Effects of Mineral Fillers in Slurry Seal Mixtures

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Slurry seal coats have become useful in maintenance operations during the past few years; however, technology has lagged construction knowledge. Present specifications for slurry seals generally constitute an empirical proportioning of components rather than a design. The primary objectives of this research were (a) to determine the effect of mineral filler (a common additive) and residual asphalt content on the slurry seal mixture, (b) to evaluate a new slurry seal testing machine, and (c) to develop a method of design.

A method was for developed estimating the optimum emulsion content so that filler effects could be studied at the same level of design. Operating and testing procedures were carefully evaluated for applicability, and the variables of this testing procedure were standardized for the ensuing slurry seal research program. The objectives were evaluated from the test results and from visual inspections of the specimens. The test variables, abrasion, shoving and relative thickness, were correlated with a visual rating system. The data show that: (a) abrasion is the best measure to consider when evaluating a slurry seal mixture; (b) limestone dust and cement were better fillers for use with Rockdale slag aggregate; (c) cement and fly ash were more suitable with concrete sand mixtures; and (d) the design equation for predicting the optimum residual asphalt content was valid for slurry seal mixtures when tested in the Young wet track abrasion device.

•A SLURRY SEAL is a mixture of fine aggregate, emulsified asphalt, and water. Initially, the consistency of the mixture is low so that it can be spread easily in thin layers on the surface of an existing pavement or on a prepared base. Slurry seal mixtures of proper consistency are pourable, free flowing, and self-leveling. After placing, the water evaporates causing the emulsion to break, and the remaining mixture is a relatively durable, skid-resistant coating resembling asphaltic concrete in appearance.

A slurry seal coat has excellent sealing properties because of its low initial consistency. This sealing property was first utilized extensively for roadway work by the County of Los Angeles, Calif., in 1955, although the use of slurry seals had been known since the 1930's (1). Since then, a great interest has developed, and slurry seal coats have become useful in maintenance operations.

However, slurry seal technology has lagged behind construction; hence, the need for a rational design procedure and evaluation method has become paramount. Present specifications for slurry seals are based on the experience of the construction engineer and constitute an empirical proportioning of the components rather than a design. The current practice among engineers and contractors is to prepare a mixture in accordance with these specifications, using local materials. In many cases, a mineral filler, usually portland cement, is added to "improve" the slurry seal mixture.

Since experience has been the basis for the design of slurry seals, a primary purpose of this research was to determine the effect of mineral fillers on the mixture, and a secondary objective was to evaluate a method of slurry seal design.

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The general approach was to develop a method for estimating the optimum emulsion content so that the filler effect could be studied at the same level of design. Accordingly, a method of testing was adopted. Operating and testing procedures were carefully evaluated to determine if the tests were applicable to this study, and the variables of this testing procedure were standardized for the ensuing slurry seal research program. The objectives were evaluated from the test results and from visual inspections of the specimens.

SLURRY SEAL CONSTRUCTION

Purpose

The primary purposes of a slurry seal are to rejuvenate old and weathered asphaltic pavements, to fill cracks and small depressions, and to prevent moisture and air from entering the pavement (1). Slurry seal was used as a crack filler in the 1930's, and this property is still useful. As an illustration of the relative effectiveness of slurry seal coats, Zube (2) shows that they can reduce the water infiltration of pavements from 750 to 25 ml/min for a given area.

It has also been observed that a seal coat of this type will completely fill cracks in the pavement, whereas in a conventional chip seal coat, the aggregate will often bridge the cracks (3). In the same manner, small depressions and pop-outs will be filled and leveled.

Applications

Streets and Highways. —Slurry seal coats are used on streets and highways for the purposes discussed. In general, slurry seals are applied to existing pavements of asphaltic concrete or to surface treatments. They have also been applied to portland cement concrete pavements to improve the skid resistance and riding qualities of the surface. A slurry seal coat does not increase or improve the strength of the pavement structure.

Slurry seals have been used for street maintenance in Las Vegas, N. M. A continuous-type mixer was employed for this project, and the slurry seal coat was placed at the rate of 2,000 sq yd/hr. The slurry seal mixture contained 1 to 2 percent portland cement, 10 percent water, and 18 percent emulsion, based on the weight of dry aggregate (4).

The application rate for slurry seals used for street and highway work usually varies from 3 to 15 lb/sq yd depending on the thickness desired and the intented purpose of the coat.

Airport Runways. —One of the major problems in resurfacing an airport runway or apron is the time factor. Many large commercial and military installations cannot make costly shutdowns for normal resurfacing maintenance. Slurry seals have been used effectively in these instances because large areas can be resurfaced in relatively short periods of time. Another advantage is that no loose stones remain on the runway and shoulders to be picked up by jet engines.

The application rate for airports will generally be a little heavier than for streets and highways, probably about 10 to 14 lb/sq yd. But here again, the desired thickness and type of application are the controlling factors. When anionic emulsions are used, the greater thicknesses will increase the curing time; therefore, cationic emulsions are recommended for use in airport construction.

Parking Lots. —Slurry seal coats have been widely used on parking lots because of the speed and economy of the operation. The rate of application for these surfaces will usually be the same as that for streets and highways.

New Construction. —The slurry seal coat is generally considered to be a maintenance measure to resurface older pavements; however, it has been applied directly to the prepared base of new construction projects. A 3-year-old city street of this type was inspected in Waco, Texas, and was found to be in good condition.

Slurry seals, when used in this manner, are spread in one or more applications depending on the thickness desired; however, if more than one application is to be made, the first must be properly cured before any succeeding layer is placed.

Bridge Decks. —Concrete bridge decks have been paved with slurry seal coats to protect the concrete from de-icing chemicals used during the winter months. This covering is usually applied in the northern regions where these chemicals are used extensively. One of the major advantages of slurry seal for this purpose is that the thin application will not increase the dead load on the bridge or raise the grade line appreciably; hence, the effective height of the curbs will remain the same. Also, successive applications can be placed at the required maintenance intervals that will level the wheelpath without increasing the thickness of cover.

Rumble Strips. —Thicker applications of slurry seal have been used experimentally in the form of rumble strips and for the protection and delineation of highway transitions and medians. This is a mixture of coarse aggregate (½ in.) in a matrix of slurry seal; it can be formed and placed in a manner similar to that of portland cement concrete. Experimental strips have been placed with thicknesses up to ¾ in.

Color. —Although they are still in the experimental stage, colored slurry seals have been successfully placed. These applications have been on small test strips, parking lots, and driveways. Colored slurry seals have a potential in the field of traffic engineering as a type of lane delineation at interchanges.

These slurry seals are made with emulsified resins instead of asphalt, which accounts for their slower development. At the present time, the cost of a colored slurry is approximately 5 or 6 times that of a conventional slurry seal coat.

Methods of Placement

Slurry seals are mixed for placement on the roadway by the batch and continuous feed methods. When processed by the batch method, the mixture is usually made in transit-mix trucks enroute to the jobsite. After mixing, the slurry seal in placed by pouring the mixture in a spreader box pulled by the truck.

The spreader box is approximately 10 ft wide and 8 ft long with an adjustable gate near the end. Placement of the slurry seal proceeds as the spreader box moves forward. The mixture flows under the gate at the predetermined lane width and is struck off to the specified thickness by a squeegee attached to the box. The consistency of the slurry seal mixture at the time of placement should be such that it will flow in a wave approximately 2 ft in front of the strike-off squeegee (1).

The quantities for a typical batch of slurry seal are 25 gal of water and 47 gal of emulsion for each ton of dry aggregate (1). However, the quantities will vary with the nature of the aggregate and the desired consistency of the mixture.

The continuous feed mixer may be one of several patented devices. These are usually self-propelled units with storage bins for the emulsion, water and aggregate. The raw materials are fed continuously into the mixer, and the slurry seal mixture is discharged into an attached spreader box similar to the one already described.

Slurry seals may also be placed manually. In this case, the slurry mixture is spread by a hand squeegee in areas that are inaccessible to the spreader box. Slurry seal is also mixed in small mortar mixers and hand placed for patching operations.

Problems in Slurry Seal Construction

The problems associated with slurry seal coat construction lie in the general areas of mixing and placing. In mixing the slurry seal, the aggregates may ball or the emulsion may break. Segregation, streaking, and surface preparation are the primary considerations when placing the slurry seal.

