggregate causes more harm than if the right or slightly less amount is used. Nevitt (14) stated that the general tendency is to over-apply aggregate when it is actually wiser to under-apply.

Even though the aggregate particles lie in a haphazard orientation after being spread by the chip spreader, they will eventually be aligned by rolling and by traffic so that their least dimension is perpendicular to the surface (1). Hence this result should be kept in mind when determining the quantity of the aggregate.

Quality. Apart from the aggregate size and gradation other properties such as shape and texture of the particles, strength, cleanliness, durability, abrasion resistance and adhesion characteristics also play important roles in the performance of seal coats. The selection of aggregate is governed by the purpose of seal coat or, in other words, by whether skid resistance, cost, durability or other factors are of most importance (3).

Generally, crushed rock is preferred to natural rock. Natural rock is less angular and more rounded. This causes lack of stability, since contact between the particles occurs at only one spot. Thus, rounded particles are more easily dislodged than the angular particles. Also, the rounded particles require more asphalt to be held in place as they have lesser surface area due to their spherical shape (18).

Aggregates which contain too much plates, splinters and flaky particles should be avoided. According to Kearby (19) elongated or flat particles should not exceed 10 percent of any combined aggregate gradation. The surface texture of the aggregates greatly influences the skid-resistance of the resulting seal coat. Pavement skid-resistance can be improved by providing a seal coat with rough and gritty texture.

The selection of light weight or normal weight aggregate depends upon the factors stated earlier, as well as traffic volumes and availability. Table III gives the advantages and disadvantages of each type (20).

Good adhesion characteristics of the aggregate are of prime importance in obtaining a durable seal coat. In a seal coat the aggregates are arranged in a layer unlike asphaltic concrete mix where aggregate forms a matrix with asphalt. Thus the aggregates in a seal coat do not gain much support from other aggregate particles (18). Hence, the aggregate must have good adhesion characteristics in order to be retained in place throughout the life of the seal coat. Aggregates for seal coats should be strong enough not to be crushed under rolling or under traffic. As stated earlier, the aggregate particles in a seal coat are not completely covered by the asphalt and hence they must be more durable than the aggregate used in the asphalt mixes.

Many testing methods and devices are available to

Table III : Aggregate Types and their Benefits and Disadvantages (Ref. 20)

Aggregate Type	Potential Benefits	Potential Problems
Lightweight	1. High skid resistance 2. Reduced windshield damage 3. Good color contrast 4. Reduce paint stripe maintainance	1. Aggregate degradation during handling 2. Low abrasion resistance 3. Gradation control 4. High water absorption 5. Higher cost
Normal Weight	1. Availability and cost 2. Relatively low water absorption 3. High resistance to degradation and abrasion	1. Poor skid resistance if polish value is low 2. Windshield damage 3. Poor asphalt adhesion with high silica Aggregates 4. Dust

indicate the durability of the aggregate. The most common methods are the Los Angeles abrasion test and the sodium sulfate soundness test (21).

Traffic

Traffic is obviously one of the most important parameters in the design of the seal coat. Unless adjustments in the quantity of asphalt are made for traffic volume, flushing may result under heavy traffic or the voids may not be filled enough for best performance under light traffic (20). In other words, heavy traffic suggests the usage of lesser quantity of asphalt than that used under light traffic. Hence, it is advised to measure and predict the traffic volume as accurately as possible. The volume of the traffic decides the quantity of binder to be applied and the size of the stone selected.

It should be noted that the design of seal coats is not similar to the structural design of pavements. Light traffic, which comprises of cars and motor bikes is of no significance in the structural design of pavements but plays an important role in the design and performance of seal coats (3).

Underlying Pavement Surface

Seal coats do not enhance the structural capability of the pavement. Therefore, the underlying pavement has to be structurally sound to support the expected vehicular loads. Seal coats, however, help in maintaining the structural stability by waterproofing and providing a wearing coat for the pavement.

The quantity and the type of binder material and the size and quantity of the aggregate cover material to be used are affected by the condition of the underlying surface. A dry or open pavement will absorb some of the asphalt intended for the new seal coat. Thus, a higher application rate or a pre-seal must be considered. On the other hand, fat or flushing pavements have surplus asphalt which may come through and embed the new chips (3). Thus, a lower quantity of asphalt may be needed depending upon the condition. In severe cases, it may be necessary to remove these fat areas prior to placing the chip seal (22).

Construction Methods

In spite of having the best materials, seal coats may perform poorly and have a shorter life span if basic construction procedures are not followed. The weather in which seal coating work is done can have a marked effect on the quality of the seal coat (22). These variations can be temperature, rain and wind.

Cold weather or pavement temperatures under 50 F can affect the initial binding characteristics of the asphalt by making it hard and less sticky and by increasing the viscosity. This increase in viscosity will cause a poorer bond between the existing surface, the asphalt, and the aggregate particles and might eventually result in cover aggregate loss.

On the other hand, seal coating during hot weather (air temperatures of 90 F or higher) can also cause problems. Pavement temperature can go as high as 150 F causing the asphalt to become less viscous. The asphalt at this temperature will have lower viscosity and it will be more fluid in nature and not have its full strength (18). This condition is particularly likely with cutbacks. Paving grade asphalt or emulsions offer a better choice. The asphalt in these forms can be less susceptible to hot weather (22).

Seal coating work should be avoided during rain or if rain is forecast. The cutbacks can float up through the cover aggregate and can stick to the tires, a highly undesirable condition. The emulsions and asphalt cements require less curing time to be resistant to rain (22).

High winds can also cause problems by distorting spray patterns from the asphalt distributor and prevent a uniform asphalt application. Also, the wind can create lot of dust in the site which is undesirable in seal coat work. Experience has shown that late spring to early fall is the most favorable season for seal coat construction.

Temperature at which the binder is stored or is being sprayed plays an important part in the resulting seal coat. Asphalt held in storage at spray temperatures maintains a uniform viscosity, handles well, and gives a good spray pattern through the distributor (22). It may be desirable to maintain the temperature somewhat below the maximum recommendation to reduce fire hazards and the danger of breaking the emulsions by overheating. Overheating for long periods can harden the emulsions and cutbacks by evaporating the emulsifying agents and solvents (22).

If asphalt needs to be stored for extended periods before sealing, proper care should be taken. In other words, the binder which comes out of the spray nozzles should have the same properties as those found in the laboratory.

Apart from the above mentioned factors, the quality of the seal coat depends upon many other factors such as experience of the construction crew, traffic control during construction, control over aggregate spreader and emulsion distributor, rolling, brooming and so on.

Seal Coat Construction

The condition of the underlying pavement plays a crucial role in the design and performance of the seal coat. Hence it is very important to study the existing pavement for its condition. If the pavement is not structurally sound enough to carry the traffic, seal coating will not be truly helpful and, hence, not recommended. Proper measures should be taken to improve the condition of the existing pavement before seal coating can be done (1).

Seal coating may be compared to painting a steel structure. Painting a steel structure which is rusted and badly corroded is not going to help. Similarly seal coating of a structurally unsound and distressed pavement is not going to help either (2). Hence, the existing pavement should be corrected of its problems.

Binder Application

Improper application of the binder is the cause for a number of performance problems. The cause for improper application is faulty adjustment and calibration of the distributor. Spray nozzle angle setting and spray bar height are two extremely important adjustments to be made to get uniform distribution of binder.

McLeod (10) stated that different application rates should be obtained by changing the forward speed of the distributor truck and not by changing the discharge rate from the nozzles or by changing the pump pressure. It is desirable that the distributor start and finish each shot on building paper to assure uniform application of the asphalt for the entire shot. After each shot, the shot rate should be checked by using the amount of asphalt consumed, the distance covered and the width of coverage.

Aggregate Application

Aggregate application should follow as quickly as possible, preferably before the emulsion breaks (22). Because asphalt is very temperature susceptible, the aggregate must be laid when the asphalt is still fluid enough to coat the aggregate. When the asphalt becomes cold and thick it fails to rise and cover the aggregate to the desired depth.

Like the distributor, the chip spreader should also be checked for uniformity and the chip spreader should operate at a speed that will prevent the cover aggregate from being rolled as it is being applied. Abrupt stops and starts should be avoided.

Rolling

Even though pneumatic rollers are preferred, steel wheel rollers should be used in conjunction with pneumatic rollers to assure embedment of aggregate. When using both the rollers, steel wheel rollers should follow the pneumatic rollers and not vice-versa.

Rollers should be operated at low speeds (4-6 mph) so that the aggregate is embedded and not displaced. It is desirable to continue rolling operations until the aggregate is completely embeded and seated.

Traffic control is another important factor to be considered. Vehicle speeds should be decreased to prevent whipoff of the aggregate. It is better to have a pilot car or truck to enforce this speed (16).

Brooming

Brooming is recommended to remove excess or loose aggregate which might cause vehicular damage, or get crushed under traffic. Usually brooming is done the day after the seal coat job. However, it depends on the type of asphalt used and its curing characteristics (2)

Design Methods

There are many procedures to design seal coats. However, getting the right application rates should not pose much of a problem. In most cases, achieving these application rates in the field is more of a problem.

Some of the earlier design methods were reviewed by Ford (15). These included Hanson's Design Method, California Design Method, Nevitt's Design Method, Kearby Design Method, Lovering Design Method, McLeod's Design Method, Mackintosh's Design Method, American Bitumul's Method, Voids Concept Design Method and the Asphalt Institute Method given in Manual Series 13.

Even though there are so many design methods, a quick, time tested and reliable method to find the aggregate application rate is by the "Tray Test" which is detailed in the Asphalt Institute Manual Series No. 19 (23). The procedure involves arranging the aggregate on a flat tray of known area so that the layer is one stone thick with minimum voids. The aggregate spread rate is the weight of the aggregate on the tray divided by the area of the tray. A square tray of side equal to 1 yard is recommended.

The emulsion application rate can also be found by the tray test. The volume of "residual" asphalt is 2/3rd the volume of water which is sufficient to just submerge the aggregate layer. Hence, the actual "application" rate should be increased to obtain the desired quantity of residual asphalt. Also, the actual application rate may have to be adjusted for the condition of the existing pavement, traffic and the aggregate characteristics.

The Asphalt Institute Design Method.

This method is one of the most used. It is a modified form of McLeod's design method. The method uses different formulas for single-size aggregate and graded aggregate (1)

Design Using One-size Aggregate. This method requires the determination of bulk specific gravity, the flakiness index, and the average least dimension (ALD) of the aggregate. Also, the traffic volume and the percent aggregate lost by whip-off must be estimated. The criteria shown in Table IV may be used to select the appropriate adjustment factor for traffic, aggregate wastage and surface absorption. The average least dimension can be found by the chart of Figure 1 using the flakiness index and the median size of the aggregate.

