A Study of Tenacity of Aggregates in Surface Treatments

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A study was made to develop a tenacity test for measuring chip retention in surface treatment. A laboratory procedure is described for forming a monolithic structure on the surface of a simulated roadbed made up on a metal panel. The aggregate chips were encapsulated on the surface so that the entire mass could be pulled away from the roadbed and the strength of the bond between the aggregate and the roadbed determined.

To keep experimental work to a minimum the number of variables studied have been limited to aggregate and asphalt spread quantity, the type, size and size distribution of the aggregate, and consistency of the asphalt. Results cover a number of these variables but are not a complete survey of all of them. To reduce variability of results, test procedures were standardized carefully and enough samples were tested so that statistical methods could be used with confidence. Additional variables studied by statistical techniques include: (a) effect of moisture and dust in the aggregate, (b) different operators, and (c) the effect of aging before testing.

•MINERAL SURFACE TREATMENT of roads for either the construction of new pavements or the repair and improvement of old roads is a relatively simple and effective operation. However, many variables affect the actual construction of this type of surface and introduce considerable variability in the final results, for example, by causing whip off of the aggregate or chips applied to the surface. Equally important is the consideration that excessive use of aggregate is uneconomical and adds to the cost of the treatment.

This research investigates factors that might be most important in determining the economic and technical utilization of surface treatments with aggregates applied to asphalts to provide a satisfactory road surface. Only preliminary laboratory research which can be correlated with field performance is considered.

A considerable amount of work has been reported on mineral surface treatments, and a review of surface treatments was made by Herrin, Majidzadeh and Marek (4) which includes an annotated bibliography, an additional supplemental list of references, and a comprehensive compilation of selected design procedures proposed by other investigators.

Another comprehensive report has been given by McLeod (5); however, much of this report is concerned with field practices rather than laboratory procedures. The most extensive work found on laboratory study of surface treatments was that of Benson and Gallaway (2). This report discusses experimental equipment used for and results of the study of chip retention. Many variables were studied and a selected bibliography is included.

Another pertinent reference is a paper by Nevitt (6) which discusses seal coat aggregates generally and, in particular, particle size gradation effects and bitumen

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requirements. A bibliography is also included. A number of the variables involved in chip retention are also considered in a report by Hank and Brown (3).

A review of the material available indicated that it would be desirable to study chip retention with the particular combinations of asphalt and aggregate components used in Florida. A design procedure following the proposed procedure of Benson (1) using the Kearby embedment vs mat thickness diagram was utilized for consideration of the asphalt and aggregate spread quantities. In addition, the studies also utilized the standard practice in Florida for these quantities, although they were at the low end of the specifications.

Herrin et al. (4) point out that there are a number of variables that must be considered in a test for evaluation of chip retention in surface treatment. Among the most important aggregate properties are type, size distribution, mean size, percent voids, surface texture, surface condition (dusty, damp), surface charge, and aggregate spread quantity. Their list of important asphalt properties includes penetration or consistency, source or type, asphalt cutbacks, asphalt emulsion, bitumen spread quantity, and embedment.

Because of the range of variables that could be investigated, only a limited number could be selected for this particular study. Those selected will be discussed in more detail later. A single slag aggregate and an asphalt cement of about 150 penetration were primarily used for the study.

The three main objectives in developing a tenacity test for chip retention were (a) to provide a test section of optimum size for laboratory work that would be useful in a simple rapid test, yet would be of proper sensitivity and indicative of actual service conditions; (b) to develop a rapid curing formulation that would adhere to the aggregate to provide a physical bond so that the aggregate could be pulled from the surface; and (c) to design a suitable arrangement whereby the force required to separate the aggregate from the asphalt could be measured with the proper degree of sensitivity.

PRELIMINARY EXPLORATORY STUDIES

To attain the objectives listed in the preceding section, considerable exploratory work was conducted to establish a procedure and an apparatus that would meet the requirements. The two principal goals of the exploratory study were to establish a technique for preparing a suitable and representative miniature roadbed and to evaluate various types of bonding agents to determine what types could best be used.