Mixing Problems. —The mixing time of the slurry seal mixture is important because, during mixing, the emulsion must coat the aggregate particles and the desired consistency must be achieved. However, if the mixing time is too long, the excessive rolling and tumbling of the mixture will cause an early break of the emulsion (1). When this happens, the mixture will retain the brown emulsion color but will have a consistency similar to that of stiff concrete. The slurry seal mixture cannot be placed in this condition, and the addition of more water will not improve the consistency.

Other factors causing the emulsion to break in the mixer are the amount of fines or mineral fillers and the chemical activity of these powders. Large amounts of mineral powders and particularly powders with high chemical activity should be avoided.

A different problem related to mixing of slurry seals occurs when dry fines or mineral powders come into contact with the emulsion. Occasionally, there is a tendency for these powders to form balls or lumps, which may reach the size of baseballs. These balls are coated with emulsion on the outside, but when broken open consist of dry uncoated aggregate. Balling can be eliminated by blending the dust and mineral fillers with the aggregate before it is introduced into the mixer (5). Another preventive measure is to wet the aggregates before they are mixed with the emulsion; however, if too much water is added initially, the resulting slurry seal will have a very low consistency and cannot be properly placed and manipulated.

Placing Problems. —The surface of the existing pavement must be carefully prepared before the slurry seal is placed. This is done by thoroughly cleaning and wetting the old surface, thus assuring a good bond of the slurry seal coat. The existing surface is wet immediately ahead of the sealing operation with a fog spray of water, or a diluted emulsion tack coat may be used if the old surface is particularly absorptive (3, 5).

Another problem is placing the slurry mixture is segregation of the aggregate, which will result in loss of adhesion. If the mixture is too fluid, the larger, heavier aggregate will segregate or settle, leaving the smaller particles and emulsion in the upper levels of the exposed surface. Since the larger aggregate will not have enough binder, the seal coat will lose its adhesion and will fail. Segregation of the aggregate and emulsion can be controlled by using a well-graded aggregate and controlling the water and, thereby, the consistency (1). Usually the gradation can be improved by the addition of a mineral filler to the aggregate; however, this will vary with local aggregates and conditions.

Still another problem in the placement of slurry seal mixtures is the streaking of the seal coat surface by oversized aggregates. If the diameter of any aggregate is larger than the depth of the seal coat, it will be caught under the strike-off squeegee and leave a long streak in the surface. This can be prevented by screening the aggregate before it enters the mixer (1).

PREVIOUS DESIGN METHODS

Existing Specifications

In general, the design of slurry seal mixtures is an art. The present design methods are based on the experience of engineers and contractors and on the performance of existing slurry seal coats. Since conditions and materials vary with time and locality, a number of general specifications have resulted from these experience methods.

The Asphalt Institute enumerates the design requirements as aggregate gradation, emulsion content, and consistency of the mixture; however, the design is regulated to comply with the consistency requirement (6). For example, this specification gives a range of emulsion content of 20 to 25 percent by weight of the dry aggregate and a water content of 10 to 15 percent. The water content of the mixture should include the water in the emulsion and in the aggregates. The specification also recommends that trial batches of the slurry seal mixture be made with the materials to be used on the job to insure that the proper proportions and consistency have been maintained. The aggregate gradation recommended in this specification is given in Table 1.

TABLE 1

SPECIFICATIONS FOR AGGREGATE GRADATION

U. S. Std. Sieve Sizes	% Passing		
	Asphalt Inst.	Amer. Bitumuls	TTI[a]
3/8 in.	100	100	100
No. 4	100	100	85-100
No. 8	100	80-100	65-90
No. 16	55-85	50-90	45-70
No. 30	35-60	30-60	30-50
No. 50	20-45	20-45	18-30
No. 100	10-30	10-25	10-20
No. 200	5-15	5-15	5-15

[a]General application.

Field Adjustments

The final emulsion content of the slurry seal mixture is selected from the trial mixtures; however, since this selection is generally the result of limited tests, the mixture may be adjusted by the project engineer for unusual conditions encountered in the field. The emulsion content may be increased if the mixture appears to be dry and porous, that is, if the slurry seal contains an insufficient quantity of residual asphalt.

The consistency of a slurry seal mixture is estimated in the laboratory, but it is controlled by field adjustments. The basic method of controlling the consistency is the addition of water to the mixture, but if too much water is added the consistency will be low and segregation may occur. The consistency of a slurry mixture is difficult to measure because the available methods seem inadequate. Some of the methods considered for possible use were slump test, penetration test, and flow devices. Subsequently, the consistency of the slurry seal mixture is not determined, but the workability of the mixture is controlled in the field by experienced operators and in the laboratory by the feel of the mixture.

Workability is controlled in the field by regulating the water content of the mixture. The workability may be improved in some cases by the addition of 1 or 2 percent mineral filler. Normally, portland cement is used for this purpose because of its availability. However, caution should be observed when adding these fillers because they may cause the emulsion to break in the mixer or produce a dry mixture.

Difficulties Resulting from Improper Design

The most important factor in the design or proportioning of a slurry seal mixture is the selection of the proper emulsion content for the particular aggregate involved. If too much emulsion is used, the resulting seal coat will be sticky and will bleed; if too little emulsion is provided, the pavement will ravel and wear excessively. These same difficulties arise in some cases where the correct amount of emulsion was used initially, but the existing surface absorbed the asphalt, resulting in a low residual asphalt content in the slurry seal.

Another design factor to consider in preventing difficulties is that of gradation. Mixtures low in fines or material passing the No. 200 sieve will generally segregate and result in raveling and excessive wear, whereas those with excessive material passing the No. 200 sieve will be brittle and develop shrinkage cracks as the water evaporates from the mixture (5). The aggregates used for slurry seal mixtures must be free of clay and other deleterious materials. Most specifications require a minimum value of 40 for the sand equivalent test. The aggregate should consist of sharp angular particles to provide a skid-resistant surface.

Objectives of Proposed Research

The development of a rational design procedure for the optimum emulsion content of a slurry seal mixture is an important need in slurry seal technology. This research will attempt to develop such a design method so that the results of this study, including abrasion, shoving, and relative thickness of the specimen, can be examined at the same level of design.

Once the design method for optimum emulsion content had been established, the evaluation of the type and amount of mineral filler was made for each of the two aggregates used in this study. These aggregates were Rockdale slag aggregate and a concrete sand; the mineral fillers studied were Rockdale fly ash, portland cement, and limestone dust.

NEW DESIGN METHOD

Basis of Design

The design procedure developed in this thesis was conceived by Jimenez and is known as the Surface Area Method for Design of Slurry Seal Mixtures. This method is based on the amount of asphalt cement required to coat the aggregate particles to a specified film thickness, and the amount of asphalt necessary to satisfy the absorptive characteristics of the aggregate. (The asphalt cement in the voids of the mixture was not considered, except indirectly by use of the film thickness.) Absorption of asphalt by the existing pavement is another factor influencing the asphalt content, but it does not enter into these calculations. The pavement absorption is corrected in the field as previously described.

The amount of asphalt to meet the film thickness requirement was calculated from the surface area of the aggregate which was determined in accordance with the California centrifuge kerosene equivalent (CKE) (7). The correct gradation was computed from a combination of the aggregate and the amount of the mineral filler under consideration. Using this gradation and the factors from the CKE test, the surface area was computed in units of square feet per pound of dry aggregate. The surface area thus determined was corrected for the specific gravity of the material in much the same manner as in the original CKE test. For the purpose of this design method, the calculated surface area was corrected by the ratio of the apparent specific gravity of the material in question to 2.65 as follows:

$$\text{Corr. SA} = \text{SA} \times \frac{\text{SG}}{2.65} \tag{1}$$

where

Corr. SA = corrected surface area, sq ft/lb;
SA = computed surface area, sq ft/lb; and
SG = apparent specific gravity of the aggregate.

The value of 2.65 was chosen as a basis for correction because it represents a good average for most fine aggregates.

The asphalt film thickness used in this procedure is one of the principal design variables. The design equation is presented so that the user may substitute into the equation a film thickness based on his own experience. A film thickness of 8μ was chosen for use in this research because it resulted in computed asphalt contents that correlated very closely to asphalt contents used with good results in field mixtures of nearly the same aggregate combination. The selection of this value for film thickness was also influenced by the fact that slurry seals may be considered as a form of asphaltic concrete, and data (8) have shown that 8μ is a reasonable film thickness for asphaltic concrete.