The quantity of aggregate, in pounds per square yard and the quantity of asphalt in gallons per square yard (GSY) can be found by the following formulas.

$$S = 37.4 G_M H_L E$$

$$A = 1.122 T H_L + V$$

where:

S = Aggregate spread in pounds / square yard

G_M = Bulk specific gravity of the aggregate

H_L = Average Least Dimension (ALD) of the Aggregate

A = Residual Asphalt Spread in GSY

T = Traffic Factor

E = Aggregate Wastage Factors

V = Variable, in GSY, to cover absorption by pavement

Design Using Graded Aggregate. When using graded aggregate the procedure uses "Spread Modulus" which can be

Table IV : Various Coefficients Used in Seal Coat Design (Ref. 1)

Aggregate	Traffic Factor T = Percentage (expressed as a decimal) of 20 percent void space in cover aggregate to be filled with asphalt.				
	TRAFFIC - Vehicles per day				
	Under 100	100 to 500	500 to 1,000	1,000 to 2,000	Over 2,000
Recognized Good type of Aggregate	0.85	0.75	0.70	0.65	0.60

Percent aggregate wastage allowed for	Wastage Factor,E
1	1.01
2	1.02
3	1.03
4	1.04
5	1.05
6	1.06
7	1.07
8	1.08
9	1.09
10	1.10
11	1.11
12	1.12
13	1.13
14	1.14
15	1.15

Condition of Existing Surface	Variable V
Smooth, non-porous	0.00
Slightly porous & oxidized	0.03
Slightly pocked, porous & oxidized	0.06
Badly Pocked, porous & oxidized	0.09
Flushed asphalt surface	-0.03

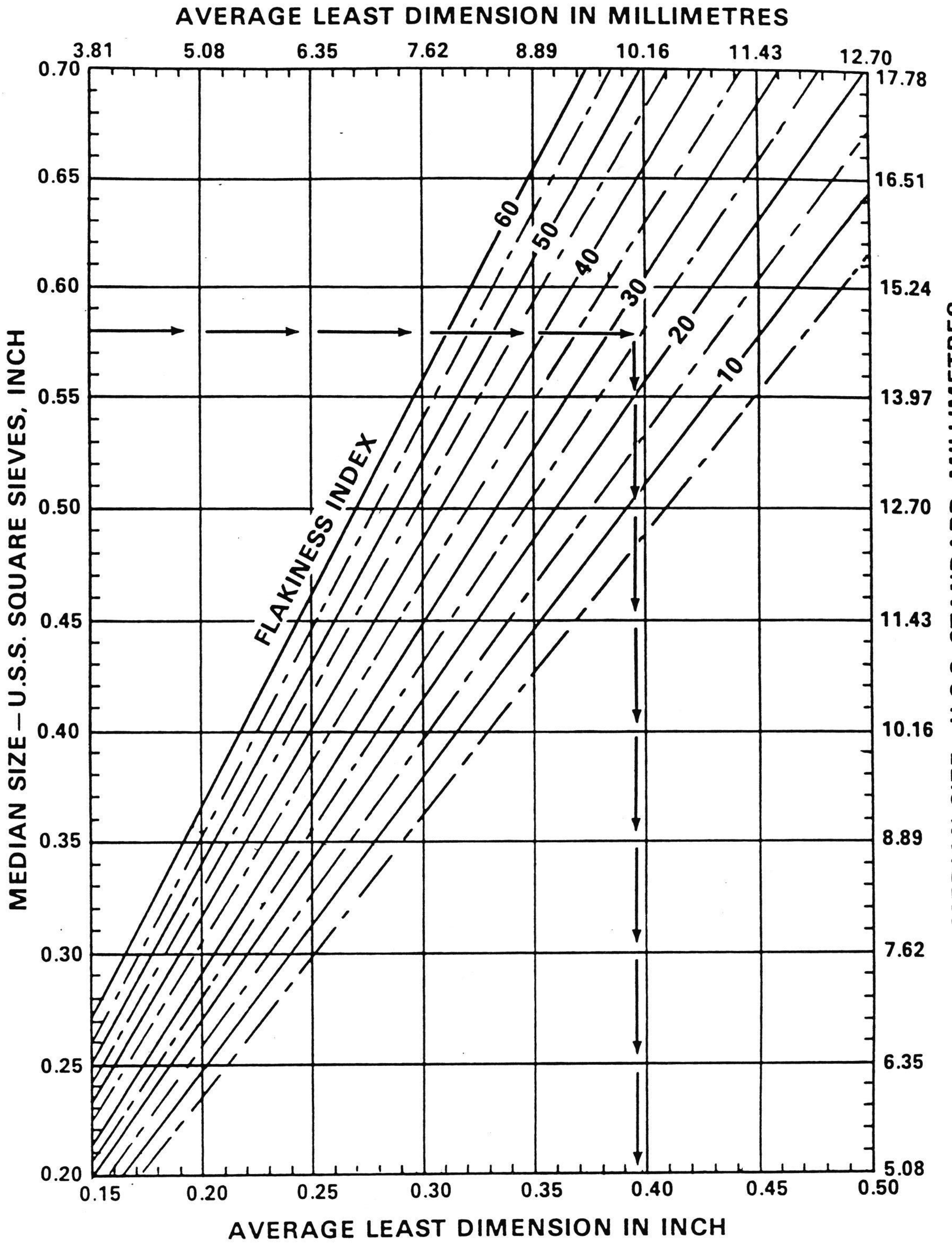


Figure 1: Chart for Determining Average Least Dimension (Ref. 2)

determined by gradation analysis of the aggregate. The formula for determining the Spread Modulus is:

$$M = 0.10(a+b) + 0.30(b+c) + 0.20(c+d)$$

where:

M = Spread Modulus

a = 100% passing aggregate size in inches

b = 80% passing aggregate size in inches

c = 20% passing aggregate size in inches

d = 0% passing aggregate size in inches

After determining the spread modulus, the application rates can be found by the following formulas.

$$S = 0.80MW$$

$$A = 1.122MT + V$$

where:

S = Aggregate spread in pounds per square yard.

M = Spread Modulus.

W = Loose unit weight of the aggregate in pounds per cubic foot

V = Variable, in gallons per square yard, to cover asphalt absorption by pavement and aggregate

A = Residual Asphalt spread in GSY

T = Traffic Factor

The computer program SEALIT will solve these equations. The computer program will be presented later.

CHAPTER III

TEST METHODS AND MATERIALS

Three different varieties of asphalt emulsions were used in four seal coat jobs. Jobs on Highway 43 and Highway 1 used CRS 2, CRS 2P and CRS 2L. For Highway 72 only CRS 2 and CRS 2P were used and for Highway 56 only CRS 2P and CRS 2L were used. Samples of emulsions from each job were collected and tested for their physical properties. The locations of jobs and details of samples collected are shown in Table V.

Four different kinds of aggregates were used for the four seal coat jobs. Samples of aggregates were collected from the stock piles and tested for physical properties. Field sampling and pavement condition rating work were recorded on video tape for further study.

Asphalt Emulsion

The emulsion samples were obtained at two different places. A "jug sample" collected from the delivery tank in a one-gallon plastic jug and a "pan sample" from the distributor. The pan sample was collected to check the actual amount of residual asphalt on the pavement and to test and compare the physical properties of the residue with that obtained from the jug sample after distillation. To collect the sample from the distributor a square metal pan of sides 1.5 ft. and about 3 in. deep was used. The interior surface of the pan was covered with heavy duty aluminum foil for easy removal of asphalt. The sample from

Table V : Details of Seal Coat Jobs and Samples Collected.

Route/Section Log Mile	County	Aggregate Type used	Emulsions used	Type of Rollers	No. of Samples		Date Sampled
					Seal Coat	Emulsion Pan	
SH 72-1	Benton	Crushed	CRS 2	Pneumatic and	3	1	9-12-90
LM 0.5		Limestone	CRS 2P	Steel Wheel	9	3	
SH 43-1	Newton	Crushed	CRS 2	Pneumatic and	6	2	7-16-91
LM 4.26		Pea Gravel	CRS 2P	Steel Wheel	6	2	
			CRS 2L		6	2	
SH 56-2	Izzard	Crushed	CRS 2P	Pneumatic and	6	3	7-25-91
LM 2.42		Limestone	CRS 2L	Steel Wheel	6	2	
SH 1-14	Cross	Crushed	CRS 2	Pneumatic and	6	2	8-14-91
LM 12.19		Limestone	CRS 2P	Steel Wheel	6	2	
			CRS 2L		6	2	

the distributor was collected by placing the pan in the center of the lane and removing it immediately after the distributor sprayed the emulsion. The pan was then covered with paper to avoid dust and other contamination.

The Saybolt Furol viscosities obtained from the jug samples were doubtful because they were no longer fresh by the time they were tested. Hence, the values reported were obtained from the tests performed by AHTD. The emulsions from jug samples were used in distillation to determine the percent residue. The residual asphalt was stored in penetration tins for further testing.

The pans were uncovered and the initial weights along with emulsion were determined. The pans with emulsion were kept in the 250 F oven until they reached a constant weight. The final weight of the emulsion was used in determining the residual asphalt on the pavement. The residual asphalt from the pans was also stored in penetration tins for further testing. The standard tests to determine the properties of the emulsion and base asphalt are given in Table VI.

Aggregate

The aggregate was collected from stock piles in quantities of 30 to 40 lbs. and tested by ASTM procedures. The standard tests to determine the properties of the aggregates are given in Table VI. Apart from testing the stockpile samples, extracted samples of aggregate were also tested for gradation and in "Tray Tests" for comparison of the application rates. The Tray Test is illustrated in

Table VI : Standard Test Methods.

ASPHALT EMULSION AND RESIDUE

No.	Test Method	ASTM
1	Saybolt Furol Viscosity	D 2170
2	Emulsion Distillation	D 244-77
3	Penetration Test	D 5-73
4	Absolute Viscosity	D 2171-78
5	Ductility	D 113-79
6	Softening point	D 36-76
7	Extraction (by Reflux Extractor)	D 2172-75

AGGREGATE

No.	Test Method	Method
1	Sieve Analysis of Fine and Coarse Aggregate	ASTM3454
2	Specific Gravity and Absorption of Coarse Aggregate	ASTM 127/128
3	Unit Weight of Aggregate	ASTM C29-76
4	Flakiness Index	MS 13
5	Average Least Dimension	MS 13
6	Spread Modulus	MS13

Asphalt Institute Manual series No. 19 (23).

Seal Coat Samples

The number of actual seal coat samples collected from each job are shown in Table V. The samples were collected on rectangular aluminum panels 1.0 ft. wide and 2.0 ft. long. Two trapezoidal asphalt-impregnated sample plates were attached to the panels with duct tape which could be later removed. These samples were tested on the Accelerated Wear Track. The trapezoidal sample plates were cut from Onduline roofing panels. The size of the asphalt plates was such that 12 samples would fit on the circular wear track at one time. The area of the asphalt sample plate covered by the seal coat was about 34 square inch.

After removing the trapezoidal sample plates, the extra seal coat material remaining on the aluminum panel was used in extraction. The aggregate from the extraction was tested for gradation.

The seal coat samples were tested for durability on the accelerated wear track. The physical properties of the residual asphalt cements and the aggregate were evaluated by ASTM methods and specifications.

Wear Track Equipment

The accelerated wear track, designed at the University of Arkansas, was originally used for the purpose of evaluating the polishing characteristics of the asphalt pavement mixtures. It was later modified to test seal coat samples for their durability (24).

The machine, about the size of a small dining table, consists of two weighted wheels which revolve around a circular track. The circular track of diameter 28 inches was capable of holding 12 seal coat samples. The details of the wear track can be found in Table VII.