Design of Mineral Surface Roadbed

As a first approach to the selection of a roadbed, a 6.125- by 5.125-in. aluminum plate was made with shoulders to retain the asphalt applied in the center. The asphalt was laid on the plate and spread uniformly by maintaining a level surface and warming the plate, without overheating, in an oven. After cooling, the aggregate was spread by hand shaking as uniformly as possible on the asphalt surface and the prepared surface was covered with a 1-in. thick rubber mat and subjected to a pressure of 15 psi in a hydraulic press. The excess aggregate was removed by turning the plate upside down without jarring. Approximately 85 percent of the spread quantity was retained. Thus, there was a 15 percent excess above the experimentally observed spread quantity obtained by hand spreading. This result corresponds approximately with those obtained by Benson and Gallaway. After pressing the aggregate into the roadbed, a circular metal form was pressed into the surface by a rotary motion with sideways displacement of aggregate where necessary to embed the form into the asphalt. This form then constituted a mold into which some type of a bonding agent could be cast to form a monolithic structure with the aggregate after the bonding agent had set. For the first experiments, 3-oz penetration tins were used as molds, as shown in Figure 1.

Figure 1 also demonstrates the manner in which the pulling arrangement for the first experiments was accomplished. A nail through the tin was attached by a hook to a chain which was, in turn, attached to the loading head of the testing machine. This arrangement permitted a vertical pullout of the bonded aggregate, and tests were made under a variety of conditions.

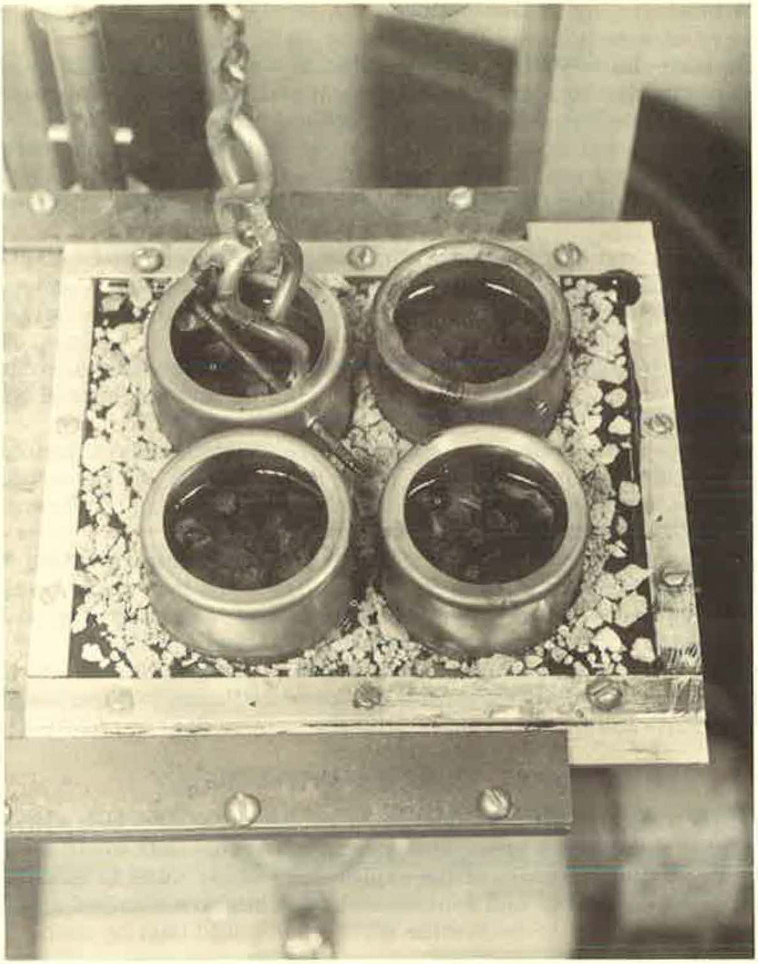

Figure 1. First experimental mold arrangements for tenacity tests.

There was great variability in this test arrangement, and, therefore, arrangements were made to change the designs of the mold and the test plate. As a matter of record, the experiments reported here used a Scott tensile tester, which consists of a crosshead moving at a constant speed against an increasing load. This machine was selected because of its availability and because a rather high sensitivity was desired. However, this type of test machine causes certain difficulties in analyzing the data, since failures at different values probably do not occur under similar conditions of deformation. In general, failure occurred in these tests by a single rapid pullout at some indicated load where the surface parted, as shown in Figure 2.