Another important design consideration is the absorptive characteristics of the aggregate. The absorption of the aggregate may be determined by the CKE test, the ASTM test for water absorption, or in any other suitable manner, but the absorption for the liquid used must be correlated to the absorption of asphalt by the same type of aggregate. The CKE test (7) was used to determine the aggregate absorption in this research, and the procedure is outlined in that test method. The amount of asphalt absorbed is assumed to be the same amount as the kerosene retained by the aggregate.

Since the design factors have been established, the residual asphalt content can be computed. The residual asphalt is the amount of asphalt cement remaining after the emulsion has broken and the water has evaporated. The equation for predicting the optimum residual asphalt content is as follows:

$$\text{RA} = 0.0002047 \times \text{SG}_\text{A} \times t \times \text{Corr. SA} + \frac{\text{KA}}{100} \tag{2}$$

where

RA = residual asphalt, lb/lb dry aggregate;
SG_A = specific gravity of residual asphalt;
t = film thickness, μ;
Corr. SA = corrected surface area, sq ft/lb dry aggregate; and
KA = kerosene absorption, percent.

An example of this computation and a typical data sheet are shown in the Appendix.

The equation coefficient consists of the conversion factors for the units of the components of the equation. The coefficient used in this research was 0.000209, based on a specific gravity of the residual asphalt of 1.02. The value of specific gravity was assumed at the beginning of the project, and all of the emulsion contents were calculated using this assumption. At the conclusion of the slurry seal testing program, the actual specific gravity of the residual asphalt was found to be 1.03. It was determined that this variation in specific gravity would not significantly affect the optimum emulsion content.

The equation will yield an estimate of the designed optimum residual asphalt content in pounds per pound of dry aggregate, or this may be taken on a percentage basis as the percent residual asphalt of the dry aggregate. If the amount of residual asphalt in the emulsion to be used is known, 67.0 percent in this case, the emulsion content in percent can be easily calculated as a percent of the dry weight of the aggregate.

Testing Device

After the design of the slurry seal mixture has been completed, specimens must be made and tested so that the design can be evaluated and compared to others that have been field proven. The purpose of the testing device for this research was to compare the optimum emulsion content with other amounts and to compare the type and amount of mineral fillers at these emulsion contents.

The testing device for slurry seals was developed by Young Brothers of Waco, Texas, and is called the Young wet track abrasion device (Fig. 1). The apparatus is constructed so that the testing head is mounted on an inclined axis. When the machine is in operation, the testing head rotates and imparts a gyratory shearing action to the surface of the specimen. In addition, it creates a sucking or lifting effect similar to that of a tire rolling on the surface of the pavement.

The testing head is a hard rubber (durometer value of 50) annulus approximately 2 in. high with an outside diameter of 3⅞ in. and an inside diameter of 1⅜ in. The head is held by a steel positioning jacket so that it may be raised or lowered on the inclined shaft. For the purpose of this research, the head was located so that its speed of rotation was 6.6 rpm.

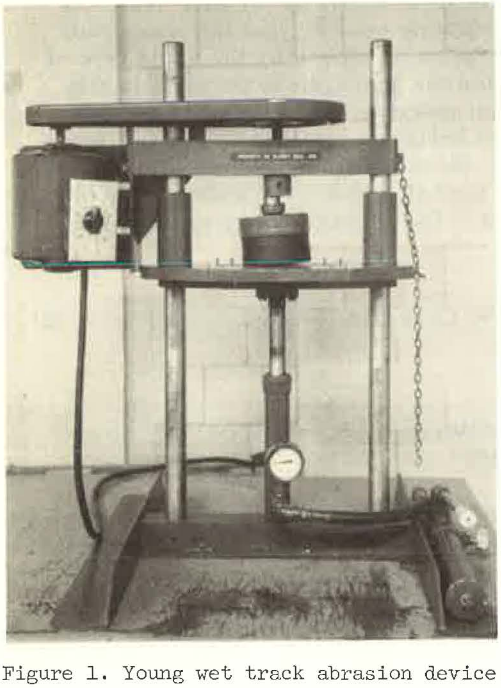

Figure 1. Young wet track abrasion device.

Testing Procedure

Operating and testing procedures for the Young wet track abrasion device, developed by Slurry Seal, Inc., were analyzed to determine their applicability to this research and the extent to which they should be adopted. The test variables examined were time, temperature, pressure, and specimen thickness. The study of these variables was conducted before the method for numerical evaluation of the tested specimens was finalized; therefore, the evaluation was made from a visual examination of the specimens on completion of these tests, and this rating of specimens was based on the experience of the operator.

Condition of Test. —To establish a standard condition of testing, the specimens were soaked in water and then tested under water. It was believed that testing under water would be the worst condition imposed on a slurry seal and would also help keep the surface of the specimen free of any abraded material. Since the specimens were tested in a water bath, the temperature could be more easily controlled.

Temperature. —The temperature at which the test is conducted has a very definite influence on the results of the experiment. A series of tests was conducted at various temperatures using a slurry seal mixture field proven by 4 years of good performance. The effects of temperature were determined by testing 6-in. diameter specimens at 56, 75, 100, and 135 F while holding the other test variables constant. The slurry seal mixture used for these experiments was a combination of 70 percent Rockdale slag aggregate and 30 percent field sand at an estimated optimum residual asphalt content of 10.7 percent. In fact, this slurry seal mixture was used as a standard for the test procedure study.

The test specimens at 100 and 135 F were slightly abraded, and a considerable amount of material was displaced from under the testing head and shoved outward and upward at the outer edge of the tested surface. This behavior will hereafter be termed shoving. At the lower temperatures, there was no evidence of shoving or abrasion in the tested area. Since the two lower temperatures were considered reasonable choices for test controls, the 75 F temperature was selected because of the ease with which it could be maintained and because it agrees closely with temperatures used in other asphalt testing procedures.

Pressure. —The wet track abrasion device is constructed so that a hydraulic jacking system holds the specimen against the testing head during the test, and a pressure gage is used to determine the pressure on the jack. This gage pressure was used to control the pressure on the specimen. Tests performed at gage pressures of 150 and 200 psi revealed that there was essentially no difference in the resistance of the specimen to pressure. Since the procedure recommended by Slurry Seal, Inc., uses a gage pressure of 150 psi, this value was used for the research.

The average pressure on the specimen was calculated by the basic principles of fluid mechanics in which

$$P_1 \times A_1 = P_2 \times A_2 \tag{3}$$

where

P_1 = pressure on jack, psi;
A_1 = area of ram, sq in.;
P_2 = pressure on specimen, psi; and
A_2 = contact area of the specimen, sq in.

The gage pressure was a known value of 150 psi and the diameter of the hydraulic jacking ram was 1 in. The contact area of the specimen was calculated as a sector of an annulus after the central angle had been determined. Thus, substituting these known quantities into Eq. 3 yields an average pressure on the specimen of 25.6 psi.

If a triangular pressure distribution is assumed, the maximum pressure will occur at the outer edge of the tested area. Such a pressure distribution did not exist, but the assumption was made to determine the relative magnitude of the maximum pressure. Hence, the pressure at the outer edge of the tested area was calculated to be approximately 38 psi.

Time. —The duration of the test was similarly studied with the emphasis placed on the length of time required to test the specimen. Time trials of 5, 10, and 15 min were employed using the standard mixture and at the temperature and pressure determined. A profile of the specimen surface was determined before and after the test, and the decrease in height and amount of shoving were obtained from these measurements. These calculations indicated that the thickness of the tested area decreased with time. An appreciable amount of shoving was not detected in the 5- and 10-min specimens, but was evident in the 15-min determinations. The greatest decrease in thickness and shoving occurred in the 15-min specimen, and it was concluded that the time should be shorter. The only difference in the 5- and 10-min specimens was the thickness of the tested area. It was felt that the 5-min duration was too short; consequently, the 10-min test period was selected.

Specimen Thickness. —The thickness of slurry seals commonly used in the field varies with the intended purpose, but the maximum is approximately ¼ in. The thicknesses considered in this study were $\frac{1}{8}$, $\frac{3}{16}$, and $\frac{1}{4}$ in. Thickness experiments were conducted using the standard mixture with varying conditions of time, temperature and pressure. When these test variables were evaluated and compared at the proposed thicknesses, it was felt that the $\frac{3}{16}$-in. specimen would be more suitable as a basis of evaluation than either the $\frac{1}{8}$- or $\frac{1}{4}$-in. specimens. Moreover, the $\frac{3}{16}$-in. thickness is representative of the thicknesses currently used in construction.