The tires were inflated to 20 psi. The operating speed was twenty revolutions per minute so as to avoid higher centrifugal forces on the seal coat. The cumulative number of revolutions was shown by the counter in the machine.

The seal coat sample plates were cut from asphalt roofing materials. The asphalt absorption of this material was assumed to be zero. The size of the sample plates was such that they would fit tightly against each other on the wear track, giving the wheel assembly a continuous surface to travel over. The asphalt sample plates were placed on aluminum plates, cut to the same size as the asphalt plates, and the entire specimen was bolted along with the wooden retaining curbs to the accelerated wear track. The aluminum plates were used to give adequate structural stability to the seal coat samples.

The temperature of the wear track could be raised by using the four heat lamps hung from the ceiling directly above the wear track. The heat lamp assembly could be raised or lowered to get the desired temperature.

Wear Track Test Method

The results from the accelerated wear test are relative. The basic criterion behind the test is to compare

Table VII : Details of Accelerated Wear Track.

Track Size	Circular - 14 " radius from centerline of drive shaft to center line of sample plates
Sample Capacity	12
Sample Plate Size	5.3" x 9.5 " x 8" deep
Seal Coat Sample Size	6.0" x 8.5" x 4.8" deep
Tire Inflation Pressure	20 psi
Wheel Loading	64 lbs
Contact Pressure	20 psi
Motor	3/4 hp. electric
Speed Control	"Zero-Max" variable speed drive 0-440 rpm
Operating Speed	20 rpm
Tires	Nylon, 11 x 6 , 2 ply rating Go-Cart "Super Slicks"

the durability of different seal coats when subjected to similar conditions of wear on the accelerated wear track. Some of the variables in the test can be the type of emulsion and quantity, type of aggregate and quantity, and temperature. The total number of wheel passes over the seal coat samples was 30,000.

After removing the seal coat samples from the aluminum panels, they are weighed and placed on the accelerated wear track. The wear track is run at an elevated or "summer" temperature of 93 F to embed and orient the aggregate in the seal coat. The number of wheel passes for each temperature variation was 2,000. The temperature and the number of wheel passes are given in Table VIII. It is noted that these temperature and wheel passes are different from those used on the TRC-65 study. The frequency of weighing depends upon how fast or how slow the seal coat is losing aggregate. It ranged from once in every 500 wheel passes during hot cycles to once in 2000 wheel passes during cold cycles.

Care was taken to ensure that the wheels were always free from asphalt. This precaution was necessary to prevent the aggregate chips from sticking to the tires. The tires were cleaned of any asphalt film which would accumulate especially under higher temperatures.

Table VIII : Temperatures and Corresponding Wheel Passes.

Surface Temperature	Number of Wheel passes	Accumulated Wheel Passes
93	600	(intial shake down)
72	1,400	2,000
93	2,000	4,000
72	6,000	10,000
72	10,000	20,000
93	4,000	24,000
72	6,000	30,000

CHAPTER IV

TEST RESULTS AND DISCUSSION

The results of laboratory tests performed on asphalt and aggregate along with results of accelerated wear test are presented in this chapter. The values reported are the average of those test values obtained for each seal coat job. The seal coat service life of the 1981 study test sections, relationship of years of service to wear track results, and economic analysis and initial performance of the CRS 2, CRS 2L and CRS 2P test sections of 1991 are also reported.

Laboratory Tests

Aggregate Tests

The gradation of the stockpile or bag samples and extracted aggregate from the seal coat samples are shown in Table IX. The gradation from the stock pile sample and that of extracted sample are not the same. The difference in the two gradations is due to sampling and construction techniques. The AHTD specification for classifying the aggregate based on the gradation is given in Table X.

The aggregate chips used in State Highway 43-1 met the specifications for class-1 and the aggregate chips used in State Highways 72-1 and 56-1 met the specifications for class-2. State Highway 1-14 had crushed limestone of relatively smaller size commonly known as "turkey scratch." This aggregate failed to meet the specifications for either class-1 or class-2 and hence was classified as class-3

Table IX : Aggregate Gradations.

Sieve Size in.	State Highway 72		State Highway 43	
	Bag	Extraction	Bag	Extraction
3/4	100.0	100.0	100.0	100.0
1/2	100.0	100.0	99.0	98.4
3/8	95.4	97.5	42.0	45.2
No. 4	25.7	42.7	11.0	15.2
No. 10	1.0	9.1	3.0	3.1
No. 20	0.6	4.3	2.0	1.5
No. 40	0.6	2.8	1.5	1.0
No. 80	0.6	1.8	-	0.5
No. 200	0.5	1.2	0.3	0.3

Sieve Size in.	State Highway 56		State Highway 1	
	Bag	Extraction	Bag	Extraction
3/4	100.0	100.0	100.0	100.0
1/2	93.0	94.5	100.0	100.0
3/8	61.0	59.9	88.0	92.3
No. 4	39.0	39.9	63.0	73.0
No. 10	3.5	8.2	9.0	14.7
No. 20	1.0	3.1	1.0	1.4
No. 40	0.8	2.1	0.9	0.9
No. 80	-	1.5	-	0.7
No. 200	0.5	1.1	0.5	0.5

Table X: AHTD Specifications for Aggregates and AASHTO Specifications for Asphalt Emulsion

Class No.	Sieve					
	3/4"	1/2"	3/8"	#4	#10	#16
1	100	90-100	-	0-15	0-3	-
2	-	100	90-100	-	0-15	0-3
3	-	-	100	50-90	0-15	0-8
4	May be either class 1 or class 2 Aggregate					

Job	Aggregate Type	AHTD Class No.
State Highway 72-1	Crushed limestone	2
State Highway 43-1	Pea Gravel	1
State Highway 56-2	Crushed limestone	2
State Highway 1-14	Crushed limestone	3

Emulsion and Residue Specifications (from AASHTO Specs.)

	Min.	Max.
Saybolt Furol Viscosity at 122 F	75	400
Residue by Distillation %	63	-
Penetration, 77F,100gm, 5s	100	200

aggregate.

The physical properties of aggregates such as unit weight, specific gravity, median size, flakiness index and average least dimension are listed in Table XI. Of the four jobs the aggregate from State Highway 1-14 had the lowest average least dimension of 0.10 in. and the highest flakiness index of 35 (It should be noted that it is not possible to find out the average least dimension from Figure 1 if the median aggregate size is less than 0.20 in. In such cases the ALD is taken as 5/11th of median size (15). The aggregate from State Highway 43-1 had the highest average least dimension and the lowest flakiness index of 0.20 in. and 9.4, respectively.

Emulsion and Residual Asphalt Tests

The AASHTO specifications for asphalt emulsion and residual asphalt are shown in Table X. The physical properties of emulsion and residual asphalt used in the four jobs are shown in Table XII. All emulsions met the specifications for percent residue, penetration, ductility and Saybolt Furol viscosity. However, there was a considerable difference in the absolute viscosity values between jug samples and pan samples. This may be due to dust or sand particles contaminating the emulsion in the pan during sampling and packing. Another reason might be due to hardening and aging effects as a result of evaporation in the oven under high temperature (275 F).

One common observation was that the polymer modified

Table XI : Physical Properties of Aggregates.

Properties	SH 72-1	SH 43-1
Loose Unit Weight lbs./cft.	79.85	78.80
Rodded Unit Weight. lbs./cft.	84.05	80.18
Bulk Specific Gravity	2.57	2.26
Median Size in.	0.19	0.25
Flakiness Index	24.70	9.40
Avg. Least Dimension. in.	0.15	0.20
Spread Modulus	0.23	0.28

Properties	SH 56-2	SH 1-14
Loose Unit Weight lbs./cft.	86.34	92.62
Rodded Unit Weight lbs./cft	93.20	96.82
Bulk Specific Gravity	2.62	2.72
Median Size in.	0.22	0.16
Flakiness Index	20.00	35.00
Avg. Least Dimension in.	0.17	0.10
Spread Modulus	0.23	0.16

Table XII : Physical Properties of Emulsions

SITE / Property	SH 72	SH 43	SH 56	SH 1	AVERAGE
CRS 2					
Saybolt Viscosity 122 F sec. *	295	282		NT	288
Jug Sample:					
% Residue (Distillation)	68.7	69.1	NOT	68.6	68.8
Penetration 77 F	184	172		158	171
Viscosity 140 F Poise	413	390	USED	540	448
Softening Point F	109	102		106	106
Pan Sample :					
Penetration 77 F	140	104		97	114
Viscosity 140 F Poise	580	1475		1000	1018
Softening Point F	115	114		106	112
CRS 2P					
Saybolt Viscosity 122 F sec. *	286	316	167	NT	206
Jug Sample:					
% Residue (Distillation)	67	67.6	68.7	72.3	68.9
Penetration 77 F	153	182	161	163	165
Viscosity 140 F Poise	900	875	1335	1385	1124
Softening Point F	106	104	112	112	109
Pan Sample :					
Penetration 77 F	107	96	91	102	99
Viscosity 140 F Poise	2350	9150	4760	3230	4873
Softening Point F	117	133	127	125	126
CRS 2L					
Saybolt Viscosity 122 F sec. *	N A	550	103	302	318
Jug Sample:					
% Residue (Distillation)		67.9	69.7	71.7	69.8
Penetration 77 F		139	142	150	144
Viscosity 140 F Poise	NOT	1475	840	930	1082
Softening Point F		113	114	115	114
Pan Sample :	USED				
Penetration 77 F		100	77	95	91
Viscosity 140 F Poise		3375	3070	1250	2565
Softening Point F		121	119	114	118

* FROM AHTD RESULTS

emulsions, i.e. CRS 2Ps, had higher softening points and higher absolute viscosity values in most cases. As shown in Figure 2, the softening points for CRS 2 ranged from 108 F to 112 F whereas the softening points for CRS 2P ranged from 112 F to 120 F. The latex modified emulsions, i.e. CRS 2Ls, had values which ranged from 116 F to 117 F.

The absolute viscosity of the residual asphalts at 140 F are shown in Figure 3. The viscosity of the polymer and latex emulsion were higher than the regular CRS 2 emulsion. For warmer regions like Arkansas, emulsions with higher softening points and viscosities are desirable for seal coating. This is due to the fact that aggregate chips are held in place even during higher summer temperatures.

Seal Coat Samples

The seal coat samples served two different purposes. Their primary purpose was to compare the durability of different types of seal coats by subjecting to accelerated wear test. In addition to this, they were helpful in determining the exact field application rates of aggregate and asphalt.

The design and measured emulsion application rates are shown in Table XIII. The application rates obtained from the seal coat samples were different from the design (intended) application rates. The variation in residual asphalt measured at each sample site is shown on the bar graph of Figure 4.