To reduce the variability of the test, the design of the mold was changed by increasing its diameter and also by substituting a solid bar for the chain in the linkage between the mold and the loading head on the Scott testing machine. The new mold, shown in Figure 3, was used in all studies following preliminary exploration work with different bonding agents. The mold is essentially 4 in. in diameter. The solid bar linkage was free to move for proper alignment and is shown in Figure 4. The use of mold with the test linkage on a small roadbed, similar to that used previously, is shown in Figure 5. After these experiments, a roadbed surface was used which could accommodate three molds at one time (Fig. 6). Since a number of these test plates was available, at least 27 test specimens could be set up when the statistical analysis was

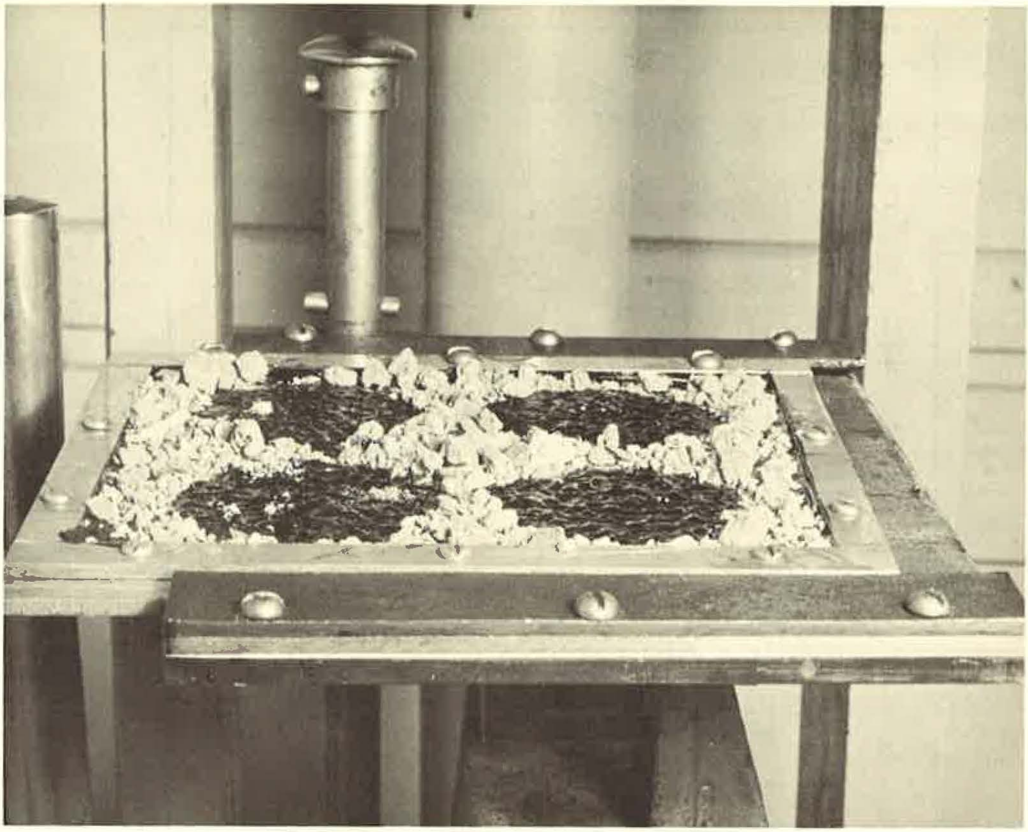

Figure 2. Illustration of nature of surface after pullout.

made for variability. However, certain defective tests, either because of improper preparation or improper assembly of the testing head, made it impossible to have 27 results in every case. The minimum number of tests run was 24. For some experiments, 51 samples were used. A few tests with limited quantities of materials were made.

Selection of a Bonding Agent

The preliminary experiments on this test were made using an epoxy resin formulation which set rapidly through the formation of a solid polymer by a heat-accelerated process. Since this heat is self-generated in the setting process, its effect on the relationship of the asphalt to the aggregate posed problems. A curing time of less than 2 hr was desired so that the samples could be tested within a reasonable time after being prepared. However, the exothermic reaction heat was too great and the bonding agent had too short a pot life, requiring a new batch for each mold poured. Shell Epon 815 with 5 percent ethylenediamine and 5 and 10 percent curing agent U gave about the same results but required 4 days to cure sufficiently. Because of these results, the epoxy type resin bonding agent was discarded.