Selection of Test Procedure. —The result of the foregoing studies was that the basic procedure outlined by the developers was found applicable to this research. The only additional test control included in the final testing procedure was temperature.

The original specimen size was modified to eliminate the edge effects of the testing head on the slurry seal sample. The specimens used in this study were 6 in. in diameter, whereas the original specimens were 4 in. in diameter. The specimen thickness was increased from $\frac{1}{8}$ to $\frac{3}{16}$ in. as previously described.

The testing procedures and specimen size adopted for this research are believed to insure adequate and efficient testing of the slurry seal mixture. Summarizing, the slurry seal specimens were 6 in. in diameter and $\frac{3}{16}$ in. thick. They were tested in a water bath at 75 ± 5 F at a gage pressure of 150 psi for 10 min in the Young wet track abrasion device.

Another factor influencing the selection of these variables was the possibility of future field correlation. Since the developers have field data on slurry seals tested in a similar manner by this machine, these data may be used for comparison with this research.

MATERIALS

Aggregate

The aggregates used for slurry seal mixtures are usually controlled by specifications based on good field performance. The aggregate gradation recommended by the Asphalt Institute Specification ST-3 (previously discussed) and the gradation limits proposed by American Bitumuls and Asphalt Co. as reported by Kari and Coyne (5) are indicated in Table 1 (6). The gradation suggested by Kari is based on the results obtained from actual construction projects. The gradation recommended by the Texas Transportation Institute (TTI) is based on the maximum density curves derived by Fuller and Thompson (9).

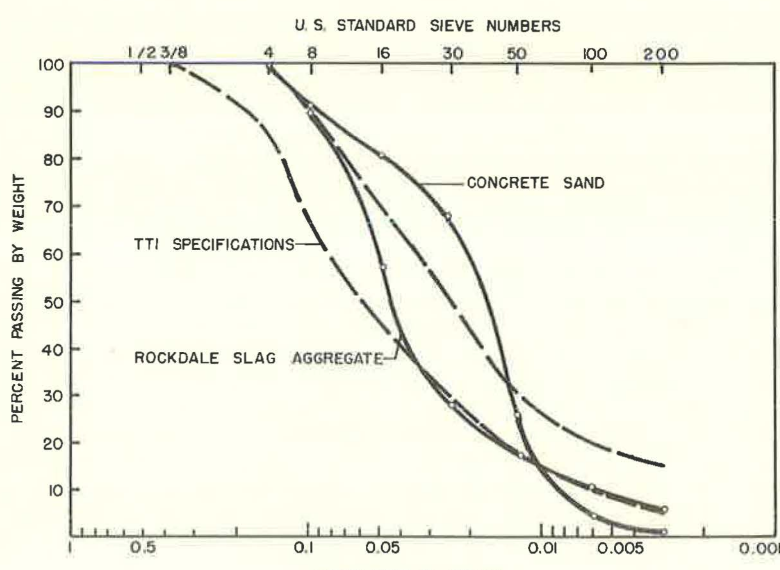

Figure 2. Aggregate gradation.

The maximum density curve was modified in consideration of workability by Jimenez, in accordance with experience gained from field studies.

The aggregates used in this study were Rockdale slag aggregate and a concrete sand. The Rockdale slag aggregate, produced at Sandow near Rockdale, Texas, is a by-product of the lignite burned at the plant as a power source. The specific gravity of this aggregate is 2.90, and the gradation is shown in Figure 2. The concrete sand was from the vicinity of Hearne, Texas. The specific gravity of this material was found to be 2.67, and its gradation is also shown in Figure 2. It appears from these graphs that the Rockdale slag aggregate, for all practical purposes, is within the previously recommended gradation limits, whereas the concrete sand is not. The Rockdale slag aggregate has not been used in the field as a complete aggregate for slurry seal mixtures; however, it appears to be satisfactory for this purpose.

The concrete sand requires an alteration of the particle size distribution before it will meet the recommended gradation. For the purpose of this research, the gradation of the concrete sand was changed to make it identical to the gradation of the slag aggregate. This was done so that the mixtures made from these aggregates could be compared on the basis of particle shape and surface texture, and the effect of asphalt content on these mixtures could be determined when the particle size distribution was held constant.

Mineral Fillers

A primary objective of this study was to evaluate the effect of three mineral fillers in slurry seal mixtures. A specification for mineral fillers, designated by the American Society for Testing Materials (ASTM) as D242-57T, was followed:

Passing No. 30 (590 μ) sieve, 100 percent;
Passing No. 50 (297 μ) sieve, 95-100 percent;
Passing No. 100 (149 μ) sieve, 90-100 percent; and
Passing No. 200 (74 μ) sieve, 70-100 percent.

The three mineral fillers used in this study were Rockdale fly ash, portland cement, and limestone dust with apparent specific gravities of 2.57, 3.03, and 2.74, respec-

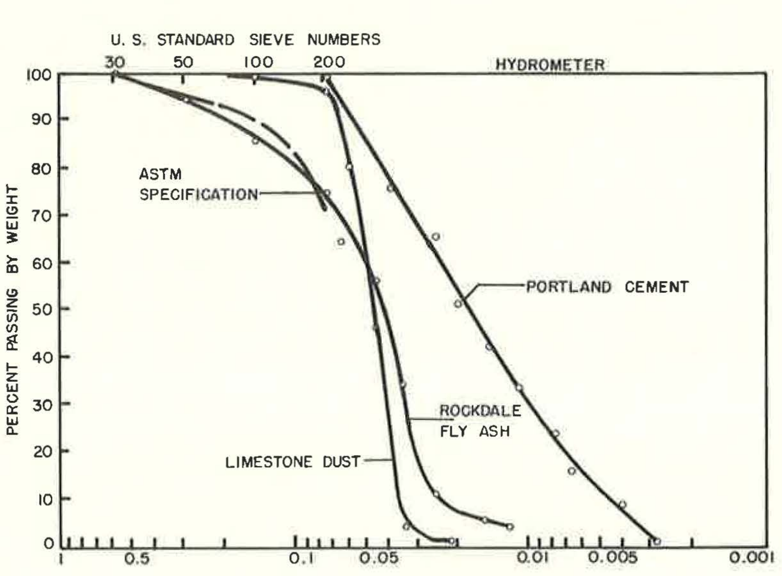

Figure 3. Mineral filler gradation.

TABLE 2

EMULSION CHARACTERISTICS[a]

Test Type	Laboratory Test	Manu. Spec.	
		Min.	Max.
Emulsion:			
Viscosity, Saybolt Furol	—	—	—
50 ml at 25 C (77 F) (sec)	87	30	100
Residual asphalt (%)	67.0	60	—
Settlement, 5 days	—	—	3.0
Demulsibility in 50 ml of 0.10N $CaCl_2$ (%)	—	—	1.0
Sieve test (%)	—	—	0.10
Miscibility in water, appreciable coagulation in 2 hr	—	—	none
Cement mixing test (%)	—	—	2.0
Residual asphalt:			
Specific gravity, 25/25 C (77/77 F)	1.034	—	—
Penetration, 100 g, 5 sec, 25 C (77 F)	80	—	—
Ductility, 5 cm/min, 25 C (77 F)	150+	—	—
Viscosity, 25 C (77 F), megapoises at $S_R = 5 \times 10^{-2}$/sec	1.8	—	—
Soluble in CCl_4	—	98	—
Ash	—	—	1.5

[a]American Petrofina SS-1h.

TABLE 3

EMULSION VISCOSITY BY THE BROOKFIELD VISCOMETER

Spindle No. 2 Speed (rpm)	Brookfield Viscosity (centipoises)[a]
2	2,500
4	1,590
10	828
20	596

[a]At 25 C or 77 F.

tively. The Rockdale fly ash was also a by-product of the burned lignite described previously. The portland cement was a Type I cement obtained locally, and the limestone dust from Pontiac, Ill., was used in the rehabilitation of the AASHO test road in Ottawa. The grain size distribution of each filler is shown in Figure 3. The particle size distribution for the filler passing the No. 200 sieve was determined by a hydrometer analysis. The fly ash is slightly outside the specification limits, whereas the portland cement and limestone dust are well within the specifications.

Portland cement and limestone dust are commonly used in field mixtures as mineral fillers, and it is believed that fly ash can also be used effectively when locally available. The cement and limestone dust are commercially available in almost any locality.