For State Highway 72-1, while the design shot rate was

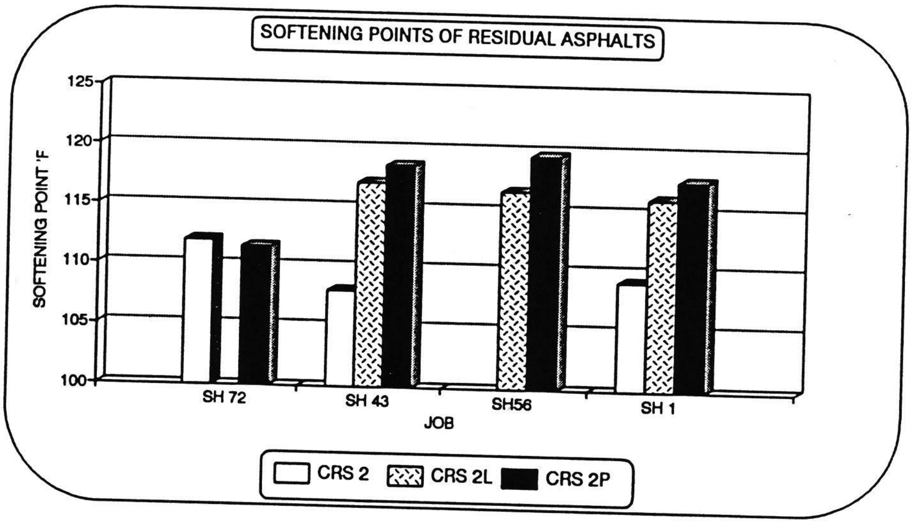


Figure 2 : Softening Points of Asphalts.

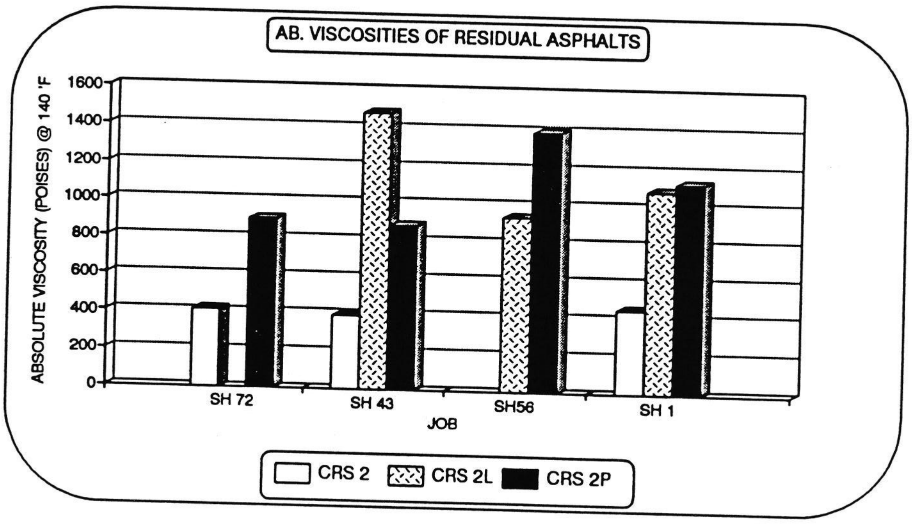


Figure 3 : Absolute Viscosities of Asphalts.

Table XIII : Emulsion Application Rates : Actual, Design and those from "Tray Test".

State Highway 72

Location	Emulsion Type	Shot Rate as found = residual vol./(%residue)	Intended Shot Rate (Design)	Shot rate from Tray Test
Site 1	CRS 2P	0.31/0.68 = 0.45	0.40	0.52
Site 2	CRS 2P	0.23/0.68 = 0.34	0.35	
Site 3	CRS 2P	0.19/0.68 = 0.28	0.30	
Site 4	CRS 2	0.26/0.67 = 0.39	0.40	

State Highway 43

Location	Emulsion Type	Shot Rate as found = residual vol./(%residue)	Intended Shot Rate (Design)	Shot rate from Tray Test
Site 1	CRS 2L	0.28/0.68 = 0.41	0.42	0.35
Site 2	CRS 2L	0.28/0.68 = 0.41		
Site 3	CRS 2P	0.27/0.68 = 0.40		
Site 4	CRS 2P	0.28/0.68 = 0.40		
Site 5	CRS 2	0.26/0.69 = 0.38		
Site 6	CRS 2	0.27/0.69 = 0.40		

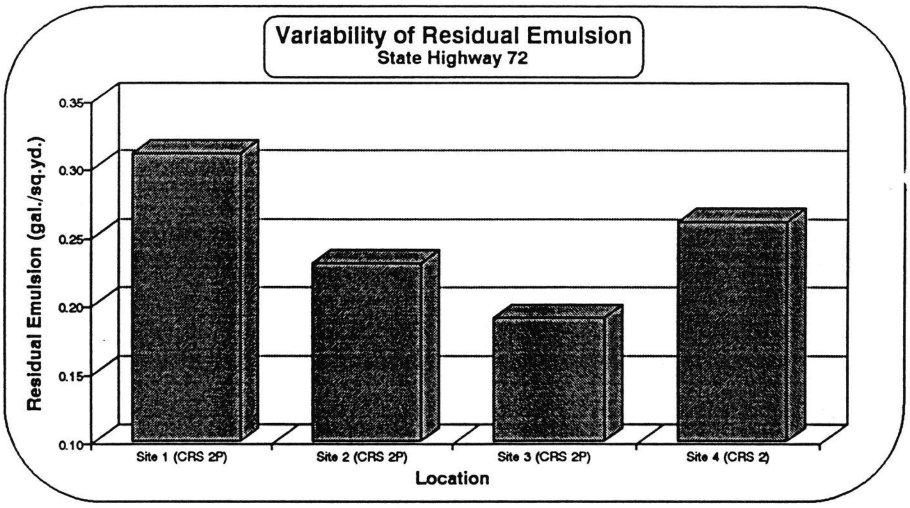
State Highway 56

Location	Emulsion Type	Shot Rate as found = residual vol./(%residue)	Intended Shot Rate (Design)	Shot rate from Tray Test
Site 1	CRS 2L	0.27/0.69 = 0.39	0.37	0.30
Site 2	CRS 2L	0.26/0.69 = 0.38		
Site 3	CRS 2P	0.22/0.69 = 0.32		
Site 4	CRS 2P	0.23/0.69 = 0.33		
Site 5	CRS 2P	0.31/0.69 = 0.45		

State Highway 1

Location	Emulsion Type	Shot Rate as found = residual vol./(%residue)	Intended Shot Rate (Design)	Shot rate from Tray Test
Site 1	CRS 2	0.16/0.69 = 0.23	0.29	0.25
Site 2	CRS 2	0.16/0.69 = 0.23		
Site 3	CRS 2L	0.24/0.72 = 0.33		
Site 4	CRS 2L	0.23/0.72 = 0.32		
Site 5	CRS 2P	0.20/0.72 = 0.29		
Site 6	CRS 2P	0.20/0.72 = 0.29		

* Shot Rates in gal./sq.yd.



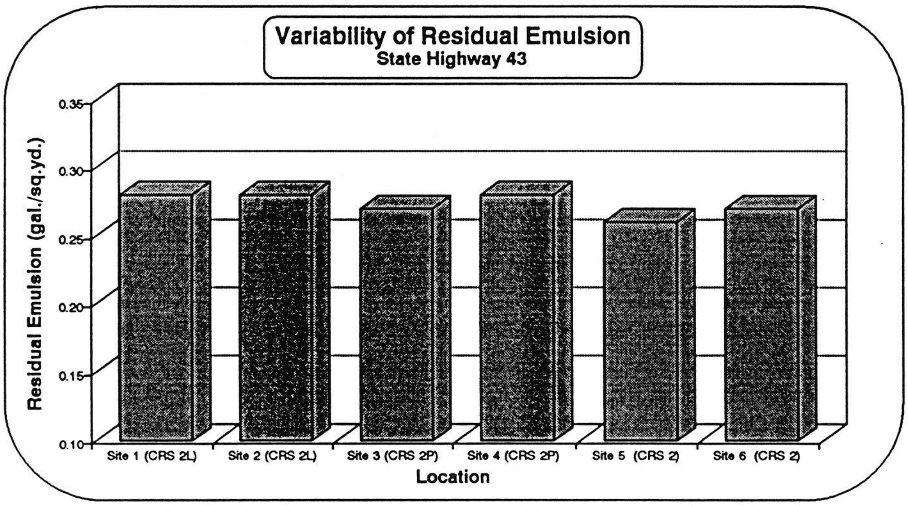
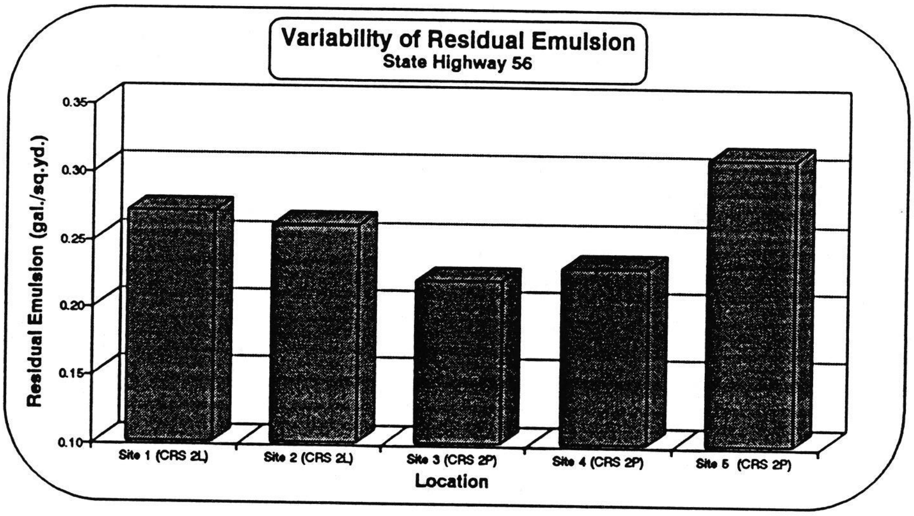


Figure 4 : Emulsion Shot Rates ; As Measured (contd.)



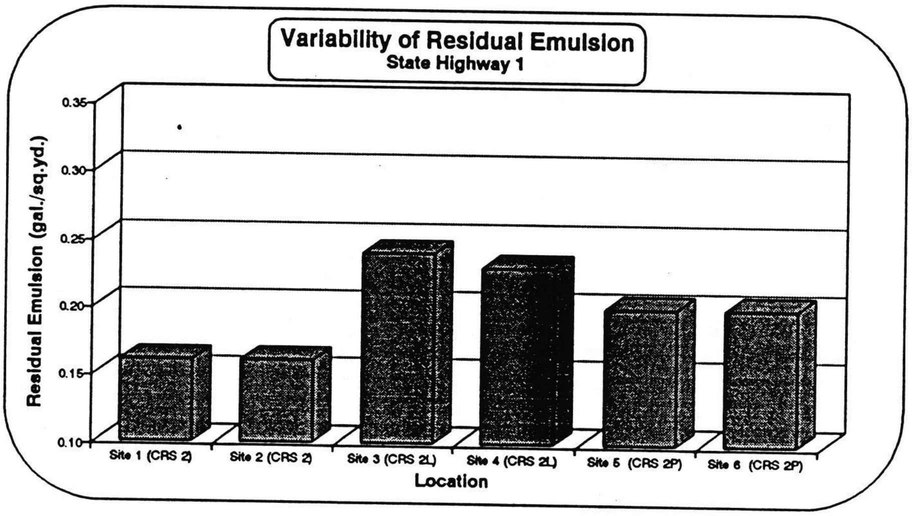


Figure 4 (contd.) : Emulsion Shot Rates ; As Measured.