A second type of polymeric bonding agent made up of polyesters was next considered for study. These materials set to solid polymers by the use of free radical forming catalysts, but their curing has a disadvantage where surfaces are exposed to oxygen. The internal curing occurring below the surface of the tenacity test molds proceeds independently and is not affected. This resin proved interesting and for a time it was thought that a satisfactory formulation could be perfected with these materials. After

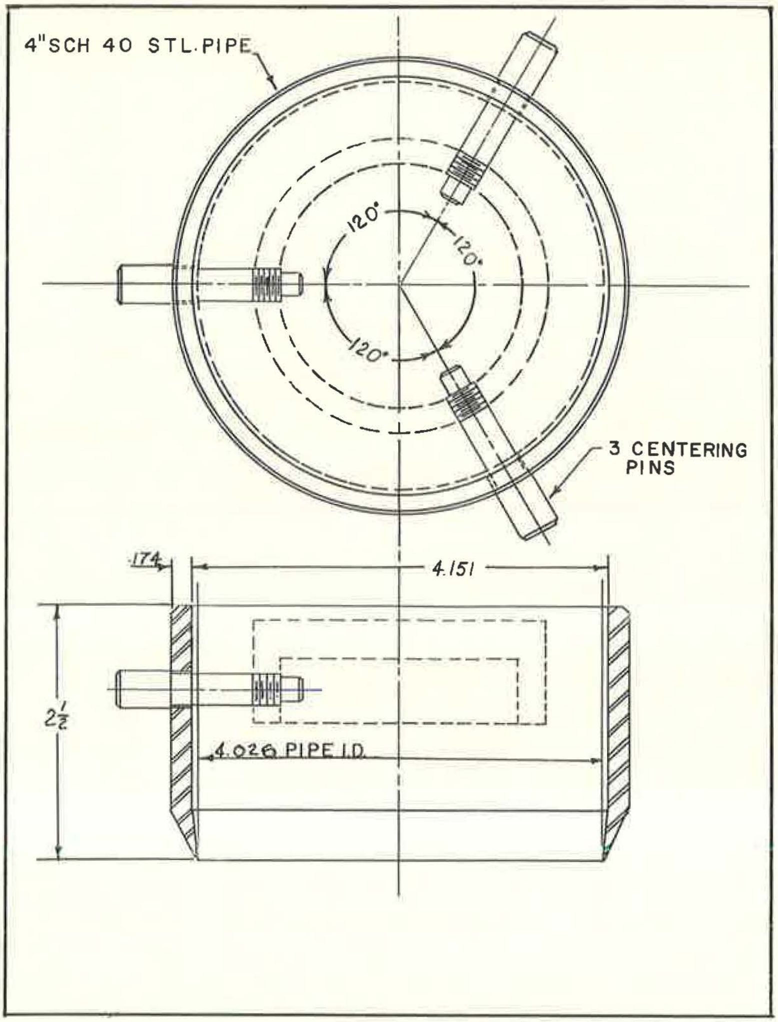

Figure 3. Large mold for tenacity test.

making various trials, a Celanese MR-62-CL polyester resin with a 3 percent cobalt accelerator (Nuodex) and 3 percent MC-1 catalyst paste (benzoyl peroxide) formulation was developed. This starts to set within 15 min and produces a satisfactory setting agent within a short time. Accordingly, a considerable amount of experimentation was carried out using this particular type of formulation. For these experiments, various spread quantities of asphalt and a slag aggregate and a Miami limestone aggregate were used. These tests were carried out concomitantly with the studies on the roadbed and small molds. Figure 1 shows the transparency of the resin and how it covers the aggregate.

Further experimental work with the polyester resins indicated that they also had certain disadvantages, principally the displacement of the asphalt from the baseplate by preferential wetting of the baseplate and a rather high shrinkage factor, resulting in some cases in the mold pulling from the baseplate without carrying the complete bonded structure with it. For these reasons, this type of bonding agent was also discarded.