Emulsion

Slurry seal mixtures are commonly made with anionic emulsions, either Type SS-1 or SS-1h. The emulsion used in this research was American Petrofina Type SS-1h produced from a Talco, Texas, field crude. The physical characteristics of the emulsion and residual asphalt are indicated in Table 2. The viscosity of the emulsion was also determined by the Brookfield viscometer using spindle No. 2. The values of viscosity and viscometer speed are given in Table 3.

PREPARATION AND TESTING OF SPECIMENS

Experimental Design

This investigation was conducted with slurry seal mixtures containing combinations of the two aggregates and three mineral fillers at five different emulsion contents. Duplicate test specimens were made for each mixture. A total of 140 specimens were prepared. Mixtures were first prepared using each of the two aggregates with no mineral filler and at the selected emulsion contents. Similarly, mixtures were made containing 2 and 4 percent (by total weight of dry aggregate) mineral filler. These filler contents were selected because 1 or 2 percent is commonly used in the field whereas 4 percent is probably the maximum amount that can be used economically.

The emulsion content of each mixture was based on a specified residual asphalt content. After the optimum residual asphalt content was estimated, the others were chosen at 2 and 4 percent above and below the estimated optimum. These values were selected because this range would include most of the values currently in use, and it was also felt that the sensitivity of the testing device might not detect differences much smaller than 2 percent.

Blending Procedure

Once the number of specimens and the emulsion and filler contents had been selected, the constituents of the mixture were proportioned. A 1,000-gm batch of dry aggregate and mineral filler was prepared for each set of specimens. This mixture was then wetted with a small portion of the mixing water to prevent balling of the fines and breaking of the emulsion. The water added to the aggregate was measured so that it could be included in the total water content of the slurry seal mixture.

The emulsion for one batch was weighed into the mixing bowl which was then transferred to the mixer. The aggregate was added to the emulsion along with enough water to give the mixture the proper consistency. The total mixing time was 2 min, and the constituents were added during the first minute of operation. The total amount of water required was controlled by the operator who judged the consistency of the mixture by experience. Normally, the water content of the slurry seal mixture was about 10 percent by weight of the dry aggregate.

The mixer used for this study was a Hobart C-10 food mixer. A mechanical mixer was preferred over manual methods because it was believed that more uniform results could be obtained and it approached field mixing conditions.

Some difficulty was occasionally encountered. The emulsion would break in the mixer, and the resulting slurry seal mixture had a very stiff consistency. This was particularly evident in the mixtures of concrete sand with fly ash and cement. No trouble was encountered in any of the mixtures containing Rockdale slag aggregate.

Molding Procedure

After the constituents were mixed, they were cast as circular specimens on 7 sq in. steel plates. These plates were thin (approximately 0.05 in.) and were primarily used to facilitate the handling, testing, and removal of the slurry seal specimens.

The specimens were cast using thin steel rings as molds. These molds had an inside diameter of 6 in. and a depth of $^3/_{16}$ in. The slurry seal mixture was placed in the mold, and the top was struck off flush to obtain the desired thickness. The molding ring was then removed, and the finished specimen was cured in an oven at 140 F for 24 hr until it reached a constant weight.

Testing Procedure

The cured specimens were tested in the Young wet track abrasion device within 48 hr after removal from the oven. The normal procedure requires the specimens to be tested within 24 hr, but the time was extended to 48 hr because of the large number of specimens.

The testing procedure included compacting the specimens in the abrasion device at normal room temperature, about 75 F. The compaction was accomplished using the

TABLE 4

COMPACTION OF SLURRY SEAL BY TRAFFIC

Time	Density (gm/cu cm)		Voids[a] (%)	
	t = 1/8 In.	t = 3/16 In.	t = 1/8 In.	t = 3/16 In.
Init.	1.48	1.46	36.8	37.6
1 day	2.12	2.12	9.4	8.6
1 wk	2.19	2.21	6.4	5.6
1 mo	2.22	2.25	5.1	3.8
2 mo	2.23	2.26	4.7	3.4

[a]Based on computed maximum theoretical specific gravity of 2.34.

standard procedures described previously; however, the surface of the specimen was protected from the testing head by a steel plate during the compaction process, and the specimen was not compacted under water. Compaction is necessary because a newly placed slurry seal has an extremely high void content. Traffic will compact the mixture in most instances as indicated in Table 4, but areas subjected to high surface shears, such as turning movements, are likely to be torn before adequate traffic compaction can be achieved.

After compaction, the specimens were measured for density and soaked in a water bath at the test temperature for at least 30 min. The testing sequence was such that the maximum soaking period was approximately 1 hr.

On completion of the minimum soaking period, the specimens were tested in the abrasion device under the standard conditions. Observations were made throughout the test to determine if excessive abrasive action occurred. When this was the case, the time that disintegration began was noted as well as the time the specimen had abraded to its full depth.

At the conclusion of the test, the specimen was dried in a 140 F oven to a constant weight, and the unit weight and final surface profile were determined. At this time, the specimens were also rated visually for abrasion, shoving, and relative thickness. From these and other measurements described in the next section, the necessary factors were obtained to evaluate the slurry seal mixture.

MEASUREMENTS AND CALCULATIONS

Measurements

Presently, the most common method of determining the quality of a slurry seal coat is by field inspection or by visual examination of a specimen. Kari and Coyne (5) developed a method whereby slurry seal specimens are tested and a wear value is obtained. This is currently the only method available for numerically rating a slurry seal mixture; however, one of the objectives of this research is to establish a better method for rating a slurry seal mixture. The necessary measurements and calculations to rate the slurry seal mixture are presented in the following paragraphs.

Density. —The density of the test specimens was determined initially after compaction and finally at the conclusion of the test. Both the initial and final densities are required to compute the density of the material in the abraded portion of the specimen. This computation is based on the fact that the density after testing is calculated from the final weight divided by the volume after test. This volume has two components: the volume of the unabraded portion and that of the abraded portion. The volume of the unabraded portion may be calculated from the initial conditions if it is assumed that this volume was unchanged by the test. Thus, all of the conditions are known except the volume of the abraded portion of the specimen. Since the volume of the abraded portion can be calculated, the only other factor needed to compute the density of this portion of the specimen is the weight of the material in the tested section. This weight was calculated from the initial condition of thickness, area, and density; however, it was assumed that the only weight change was due to the abrasion of the machine. Hence, the weight of material in the abraded portion is the initial weight of this portion less the abrasion. With these factors known, the bulk specific gravity (SG_t) of the tested portion of the specimen was computed.

Thickness. —The thickness of the test specimen was determined initially when the compaction process was completed. The measurements were made with a dial gage mounted on a stand so that the gage could be positioned horizontally and vertically over the specimen. The measurements were made from a fixed reference, and the thickness was obtained by subtracting the thickness of the steel plate. The initial measurements

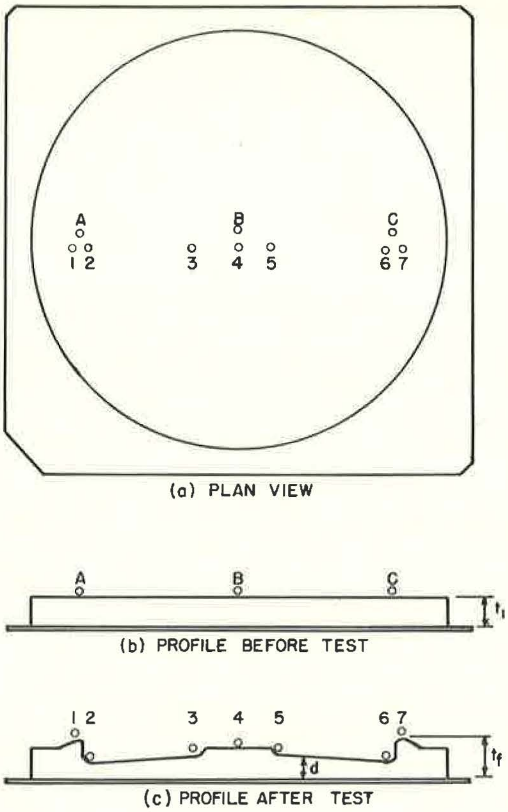

Figure 4. Sketch of typical specimen.

were made on a diameter of the specimen with the thickness determined at the center and 1 in. from each edge. These are shown in Figures 4a and 4b as measurements A, B, and C. The average of these depths was taken as the initial thickness, t_i.