0.28 GSY, the actual shot rates ranged from 0.19 to 0.31. However, this was intentionally varied to see if lower shot rates for CRS 2P were permissible due to their supposedly better aggregate holding characteristics.

The residual emulsion for the seal coat job on State Highway 43 was more or less uniform. There was considerable variation in residual emulsion for the jobs on State Highways 56 and 1. This variation may show the effect of using different emulsions (CRS 2, CRS 2P and CRS 2L) in the same distributor without adjusting for the possible different viscosity of the emulsions.

The aggregate quantities also varied considerably. Table XIV shows the design rates and the variation in field rates, along with the application rates as obtained by tray test. This variation in aggregate application rates are illustrated by the bar graph of Figure 5.

The spread rate on Job SH 72 ranged from 13 PSY to 17 PSY, the average being 15.75 PSY and the standard deviation being 0.96. The spread rate on Job SH 43 also ranged from 13 PSY to 17 PSY. The average was 14.78 PSY and the standard deviation was 1.35. The spread rate on Job SH 56 ranged from 16 PSY to 20 PSY average being 17.58 PSY and the standard deviation being 1.16. For Job SH 1 the range was 7.2 PSY to 12 PSY. The average was 11.53 PSY and the standard deviation was 1.62.

<u>Wear Track Test Results</u>

The seal coat wear was represented by the percent

Table XIV : Aggregate Application Rates.

State Highway 72	Design Rate = 14 PSY					Tray Test Design Rate = 15 PSY						
Location	1	2	3	4	5	6	7	8	9	10	11	12
Agg. Spread rate PSY	16.1	15.7	16.7	14.8	13	16.2	16.2	16.2	16.2	16.2	16.2	16.2

State Highway 43	Design Rate = 13 PSY					Tray Test Design Rate = 16 PSY												
Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Agg. Spread rate PSY	15.5	15.8	15.3	15.3	15.2	15.1	13.2	13	12.4	13	16.4	12.9	16.6	16.4	16.2	14.8	14.9	14.5

State Highway 56	Design Rate = 12 PSY					Tray Test Design Rate = 18 PSY						
Location	1	2	3	4	5	6	7	8	9	10	11	12
Agg. Spread rate PSY	16.5	16.7	16	20.3	17	17.3	17.4	17	17.9	19.2	17.1	18.8

State Highway 1	Design Rate = 12 PSY					Tray Test Design Rate = 12 PSY												
Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Agg. Spread rate PSY	10.6	10.6	9.64	10.8	7.21	8.78	12.5	12.9	13.1	12.5	12.3	11.8	12.5	12.1	12.3	12.5	10.7	11.6

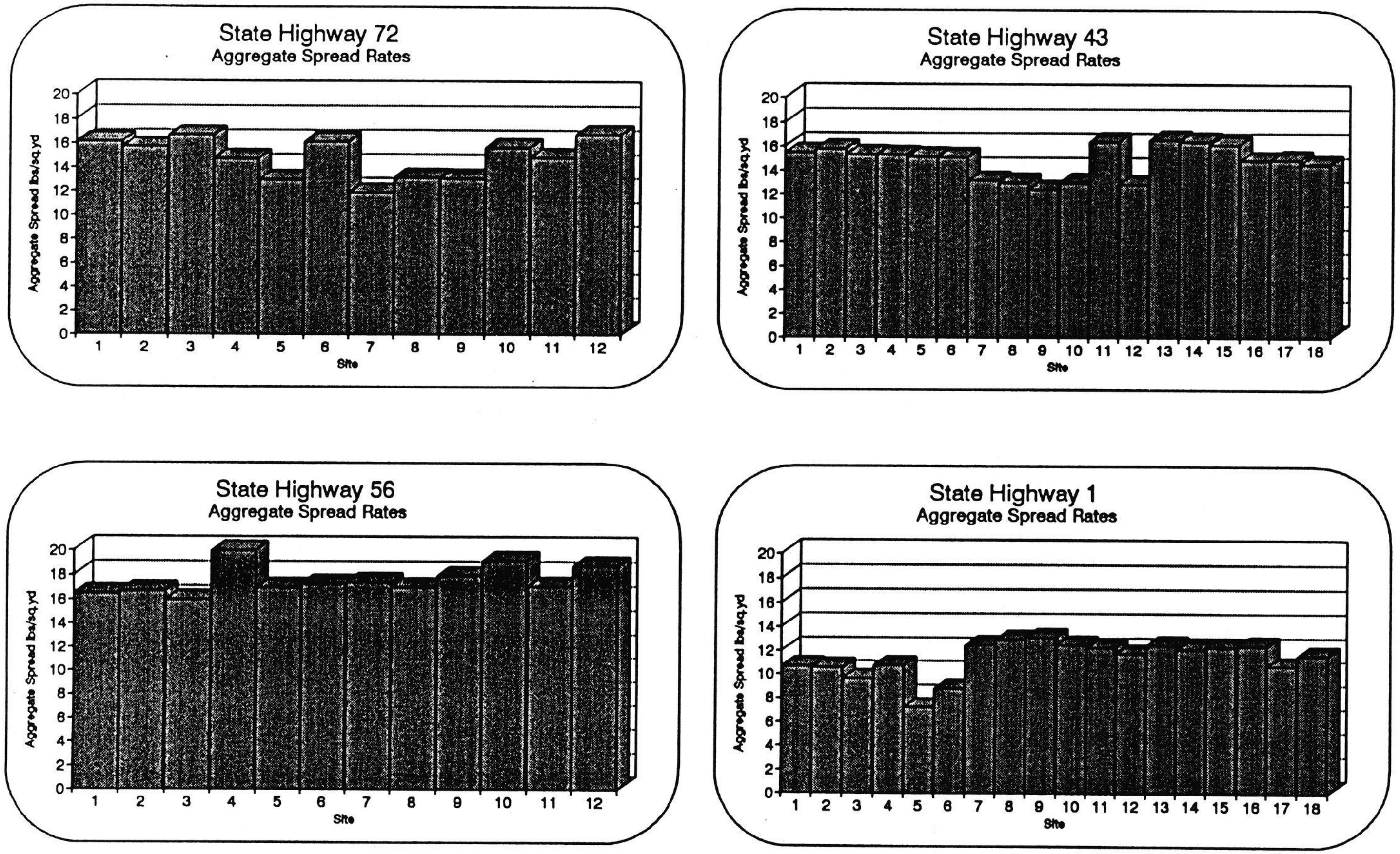


Figure 5 : Aggregate Spread Rates ; As Measured.

weight loss at the end of the test. The testing was ended after 30,000 wheel passes or after 30 percent of the seal coat material was lost, whichever came first. Table XV shows the average total weight loss at the end of the accelerated wear test. Figure 6 illustrates the weight loss graphically for each job and by emulsion type. Samples from Jobs SH 72, SH 43 and SH 56 withstood 30,000 wheel passes while those from SH 1 withstood only about 14,000 wheel passes.

For SH 72 the average weight loss ranged from 17 percent to 34 percent. Table XV shows that the weight loss increased to 34 percent when the emulsion application rate was reduced 0.30 GSY. For SH 43 the average weight loss for samples using CRS 2, CRS 2L and CRS 2P were 23 percent, 16 percent and 10 percent respectively. For SH 56, which used only CRS 2L and CRS 2P, the weight losses were 16 percent and 11 percent respectively. For SH 1 the weight losses were, 30 percent for CRS 2, 22 percent for CRS 2L and 21 percent for CRS 2.

In all four jobs, seal coats using CRS 2 suffered a higher weight loss followed by those using CRS 2L and CRS 2P. Samples with CRS 2 also showed bleeding or blackening of samples at higher temperatures. But the samples with CRS 2P and CRS 2L did not bleed and the aggregate chips remained cleaner compared to those with CRS 2.

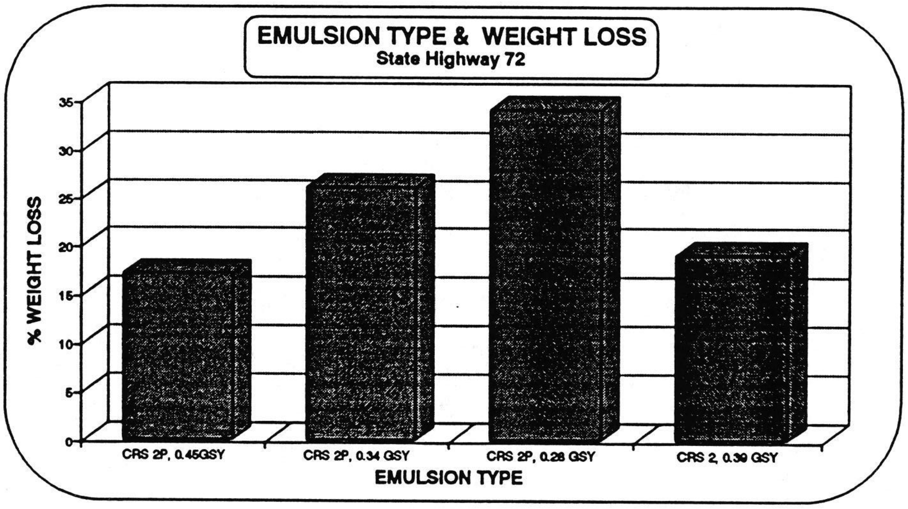
The poor performance of the seal samples from State Highway 1 was mainly due to the aggregate gradation. The

Table XV : Final Weight Loss of Seal Coat Samples.

Job \ Emulsion	Total Weight Loss @ 30,000 wheel passes			
	CRS 2 @ 0.40 GSY	CRS 2P 0.30 GSY	CRS 2P 0.35 GSY	CRS 2P 0.40 GSY
SH 72	19	34	26	17

Job \ Emulsion	Total Weight Loss @ 30,000 wheel passes		
	CRS 2	CRS 2L	CRS 2P
SH 43	23	16	10
SH 56	N.A.	16	12

Job \ Emulsion	Total weight Loss @ 14,000 wheel passes.		
	CRS 2	CRS 2L	CRS 2P
SH 1	30	22	21



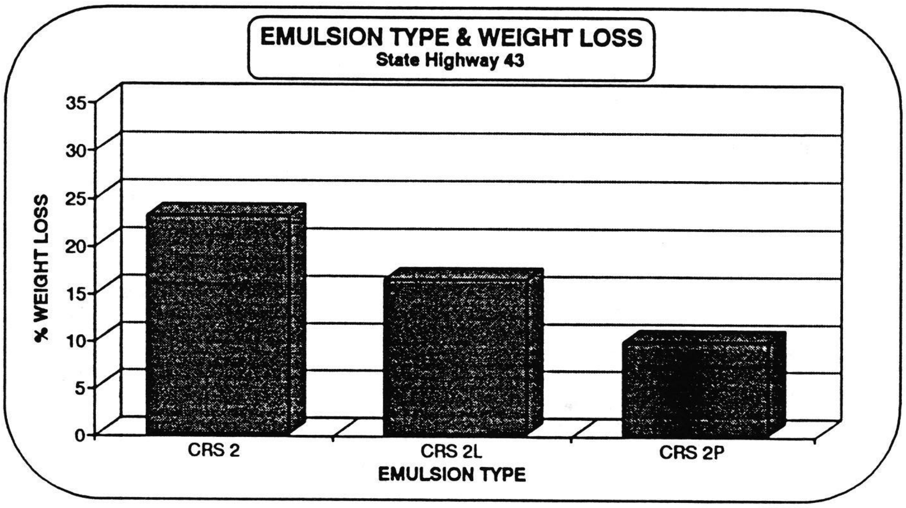
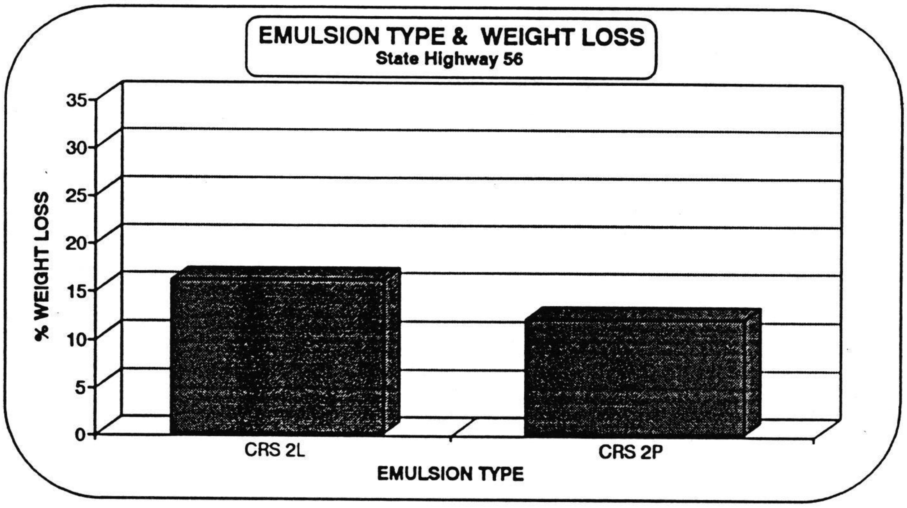


Figure 6 : Emulsion Type and Weight Loss (contd.)



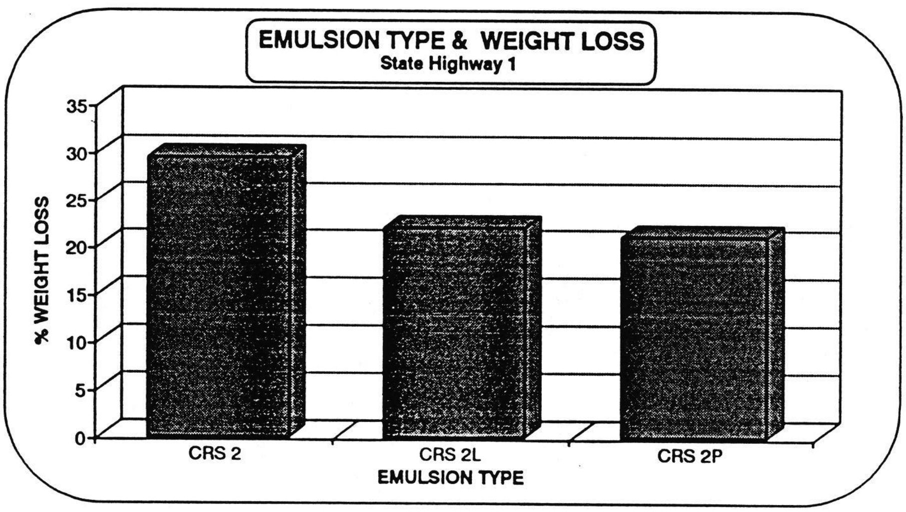
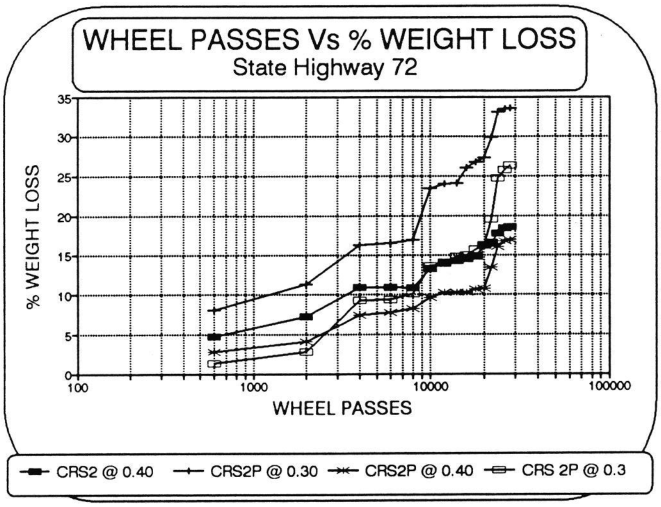


Figure 6 (contd.) : Emulsion Type and Weight Loss.

median aggregate size was only 0.16 in. which is rather small. Smaller aggregate chips will eventually "sink" into the asphalt layer under traffic load and thus contribute little to the overall performance of the seal coat. The samples on the wear track lasted for only 14,000 wheel passes.

Seal coat samples on SH 72 showed that reducing the quantity of CRS 2P had a deteriorating effect on seal coats. Samples with residual emulsion of 0.31 gal./sq.yd. lost about 17 percent of seal coat material after 30,000 wheel passes whereas, the loss was 34 percent when the residual emulsion was 0.26 GSY. Hence, it may be concluded that when the design emulsion application rate is lowered, even polymer modified emulsions begin to perform poorly. This may be due to the reduction in aggregate embedment depth which would normally be 50 to 70 percent if the design shot rate is used.

The results from the accelerated wear test indicate that polymer modified emulsions hold aggregate chips better at higher temperatures than the regular emulsions. The typical relationship between wheel passes and weight loss are shown in Figure 7 for SH 72 and Sh 43 and in Figure 8 for SH 56 and SH 1. The slope of the line representing the weight loss is high for CRS 2 compared to CRS 2P during warm cycles. The CRS 2Ps generally have higher absolute viscosity and higher softening points which may enable them to hold the aggregate better as the test temperature is



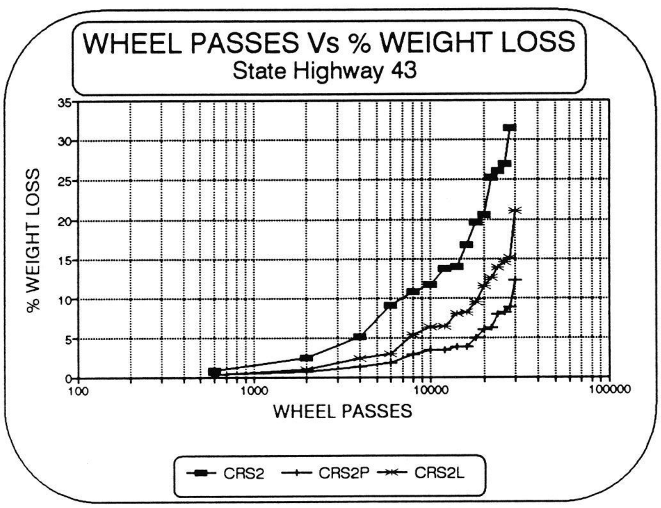
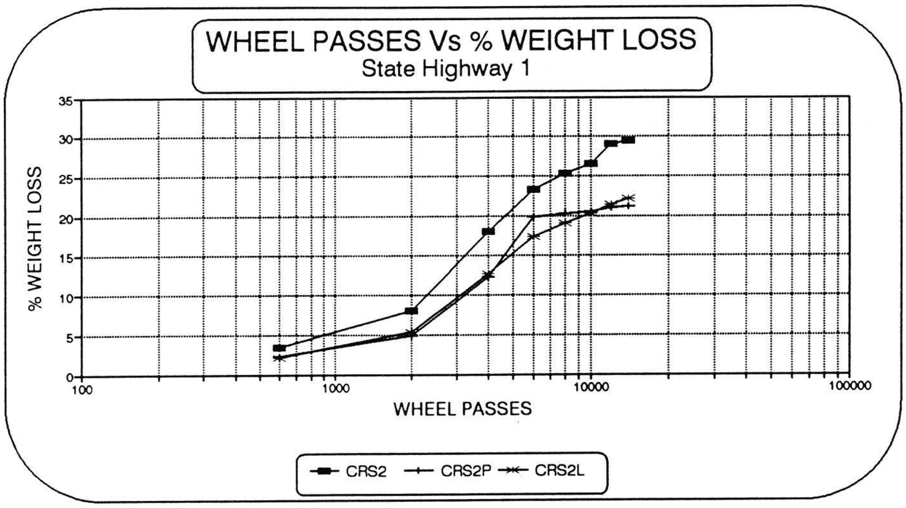


Figure 7 : Graphs Showing Wheel Passes and Corresponding Weight Loss (SH 72 & SH 43)



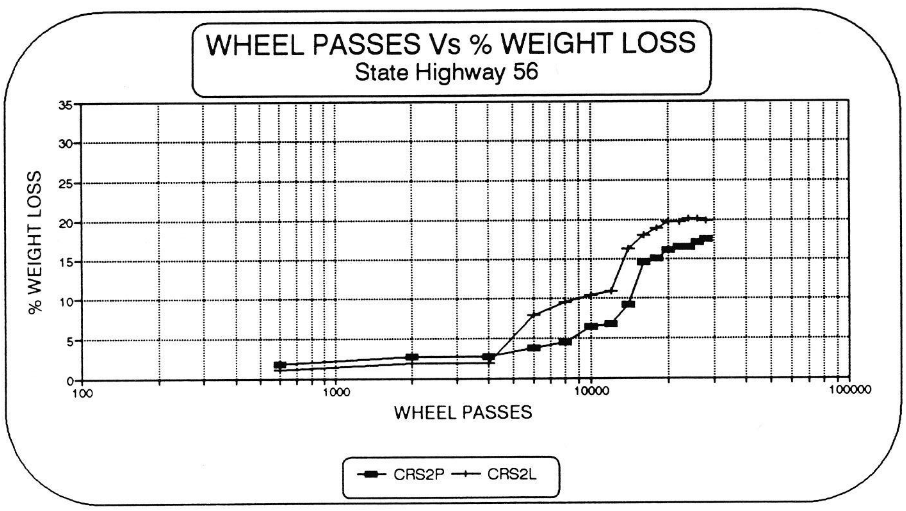


Figure 8 : Graphs Showing Wheel Passes and Corresponding Weight Loss (SH 1 & SH 56)

increased.

Performance, Service Life and Economics

Performance

The initial performance of the 1991 polymer, latex and regular CRS 2 chip seal jobs are shown in Table XVI. For comparison purposes the design and actual emulsion application rates in gallons per square yard (GSY), skid number 40 (SN-40) and percentage wear from the laboratory test tract are also shown in Table XVI.

In general the data indicates the polymer jobs gave a higher SN-40 value, better laboratory wear resistance and higher condition rating than the latex jobs. Likewise, the test data indicated that latex jobs were better than regular CRS 2 jobs.

The cost information reported later shows that polymer jobs cost more than latex jobs, which cost more than CRS 2 jobs. Thus, the most economical material to use in chip seals may be determined by economic analysis taking into account their cost, time value of money and service life of each job constructed with the different emulsions.