The final measurements were made on the same diameter at locations numbered 1 to 7, and these are shown in Figures 4a and 4c. Measurements at locations 1 and 7 were made at the outer rim of the abraded portion of the specimen where the greatest amount of shoving was present. The average of these measurements was the final thickness, t_f. The measurement at location 4 was not used in this study. Measurements at locations 2, 3, 5, and 6 were taken inside the tested portion as indicated in the figure. The average depth of the specimen at these locations was indicated by the distance, d.

All of these thickness measurements were made at locations that were, in the opinion of the operator, representative of the surface of the specimen. The thickness at each location was the average of several readings taken in the immediate vicinity of that location.

Calculations

Shoving. —The shoving behavior has been described previously. This characteristic is measured by the increase in thickness at the outer edge of the tested surface as a percentage of the original thickness. The computation of the shoving characteristic is

$$S = \frac{t_f - t_i}{t_i} \times 100 \tag{4}$$

where

S = shoving, percent,
t_f = final thickness, average of 1 and 7, in., and
t_i = initial thickness, average of A, B, and C, in.

Shoving was observed in nearly all of the specimens tested, although it was significantly greater in some of the specimens. The shoving feature is discussed in the following chapter.

Relative Thickness. —The relative thickness, T_R, of a slurry seal specimen is defined as the ratio of final to initial thickness of the test specimen caused by the action of the abrasion device. The volume of the portion of the specimen under abrasion will usually be reduced, and a depressed area of the general shape shown in Figure 4c will be formed. However, this not always the situation because the depressed section did not occur on all specimens. In some samples the abrasive action of the testing head was so great that all of the material in the tested area was worn away, and in other samples there was no compaction or wear at all. Hence, evaluation of the relative thickness must consider the wear on the specimen.

The relative thickness was determined considering the average final depth as a percentage of the initial thickness. This calculation is shown by

$$T_R = (d/t_i) \times 100 \tag{5}$$

where

T_R = relative thickness, percent;
d = final thickness, average of 2, 3, 5, and 6, in.; and
t_i = initial thickness, average of A, B, and C, in.

Abrasion. —The wear or material loss of the slurry seal specimen will be termed the abrasion. This feature is measured as the percent weight loss of the material in the tested portion of the specimen. The weight loss was found by the difference in dry weights as determined in the density measurements made before and after testing. The weight of the material in the abraded portion of the specimen is a function of the area of the annulus (tested area), the initial thickness, and the initial density. The calculation is

$$W_A = 168.8 \times t_i \times SG_i \tag{6}$$

where

W_A = weight of mixture in area to be abraded, gm; and
SG_i = initial specific gravity of specimen.

This calculation is based on the assumption that the area under the testing head remains constant throughout the test. Using this value, the abrasion computation is

$$A = \frac{W_i - W_f}{W_A} \times 100 \tag{7}$$

where

A = abrasion, percent;
W_i = initial weight of specimen, gm;
W_f = final weight of specimen, gm; and
W_A = weight of mixture in area to be abraded, gm.

It is believed that this characteristic is the most important for the purpose of evaluating any slurry seal mixture. The range of abrasion values for this study was from 0 to more than 100 percent. The values greater than 100 arose from the fact that for cases where abrasion was appreciable, the testing head vigorously attacked the outer edge of the abraded area. When this was the case, the previous assumption is no longer valid, but a slurry seal mixture in this condition would not be considered for field use. Therefore, the slurry seal may be rated visually as unacceptable.

ANALYSIS OF DATA

Effects of Filler Content

As outlined previously, slurry seal specimens were made and tested using Rockdale slag aggregate and a concrete sand with 0, 2, and 4 percent Rockdale fly ash, portland cement, and limestone dust. The effects considered were abrasion, shoving, and relative thickness as discussed in the section on the preparation and testing of specimens. The density of the specimens was also studied to obtain a better understanding of the specimens and their behavior during the test; however, the density was not considered a test variable.

A statistical evaluation in the form of an analysis of variance (AOV) was made for each of the test variables including density. The analysis of variance was arranged as a two-way classification with two observations per combination. All tests were evaluated at the 5 percent significance level, and the two classifications were filler content as columns and residual asphalt content as rows. The AOV disclosed that in many cases there was interaction between the filler content and asphalt content. This indicates that the effects cannot be separated because they are not independent. In addition, the AOV often showed no effects of filler or residual asphalt content on the results; however, the data revealed that there were effects. Further examination of the data showed the variance within the combinations was greater than the variance between the groups; therefore, no effects were indicated by the AOV. Additional information obtained from the statistical analysis was the indication of filler and/or residual asphalt content effects.

The computations of the test measurements and the analysis of variance were made using the IBM 709 computer.

In addition to the statistical analysis, a visual rating system was established so that the slurry seal specimens could be rated as they were tested. Typical specimens were photographed and are included here to provide a basis of comparison for the potential users of this system. The slurry seal specimen with less than 1 percent abrasion, little or no shoving, and a high relative thickness (85 to 100 percent) was rated as excellent (Fig. 5). Specimens with 2 to 5 percent abrasion, little shoving and a medium relative thickness (60 to 85 percent) were classified as good (Fig. 6). If the specimen

Figure 5. Slurry seal test specimen—excellent: A = < 1 percent, S = < 10 percent, T_R = 85-100 percent.

Figure 6. Slurry seal test specimen—good: A = 2-5 percent, S = 10-15 percent, T_R = 70-85 percent.

Figure 7. Slurry seal test specimen—fair: A = 5-10 percent, S = 10-15 percent, T_R = 65- 80 percent.

Figure 8. Slurry seal test specimen—unsatisfactory: A = > 10 percent, S = > 15 percent, T_R cannot be determined.

was fair (Fig. 7), the abrasion was less than 10 percent, some shoving was noticed, and the relative thickness ranged from 65 to 80 percent. Specimens with more than 10 percent abrasion were rated as unsatisfactory (Fig. 8). This rating system was used as the best judge of the slurry seal specimen at the time of testing, and it could possibly be correlated to field performance. An abrasion value of 10 percent is approximately the same as a wear value of 70 gm/sq ft as reported by Kari (5).

The shoving of specimens was termed noticeable if a slight hump could be felt by passing the hand over the outer rim of the abraded annulus. Shoving values of less than 10 percent could not be detected by the hand, whereas values above 10 percent could be felt. For the purpose of this rating system, shoving values up to 15 percent are not considered excessive. When abrasion was not excessive, the relative thickness was estimated by the observer for the visual rating of the specimens. The range of values for the classification has been discussed previously.

Rockdale Slag Aggregate. —The data indicated that the abrasion was slightly increased in the Rockdale slag aggregate mixtures with the addition of mineral filler even though the asphalt content was adjusted for the addition of filler. Mixtures containing fly ash abraded more than those with cement or limestone dust; however, the abrasion did not increase to the extent that the samples were unacceptable by the visual rating system. The maximum abrasion, with the exception of one set of fly ash specimens, was approximately 5 percent which was rated as good to fair by the visual method. In most cases, the weight loss was not increased above the 1 percent abrasion level by the addition of mineral filler. Also, the density of specimens containing filler was generally less than that of specimens with no filler. This reduction in density might have been caused by a fluffing effect of the filler. The data indicate that abrasion was slightly greater in the less dense samples.

Summarizing, the weight loss increased as the filler content increased; however, the abrasion of the cement specimens seemed to reach a maximum value at the 2 percent level and to decrease slightly as the filler content was increased to 4 percent.

The shoving of Rockdale slag aggregate mixtures was improved by the addition of mineral filler in all cases tested, although higher percentages of filler were usually required to accomplish this result. Fly ash was the only filler used that appreciably reduced the shoving at 2 percent filler content. However, the shoving for all these mixtures was not considered excessive when rated by visual methods. The maximum shoving was approximately 16 percent in the Rockdale slag aggregate specimens with no filler, and the minimum amount was about 1 percent in the specimens containing fly ash and cement.

The relative thickness of the specimens tested was slightly decreased by the addition of mineral filler, but this reduction was generally less than 5 percent. Therefore, for all practical purposes, the relative thickness of the specimens was unaltered. The relative thickness ranged from 69.8 to 74.9 percent, with the lowest value occuring in the cement specimens and the highest in the specimens containing no filler. All of these were rated as fair by the visual rating system as shown in Figure 7.