The field evaluation of Job 72-3 indicates some of the problems encountered in trying to determine chip seal performance. In 1990, after the seal had been in place only a month, the CRS 2P section with a design application rate of 0.40 GSY had a condition rating of 90. In July of 1992 this section's condition rating was 75 because excessive bleeding was observed in the wheel paths. The measured

Table XVI: Initial Chip Seal Performance

Route/ Section	Emulsion Type	Application Design	Application Actual	% Wear	SN 40	Condtion Rating
72-3	CRS-2P	0.40	0.47	20	23	90/75
72-3	CRS-2P	0.35	0.35	26	34	85/80
72-3	CRS-2P	0.30	0.27	35	36	80/85
72-3	CRS-2	0.40	0.39	17	39	90/85
43-1	CRS-2P	0.42	0.41	14	51	90
43-1	CRS-2L	0.42	0.42	16	54	85
43-1	CRS-2	0.42	0.39	22	41	65
56-2	CRS-2P	0.38	0.35	15	66	95
56-2	CRS-2L	0.38	0.40	20	62	88
1-14	CRS-2P	0.29	0.30	40	46	65
1-14	CRS-2L	0.29	0.34	42	38	78
1-14	CRS-2	0.29	0.24	53	37	45

Note: Condition Rating Dates: R/S 72-3,10/90 and 7/92; R/S 43-1, 7/92; R/S 56-2, 9/92; R/S 1-14, 8/92.

SN-40 Test Data Received January 1992.

application rate for this section was 0.47 GSY. The comparable CRS 2 section, which had a measured application rate of 0.39 GSY had a condition rating of 90 in 1990 and had decreased to 85 in the 1992. This data would indicate that CRS 2 emulsion gave a better chip seal than did the CRS 2P emulsion. Two other sections were constructed with CRS 2P, using reduced application rates, are also shown in Table XVI. The section with 0.35 GSY application rate had a 1990 rating of 85, which decreased to 80 in 1992. The other CRS-2P section with an actual application rate of 0.27 GSY indicated an increase in condition rating from 80 to 85 over the same time period. Possibly, this would indicate the best design shot rate for the traffic and aggregate on Job 72-3 would be 0.27 GSY.

The wear track results of Job 72-3 are relative values for this job only, these weight losses are not comparable with other jobs because the field plate samples were taken perpendicular to the road centerline rather than the standard method of parallel to the traffic flow. The CRS 2P wear track data is of interest because the section with an application rate of 0.27 GSY had a wear loss of 35 percent versus 26 percent for the 0.35 GSY job and 20 percent for the 0.47 GSY job. The CRS 2 section with an application rate of 0.39 GSY had a wear loss of only 17 percent. The SN-40 value for the CRS 2 section was 39, while the CRS 2P section's skid number ranged from 23 to 36.

The 1992 condition ratings for the CRS 2P sites of Job

43-1 and Job 56-2 were 90 and 95, respectively. The CRS 2L sites of the Job 43-1 and Job 56-2 were 85 and 95, respectively. These ratings indicate that both polymer and latex emulsion material were providing pavements with excellent serviceability after about 1 year of service. No CRS 2 emulsion material was available for use on Job 56-2 at the time of chip sealing.

The CRS 2 section of Job 43-1 had a 1992 condition rating of 65 which seems low, compared with other sections. However, the CRS 2 section had a wear track loss of 22 percent which indicates less resistant to wear than the CRS 2P and CRS 2L sections with 14 percent and 16 percent loss, respectively. The skid number data also indicates less surface friction available in the CRS 2 section, having a SN-40 value of 41, whereas the CRS 2P and CRS 2L sections had skid number values of 51 and 54, respectively.

The condition rating of the seal coat on Job 1-14 was the lowest of the four sections investigated. The CRS 2P section had an wear loss of 40 percent, and a 1992 condition rating of 65. The CRS 2L section had a wear loss of 42 percent and a condition rating of 78. The CRS 2 section had a wear loss of 53 percent and only a condition rating of 45. The average shot rates reported in Table XVI show the CRS 2 emulsion rate at only 0.24 GSY, while the CRS 2P and CRS 2L emulsion sections had 0.34 and 0.30 GSY, respectively. Insufficient asphalt may have contributed to the lower condition rating and higher wear loss of the CRS 2 section.

The low condition rating for Job 1-14 may also be attributed to the small size aggregate used along with the lack of embedment of the aggregate into the emulsion due to the low compaction effort of the pneumatic roller used on this job. It is noted that Jobs 72-3, 43-1 and 56-2 were constructed using both pneumatic and steel wheel rollers for embedment of the aggregate into the fresh emulsion. The aggregate spread modulus size for Job 72-3, Job 43-1, Job 56-2 and Job 14-1 was 0.23, 0.28, 0.23 and 0.16 inches, respectively.

Continuing examination of the field performance of these test sections using video camera and skid trailer may be used to compare the performance of the different emulsions, aggregates and construction methods. The visual appearance of the pavement sections may be compared with the initial appearance using the video tapes taken during the sampling process and the later 1990 and 1992 field condition rating work on each study section.

<u>Service Life</u>

The service life of a chip seal is defined as the age at which the pavement needs to be resealed to maintain satisfactory performance. Factors that affected the comparison of service life of the road sections under study include: levels of traffic, climatic conditions, funds available and squeaky wheels, condition of existing pavement at time of sealing, variation in the field personnel doing the condition rating and the qualitative method used to determine pavement condition.

The service life of the chip seals constructed in 1981, which were studied on Transportation Research Project No. 65 (TRC-65) "Evaluation of Asphalt Surface Treatment Characteristics and Performance", were determined from searching AHTD maintenance records. The 17 jobs evaluated on this project were constructed using local aggregates and CRS 2 emulsion. In addition, three seal coats were studied that were constructed, using Styrelf additive to the AC-20 asphalt cement. This was the "polymer emulsion" in 1981. The service life of these chip seal jobs is shown in Table XVII. The age of the chip seals when resurfaced range from 2 years for Job 130-06 and Job 8-6 to 11 years for Job 58-0. Jobs 82-2, 1-14, 7-14 and 49-4 were high type ACHM carrying a much higher level of traffic than most of the other 1981 jobs. ACHM overlays were placed over these sections rather than using chip seals to maintain their serviceability.

Regression analysis of the service life and wear track weight loss of these jobs gave the following relationship.

$$N = 20.46 - 4.6 \text{ LN WEAR}$$

where:

N = Service Life, years

LN WEAR = Natural Log of WEAR TRACK % LOSS

For a wear loss of 10 percent, the service life would be predicted to be 9.9 years. For a wear loss of 50 percent, the service life would be predicted as 2.5 years. Due to the many variables affecting the chip seal service life and its estimation, this equation has a coefficient of

Table XVII: Service Life and Annual Cost for 1981 Jo

Route / Section	Equivalent Uniform Annual Cost / Mile	Service Life When Replaced (Year)
58-0	550	11
102-1	699	8
95-2	859	6
348-2	624	8
7-13	1053	3
8-6	2112	2
21-4	1273	3
37-2	696	5
31-1	696	5
35-3	813	4
26-1	1084	4
49-9	474	5
130-6	1024	2
1-14	357	7
90-3	474	5
75-5	501	5
155-4	954	5
237-0	1405	3
I40-33	947	5

determination of 0.5. This means that 50 percent of the relationship between chip seal service life and wear track results are explained by this equation. However, it is noted that the reported age of the chip seals given in Table XVII was not necessarily equal to their service life because of the several factors previously stated. In addition each highway district has varying maintenance needs that dictate when to program a chip seal job.

The accelerated wear track test procedure developed on the TRC-65 project may be safely used to compare asphalt materials and aggregates proposed for use in chip seals. The wear track test procedure results in a wear loss determination that is related to relative chip seal performance.

Economic Analysis

The material cost for each seal coat was determined for each job. The price of CRS 2, CRS 2L, and CRS 2P emulsions and the average aggregate cost for all ten districts were used in the calculations. The price per gallon of each type of emulsion were: CRS 2, $0.50; CRS 2L, $0.60; and CRS 2P, $0.70 Likewise, the AHTD average price per ton for each aggregate type was determined to be as follows: class 1, $8.82; class 2, $8.96; class 3, $10.15; and class 4, $9.46. No estimate of the equipment and labor cost used in the construction of the chip seals was obtained.

The cost of the quantities of emulsion and aggregate per square yard for each of the 1991 jobs are shown in Table

XVIII. The cost per square yard ranged from $0.20 for the CRS 2 section of Job 14-1 to $0.35 for the CRS 2P section of Job 72-3.

The cost of materials used on the 1981 jobs are given in Table XIX. The 1991 material costs were used, along with the measured aggregate and emulsion application rates of the 1981 jobs. The cost of the styrelf emulsion was estimated to be equal to the CRS 2P emulsion. The unit cost ranged from $0.37 on Job 58-0 to $0.16 on Job 130-6.

A unit road section sized one mile long and twenty feet wide was used in the calculations to compare annual costs of the different jobs. The Equivalent Uniform Annual Cost (EUAC) using six percent interest rate and the job service life was calculated for each different seal section.

The EUAC of the 1981 jobs are shown in Table XVII. The EUAC ranged from $357 on Job 1-14 to $2112 on Job 8-6. The high annual cost of Job 8-6 was caused by its short life of only 2 years. Examination of record photographs taken during the sampling process of this job indicate the pea gravel used was wet and may have been dirty. Laboratory test results on this aggregate showed that it had a dust coating of 1.2 percent minus #200 material. The other seal coat lasting only 2 years was on Job 130-6, its premature failure resulted from the construction procedure of applying the aggregate chips after the emulsion had broken. Job 26-1 lasted only 4 years, resulting in an annual cost of $1084. At the time of this construction it was pointed out by the

Table XVIII: Cost of Materials on 1991 Jobs
(Cost per Square Yard of Chip Seal)

Job #	Agg. Class	AC Type	AC Cost	Agg. Cost	Total Cost
1-14	3	CRS 2	0.12	0.06	0.18
1-14	3	CRS 2L	0.20	0.07	0.27
1-14	3	CRS 2P	0.20	0.06	0.26
43-1	2	CRS 2	0.20	0.08	0.28
43-1	2	CRS 2L	0.26	0.08	0.34
43-1	2	CRS 2P	0.29	0.07	0.36
72-3	2	CRS 2	0.20	0.08	0.28
72-3	2	CRS 2P	0.25	0.07	0.32
56-2	2	CRS 2L	0.23	0.09	0.32
56-2	2	CRS 2P	0.23	0.09	0.32

Table XIX: Cost of Materials on 1981 Jobs (Cost per Square Yard)

Job #	Agg. Class	AC Cost ($)	Agg. Cost ($)	Total Cost ($)
58-0	1	0.25	0.12	0.37
102-1	1	0.23	0.14	0.37
95-2	1	0.25	0.11	0.36
348-2	1	0.20	0.13	0.33
7-13	2	0.15	0.09	0.24
8-6	2	0.19	0.14	0.33
21-4	2	0.20	0.09	0.29
37-2	2	0.16	0.09	0.25
31-1	2	0.15	0.1	0.25
35-3	2	0.17	0.07	0.24
26-1	2	0.19	0.13	0.32
49-9	3	0.10	0.07	0.17
130-6	2	0.10	0.06	0.16
1-14	3	0.10	0.07	0.17
90-3	3	0.10	0.07	0.17
75-5	3	0.11	0.07	0.18
155-4*	1	0.25	0.1	0.35
237-0*	2	0.19	0.13	0.32
I40-33*	3	0.28	0.06	0.34

* Jobs Placed with Styrelf. Used CRS 2P Cost.