Concrete Sand. —The data show that abrasion of the sand mixtures was not significantly improved by the addition of mineral filler if the proper amount of asphalt was used. The AOV showed that interaction between the filler content and residual asphalt content was present for all filler types. The only case where the addition of filler appeared to improve the abrasion characteristics was in the +2 percent of optimum residual asphalt mixtures; however, this apparent improvement was created by an excessive amount of abrasion in one of the specimens of the sand mixture with no filler. The abrasion of specimens made with limestone dust seemed to increase with larger amounts of filler as was the case in the slag mixtures, but again, this increase was relatively small. All of the specimens prepared at the optimum asphalt content were rated as fair to excellent by the visual rating system; however, those prepared at asphalt contents below optimum were abraded excessively and were rated unsuitable for use in slurry seal coats.

The effect of mineral filler on abrasion for specimens at optimum residual asphalt content can be seen in Figure 9. The abrasion of the specimens in these tests ranged from almost 0 to 125 percent.

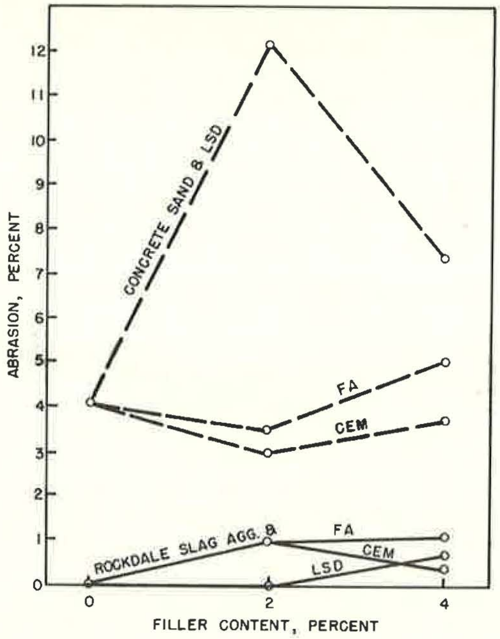

Figure 9. Effect of mineral filler on abrasion at optimum residual asphalt content.

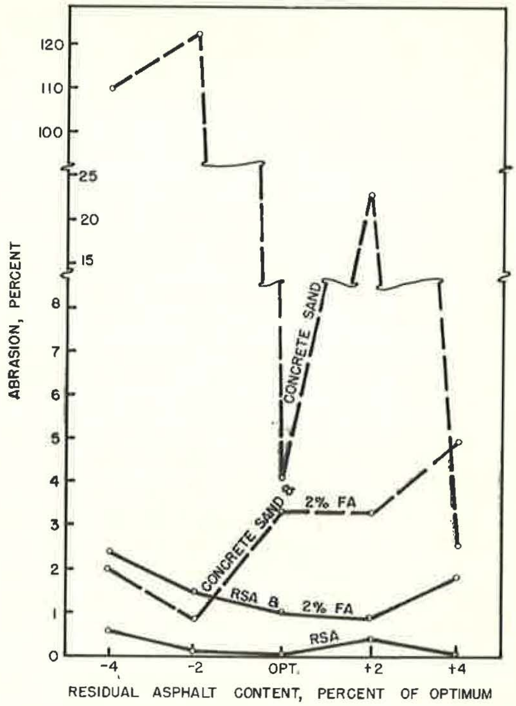

Figure 10. Effect of asphalt content on abrasion.

Shoving of the test specimens generally increased with the addition of fly ash and cement, but there was essentially no effect on the specimens with the addition of limestone dust. In the fly ash specimens, an increase from 2 to 4 percent filler did not affect the shoving for any particular residual asphalt content, whereas increasing the cement content by the same amount generally increased the shoving. The range of shoving values was from approximately 0 to 29 percent in the case of specimens prepared with fly ash.

The relative thickness of the specimens could not be evaluated for the sand mixtures because there was excessive abrasion of the samples. The reduction in thickness due to the action of the testing device cannot be separated from the reduction caused by excessive wear on the specimen; therefore, when the abrasion is high, for instance in excess of 10 percent, the relative thickness is meaningless.

Effects of Asphalt Content

The residual asphalt content was an important factor in the behavior of the test specimens. In every case, the residual asphalt content had an effect on the variable under consideration. In the following paragraphs, these effects are discussed for each of the aggregates tested.

Rockdale Slag Aggregate. —The data indicate the abrasion of the test specimens decreases as the residual asphalt content increases from -4 percent of optimum to optimum. If the residual asphalt content is increased to +2 percent of optimum, the abrasion also increases; however, further increases in asphalt content will not necessarily increase the abrasion. In the specimens containing cement and limestone dust, the abrasion at +4 percent of optimum residual asphalt content was approximately the same as the +2 percent value; however, the fly ash specimens indicated a slight decrease in abrasion at the +4 percent asphalt level. The effect of asphalt content on abrasion is shown in Figure 10 for Rockdale slag aggregate with no filler and with 2 percent Rockdale fly ash.

The shoving of the test specimens followed the same trend as the abrasion. The maximum amount of shoving occurred at -4 percent of optimum residual asphalt content, and the minimum values were at the optimum. The shoving then increased with increasing asphalt content to the +2 percent level with a slight drop at +4 percent residual asphalt content.

The relative thickness of the specimens generally increased with increasing residual asphalt content with the greatest thickness occurring at -2 percent of the optimum asphalt content; however, the peak value of relative thickness for the specimens containing fly ash occurred at optimum residual asphalt content. The relative thickness then decreased with increasing amounts of asphalt.

Concrete Sand. —The residual asphalt content was the primary factor in determining the suitability of the concrete sand for use in slurry seal mixtures. When the proper amount of asphalt was used, excessive abrasion was minimized, and the mixtures were usually acceptable. The data revealed that the abrasion was substantially decreased as the residual asphalt content was increased to the optimum amount; however, the abrasion was also affected by the type and amount of filler in the mixture. The specimens prepared with fly ash did not exhibit abrasion values in excess of 5 percent at asphalt contents below optimum, and the abrasion was decreased as the asphalt content was increased to optimum and above. As the residual asphalt was increased to +2 and +4 percent of the optimum amount, the abrasion for all practical purposes remained about the same; however, there was some fluctuation in the values with various types and amounts of filler. The specimens containing no filler were abraded excessively at +2 percent of optimum asphalt content, but the wear was back to an acceptable level when this asphalt content was increased to +4 percent of optimum. These observations were confirmed by the AOV which indicated that interaction was present between the filler content and the residual asphalt content. An example of the effect of asphalt content on abrasion is shown in Figure 10. The data indicate a range of abrasion values from 0.2 percent at +4 percent of optimum asphalt content to 125.6 percent at the -4 percent level. These specimens were classified as excellent to poor by the visual rating system.

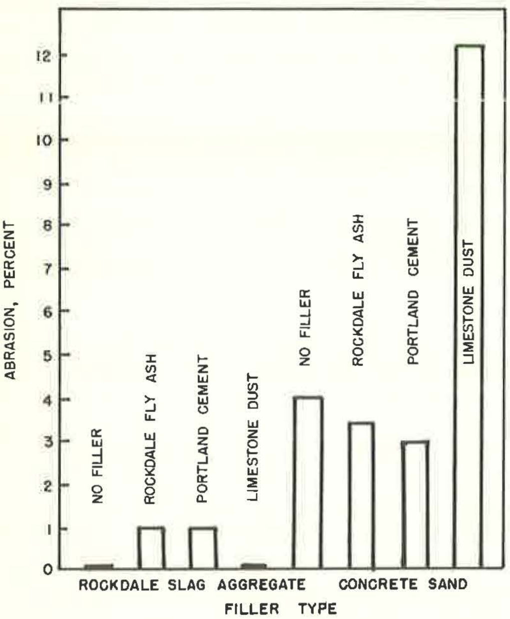

Figure 11. Effect of filler type on abrasion at optimum residual asphalt content and 2 percent filler content.

The shoving of the test specimens varied considerably but the data seemed to indicate that shoving was high at the lower asphalt contents and decreased as the amount of asphalt was increased. Consequently, the lower asphalt contents should be avoided when preparing slurry seal mixtures with this aggregate.

The relative thickness could not be evaluated because of the excessive abrasion of the specimens at the lower asphalt contents.

Effects of Filler Type

An analysis of variance was made for each of the aggregates at fixed filler contents to determine the effects of the filler type. The comparison was made at 2 and 4 percent filler contents for Rockdale slag aggregate and concrete sand with the filler type (fly ash, cement and limestone dust) as the columns and residual asphalt content as the rows.