Job Foreman during stockpile sampling that a thin coating of clay like material would cover your hands when picking up the material. Special attention was given to these aggregate materials during laboratory evaluation; when washed over the #200 screen, only 0.4 percent material was present. This confirmed the visual evaluation that the aggregate was "clean". Perhaps this observation indicates that the quality of the "clay" coating on the pea gravel is more important than the actual amount.

The economic decision of which emulsions to use, either CRS 2P, CRS 2L or CRS 2, can not be justified until the actual service life of the sections under study is known. The procedure used in the evaluation of TRC-65 study sections may be used to determine the most economical material to use.

Computer Program

Even though there were two computer programs available for designing seal coats, a new, more user friendly program was needed. The old programs which were written in BASIC had some drawbacks. One of the programs would not work for certain aggregate gradations, and it was not possible to change input data without starting the program from the beginning. Hence, it was desirable to develop a new program which would be more user friendly by enabling the user to change input data without having to start the program all over again.

Hence, a work sheet proved to be a better choice.

Since spread sheet software like LOTUS 123 and Quattro Pro is quite popular in almost all the technical departments nowadays, using the program would not pose much of a problem.

SEALIT, a work sheet in QUATTRO PRO was developed adopting The Asphalt Institute's design procedure. It is very simple to use and is self explanatory. The average time to design a seal coat using the spread sheet is approximately 3 minutes provided all the data needed are handy. Since this program is a work sheet, the user can change any particular input data like gradation or traffic at any time without having to start the program from the beginning. The program is capable of designing seal coats using both flakiness index and spread modulus. The engineer can then judge what application rates to use.

The data needed to run the program includes gradation of aggregate, flakiness index, bulk specific gravity, traffic factor, aggregate wastage,and the variable to cover absorption by pavement.

The average least dimension and spread modulus are calculated by the work sheet mathematically. Thus, the use of gradation charts and other graphs are avoided. The work sheet for SEALIT is shown in full in the Appendix.

Summary of Results

From the accelerated wear track test it was found that the polymer modified emulsions hold aggregate chips better than the regular emulsions at higher temperatures. However, there is no evidence that the design quantity of CRS 2P can be reduced. On the contrary, tests on seal coat samples from State Highway 72 showed that the wear increased as the quantity of emulsion was reduced.

The size of the aggregate is as important as the quality of emulsion. Samples from State Highway 1 performed very poorly mainly because of the smaller aggregate size. The use of polymer-modified emulsion was not very helpful in improving the overall performance of the seal coat.

The application rates for emulsion and aggregate obtained from tray tests and by using the Asphalt Institute design procedure were very close. Hence, the Asphalt Institute Design Procedure can be trusted to give correct application rate at least for the aggregate. However, to obtain reasonably accurate emulsion application rates, the input data like existing road condition, traffic, aggregate gradation should be very accurate.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

On the basis of experimental work conducted and within the limitations of the test procedures and for the range of materials and conditions utilized in this research project, the following conclusions are warranted:

1. The polymer and latex modified emulsion chip seals are more durable than CRS 2 chip seals, but they may not be as cost effective.
2. Class 1 and Class 2 aggregates are better than Class 3 aggregates for chip seals.
3. The Asphalt Institute Design procedure given in Manual Series 13, Asphalt Surface Treatments and Asphalt Penetration Macadam gives reasonably accurate application rates when compared with the "Tray Test".
4. Results of the wear track test on samples from State Highway 72 indicate that seal coat weight loss increases if the quantity of CRS 2P is lowered below the design rate.
5. All other factors being equal, to obtain a good chip seal it is necessary to apply the proper amount of liquid asphalt that is compatible with either Class 1 or Class 2 aggregate, compact with pneumatic and steel wheel rollers until aggregate is seated. Proper attention to good workmanship is the key to obtaining good chip seals.

On the basis of the results of this investigation, the following recommendations are presented:

1. From the laboratory tests, Class 1 or Class 2 aggregates with Polymer Modified Emulsions make the best chip seals. However, to ensure maximum seal coat life all the basic rules of construction should be followed.
2. Class 1 or Class 2 aggregates with CRS 2 also perform reasonably well. However, Class 3 aggregate should be avoided as far as possible. Using polymer-modified emulsions with Class 3 aggregate will only increase the cost with no significant increase in performance.
3. Assuming high quality construction, the following combination shows the performance of Seal Coats.

   Class 1 or Class 2 aggregate + CRS 2P => Excellent

   Class 1 or Class 2 aggregate + CRS 2 => Good

   Class 3 aggregate + CRS 2P => Average

   Class 3 aggregate + CRS 2 => Poor.
4. For roads with high traffic, the first combination is recommended. However, the quality of construction can never be over stressed in seal coat construction. When using other combinations, use of engineering judgement is recommended depending on the importance of the job.
5. Laboratory tests show that the Asphalt Institute Design Procedure gives application rates which are accurate for all practical purposes. Since the computer program "SEALIT" is based on this procedure, it is recommended that this program be used when designing seal coats.

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APPENDIX

SEALIT

(A Program to Design Asphalt Chip Seals)

By: Nat Banihatti 1993 Dept. of Civil Engineering, University of Arkansas, Fayetteville, AR

Instructions :

1. Enter Data in those cells which are marked [ ] <<

2. All other cells have been protected to prevent accidental alteration.

Note : This program is based on the Asphalt Institute procedure for Seal Coat Design given in Manual Series 13.

JOB I.D. :	STATE HIGHWAY 72-1
DATE (MM/DD/YY/):	1/24/1994
BY :	Nat Banihatti
OTHER INFO. :	Aggregate: Crushed Limestone Emulsion: CRS 2P

DESIGN USING ONE-SIZE AGGREGATE:

Determination of median size, P50 :

(Enter in INCHES. Use table on right for sieves with nos. and fractions)

% passing next higher to 50%	95.4	<<
Size (in.) corresponding to this %	0.375	<<
% passing next lower to 50%	25.7	<<
Size (in.) corresponding to this %	0.1874	<<

Sieve	Size(in.)
1 1/8	1.1250
3/8	0.3750
#4	0.1874
#10	0.0787
#16	0.0468
#20	0.0330
#40	0.0165

MEDIAN SIZE OF THE AGGREGATE 0.25 in.

Determination of Average Least Dimension :

ENTER FLAKINESS INDEX OF THE AGGREGATE 25 <<

AVERAGE LEAST DIMENSI- -ON. (inches)	0.18

Enter Bulk Sp. Gravity of Aggregate 2.7 <<
Enter Aggregate Wastage in %ge 5 <<

Enter Traffic Factor "T" 0.7 <<

Traffic Factor	
Traffic	"T"
<100	0.85
100-500	0.75
500-1000	0.70
1000-2000	0.65
over2000	0.60

Enter Variable "V" to cover absorption by pavement (see below) 0 <<

Variables for Pavement Condition	
Condition of Surface	"V"
Smooth non-porous	0.00
Slightly porous & oxidized	0.03
Slightly pocked,porous & oxidized	0.06
Badly pocked,porous & oxidized	0.09
Flushed Asphalt Surface	-0.03

Enter the % Residue of Asphalt Emulsion 68.45 <<

RESULTS

AGGREGATE SPREAD = 19.18 lbs/sq.yd.

ASPHALT EMULSION SHOT RATE = 0.21 gal./sq.yd.
(Residual Asphalt Emulsion = 0.14 gal./sq.yd.)

DESIGN USING GRADED AGGREGATE :

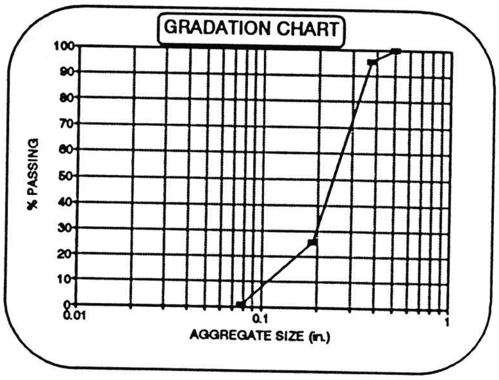
From Gradation Data,

Enter 100 % passing aggregate size in in.	0.5	<<
Enter the %ge passing next higher to 80 %	95.4	<<
Enter the Size in in. corresponding to this %ge	0.375	<<
Enter the %ge passing next lower to 80 %	25.7	<<
Enter the Size in in. corresponding to this %ge	0.1874	<<
Enter %ge passing next higher to 20 %	25.7	<<
Enter the size in in. corresponding to this size	0.1874	<<
Enter the %ge passing next lower to 20%	1	<<
Enter the size in in. corresponding to this size	0.0787	<<

Sieve	Size(in.)
1 1/8	1.1250
3/8	0.3750
#4	0.1874
#10	0.0787
#16	0.0468
#20	0.0330
#40	0.0165

80 % passing size	0.33	in.
20 % passing size	0.16	in.
0 % passing size	0.07	in.

Hit "F10" to see full size graph.



SPREAD MODULUS = M = 0.26

Enter Loose unit weight of Aggregate. Lbs/cubic foot — 95 <<

RESULTS

AGGREGATE SPREAD =	19.44	lbs./sq.yd.
ASPHALT EMULSION SHOT RATE =	0.29	gal./sq.yd.
(Residual Asphalt Emulsion =	0.20	gal./sq.yd.)

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JOB I.D. :	STATE HIGHWAY 72-1
DATE :	1/24/1994
BY :	Nat Banihatti
OTHER INFO. :	Aggregate: Crushed Limestone Emulsion: CRS 2P

DESIGN INPUTS:

ONE-SIZE AGGREGATE :

Median Size of Aggregate	=	0.253	in.
Bulk Sp.Gr. of Aggregate	=	2.700	
Flakiness Index of Aggregate	=	25.000	
Average Least Dimension	=	0.181	in.
Aggregate Wastage in %ge	=	5.000	
Traffic Factor	=	0.700	
Aggregate Absorption	=	0.000	

GRADED AGGREGATE :

100% passing size	=	0.500	in.
80% passing size	=	0.334	in.
20 % passing size	=	0.162	in.
0% passing size	=	0.074	in.
Loose Unit Wt. of Aggregate	=	95.000	lbs./cu.ft.
Spread modulus	=	0.256	

RESULTS

One Size Aggregate :

Aggregate Spread	=	19.175	lbs./sq.yd.
Asphalt Emulsion Shot rate	=	0.208	gal./sq.yd.
(Corresponding Residual Asp.Emulsion	=	0.142	gal./sq.yd.)

Graded Aggregate :

Aggregate Spread	=	19.437	lbs./sq.yd.
Asphalt Emulsion Shot Rate	=	0.293	gal./sq.yd.
(Corresponding Residual Asp. Emulsion	=	0.201	gal./sq.yd.)

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