Rockdale Slag Aggregate and 2 Percent Filler. —The AOV indicates that abrasion was less for limestone dust mixtures than for the other fillers, and that cement was generally more effective than fly ash in reducing the abrasion. An example of the effect of filler type on abrasion for 2 percent filler content and at the optimum residual asphalt content is shown in Figure 11. The abrasion for these mixtures ranged from 0 to 5 percent, and all were classified as good to excellent by the visual rating system.

Rockdale Slag Aggregate and 4 Percent Filler. —The data showed that as the filler content was increased to 4 percent, the cement tended to become the more effective filler in reducing abrasion, and the limestone dust continued to give good performance. Although the specimens containing fly ash showed the most abrasion, they were still acceptable by the visual rating system. The abrasion for this group of specimens ranged from 0 to 12.3 percent. This maximum abrasion value occurred in the fly ash specimens at the +2 percent of optimum residual asphalt content. These specimens received a rating of excellent in the visual classification, and there appeared to have been very little material loss. However, even if these high values were disregarded in the analysis, the results would not change significantly.

Concrete Sand and 2 Percent Filler. —The data indicate that specimens made with fly ash will reduce the abrasion considerably more than either cement of limestone dust for lower (less than optimum) residual asphalt contents; however, the cement becomes more effective at optimum asphalt content and above. The limestone dust appeared to be the least effective in reducing abrasion for this particular aggregate. The abrasion ranged from 0.8 percent to 75.3 percent.

Concrete Sand and 4 Percent Filler. —When the filler content is increased to the 4 percent level, the indication is that cement is foremost in producing a low abrasion level. The fly ash was also effective in reducing the weight loss; however, the specimens made with limestone dust showed a greater amount of wear. The range of abrasion values for these specimens was from 0.2 to 107.6 percent.

Effect of Particle Shape and Texture

The original gradation of the concrete sand was changed by separation and recombination so that it would be the same as the gradation of the Rockdale slag aggregate. This was done so that the aggregates could be compared to determine the effect of particle shape and texture. The Rockdale slag aggregate has an angular particle shape and is rough textured, whereas the concrete sand has rounded smooth-textured particles.

The comparison was made by rearranging the data so that an analysis of variance could be made to test for differences in the aggregates. This was accomplished by using a two-way classification with the aggregate type as the columns and residual asphalt content as the rows. The AOV was made for the aggregates with no mineral filler, for the aggregates of each filler content, and for each type of filler.

The data revealed that for all types and amounts of mineral filler and for all except two of the 70 asphalt contents tested, the abrasion in the Rockdale slag aggregate specimens was less than that of the concrete sand. This seems to indicate that the more angular and textured particles make better slurry seals than the rounded smooth-textured particles.

SUMMARY AND CONCLUSIONS

Mixture Design

The results of the test conducted with the Young wet track abrasion device seem to verify the design equation (Eq. 2). The predicted optimum residual asphalt contents occurred, for the most part, at or near the minimum values of specimen abrasion. The predicted optimum asphalt content nearly always resulted in a good mixture (by visual rating system) suitable for use in slurry seal coat construction. However, the proper aggregate gradation is essential in obtaining good mixtures.

Test Variables

The data indicated that abrasion was the best measure of the slurry seal performance in the laboratory. The relative thickness and, to some extent, the density of the tested portion of the specimens are dependent on the amount of abrasion; when this weight loss is excessively high, these effects cannot be separated. The shoving did not seem to follow any particular trend or pattern that would influence the suitability of a slurry mixture. However, these effects should be measured and reviewed to obtain a better understanding of the mixtures.

Type and Amount of Mineral Filler

Mineral fillers are used in slurry seal mixtures to improve the gradation and workability of the mixture. This research indicated that when mineral fillers are used for this purpose in Rockdale slag aggregate or concrete sand slurry seals, the effectiveness of the mixture may be reduced by an increase in the abrasion of the slurry seal coat. However, this increase in abrasion may be very slight, and the qualities gained may offset the increased wear. It was also found that some fillers will produce less wear than others, and the data show that limestone dust and cement are the best of the fillers tested for use with Rockdale slag aggregate in slurry seal mixtures, whereas cement and fly ash are better suited for mixtures of concrete sand. In addition, the amount of filler did not significantly affect the abrasion values of properly designed slurry seal; therefore, the amount of filler will be governed by economy and the intended purpose.

Asphalt Content

As pointed out in discussing the design method, if the residual asphalt content is estimated by Eq. 2, the slurry seal mixture will give good performance when tested in the Young wet track abrasion device. It may be generally stated that a properly designed slurry seal will give good service irrespective of the amount and type of mineral filler.

ACKNOWLEDGMENTS

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Appendix

EXAMPLE DATA SHEETS AND CALCULATIONS

Surface Area

Sieve Size	Surface Area Factor	X	Total %/100 Passing	=	Surface Area
Max.	2		1.00		2.00
#4	2		0.991		1.98
#8	4		0.893		3.57
#16	8		0.568		4.54
#30	14		0.275		3.85
#50	30		0.177		5.31
#100	60		0.103		6.18
#200	160		0.059		9.44

Total Area = 36.87 sq ft/lb

Absorption

	A	B	AVG.
Tare + dry sample, gm.	407.0	407.1	
Tare, gm.	307.0	307.1	
Tare + wet sample, gm.	411.6	411.8	
% Kerosene Ret. (C.K.E.)	4.6	4.7	4.65

Note: See California test method #303B

SLURRY SEAL DATA SHEET

Kerosene absorption 4.65 %   Film thickness, t 8 microns

Surface Area 36.87 ft^2/lb App. Specific Gravity 2.90

Corrected Surface Area = $SA \times \frac{2.65}{\text{app. SG}}$

$= 36.87 \times \frac{2.65}{2.90} = 33.8\ ft^2/lb$

Asphalt for Surface Area/lb Aggr.

$= 0.0002047 \times SG_A \times t \times \text{corr. SA}$

$= 0.0002047 \times 1.03 \times 8 \times 33.8 = 0.0570$ lb

Asphalt for absorption/lb Aggr. = Kerosene Absorption ÷ 100

= 4.65 ÷ 100 0.0465 lb

Total Residual Asphalt/lb Aggr. 0.1035 lb

Amount of asphalt in given emulsion = 67 % by wt.

Emulsion/lb Aggr. = $\frac{\text{total Residual Asphalt}}{\text{Asphalt in Emulsion}} = \frac{0.1035}{0.67} = 0.154$ lb

Remarks (evaluation): ______

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Discussion

W. H. CAMPEN, Omaha Testing Laboratories, Omaha, Neb. —On the whole, this paper is very good. It enumerates many good points relative to the use, design and construction of slurry seals.

The use of the surface area as a criterion for design is sound. However, the assumption that slurry seal mixtures should have the same film thickness as similar hot-mixed hot-laid mixtures is questionable. In my opinion, slurry seal mixtures should be much richer in asphalt than hot ones. More specifically, slurry seal mixtures should have film thicknesses about 50 percent greater than hot ones. Based on many years of experience in both the laboratory and the field, I have come to the conclusion that a film thickness of about 6μ is adequate for hot asphaltic concrete mixtures having maximum sizes of about 0.2 in. and higher. Therefore, I would recommend a minimum of 9μ for slurry seal mixtures.

My experience has shown that lean slurry seal mixtures are brittle and either fail to adhere to the treated surfaces or abrade easily. For this reason, I prefer the richer ones, even if they tend to shove a little.

WILLIAM J. HARPER, RUDOLF A. JIMENEZ, and BOB M. GALLAWAY, Closure—The authors thank Mr. Campen for his discussion of this paper. However, we would like to remind Mr. Campen that the film thickness in the design equation is not specified; hence, the user of this method may substitute a film thickness based on his own experience or use our value of 8μ.

The computed residual asphalt content is based on both film thickness and absorption requirements. For example, in the illustration in the Appendix of the paper, the amount of asphalt required for absorption is 0.0465 lb/lb of aggregate and that for effective film thickness is 0.0570 lb/lb of aggregate. The total amount of residual asphalt for this example is 0.1035 lb/lb of aggregate. Using this amount and a corrected surface area of 33.8 sq ft/lb of aggregate, the ratio of asphalt to aggregate surface area obtained is 14.5μ. Although this value may appear to be high, it is necessary for coating the usual existing pavement surface. In view of this, it appears that we are in accord with Mr. Campen in that slurry seals should be richer in asphalt than asphaltic concrete.

The film thickness of 8μ used in this study was based on experience, substantiated by field performance of existing slurry seals in Texas.