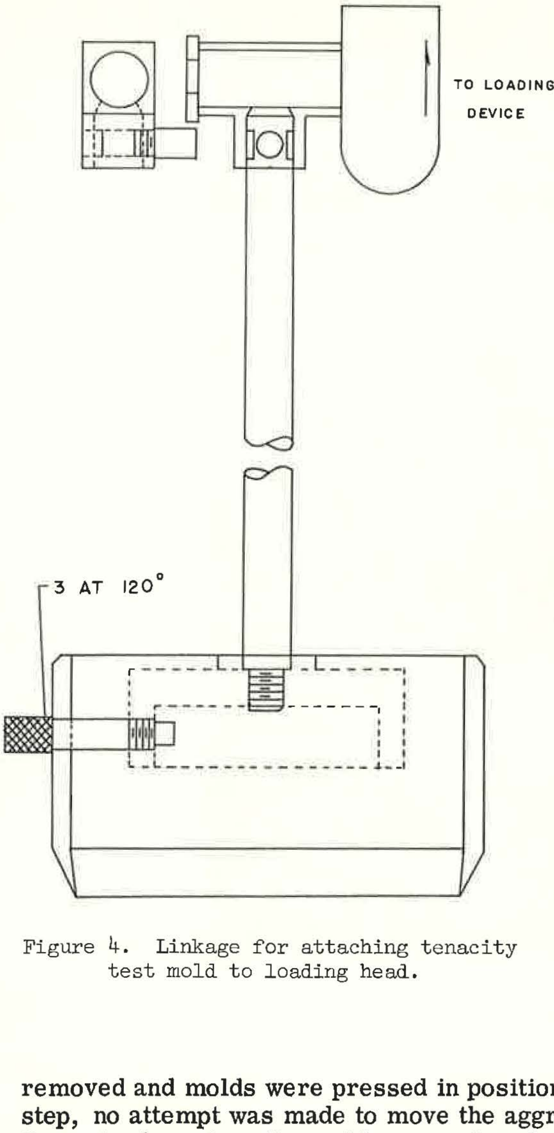

Figure 4. Linkage for attaching tenacity test mold to loading head.

Following the experiments with the organic-type bonding agents, it was decided to try an inorganic type such as Hydrocal (U.S. Gypsum Co.). This agent sets in a relatively rapid time and is quite simple to handle. Accordingly, after satisfactory preliminary experiments, this material was used throughout the remainder of the work done on the tenacity test. The details of the preparation of the Hydrocal are given in the Appendix. The enlarged test plate, together with three molds, is shown in Figure 6 after the Hydrocal has been added and the samples have set.

On completion of these exploratory experiments, it was thought that the test had some merit as a measure of the strength of the bond between the asphalt and the aggregate as typifying a mineral surface roadbed. Accordingly, a more elaborate experimental program was undertaken to obtain certain quantitative information regarding the test data.

EXPERIMENTAL WORK

The test procedure is described in the Appendix. Essentially, the procedure consisted of adding an excess of asphalt to the preheated test plate and then removing the excess with a doctor blade, leaving the desired asphalt spread quantity on the test plate. As mentioned before, the aggregate was then spread on the cooled asphalt by hand as uniformly as possible and the mixture was compressed in a hydraulic press with a rubber mat on top of the aggregate. The excess aggregate was removed and molds were pressed in position on the compacted roadbed. During this step, no attempt was made to move the aggregate; if a large aggregate was in the way, it was broken since the molds were placed on the roadbed under pressure. The Hydrocal slurry was then prepared, poured into the molds, and permitted to harden in a constant temperature room at 73 F. All tests at ambient temperature ranges were made at 73 F. However, other tests (reported later) were made with the test machine placed in a constant temperature room large enough to permit a man to work. These tests were made at temperatures up to 140 F.

Materials Used

The two asphalt cements used for most of these tests were Florida AC-15 materials, commercially supplied, which met AASHO specification M20 for the 150 to 200 penetration grade. One (S59-16) had a penetration of 168 and a viscosity at 77 F of 0.33 megastokes. A second sample (S62-9) of AC-15 was required because the initial supply was exhausted. This sample had a penetration of 150 and a viscosity at 77 F of 0.32 megastokes. In addition, for one set of results four other asphaltic materials of differing viscosities were studied. Data on these materials are given in Table 1.

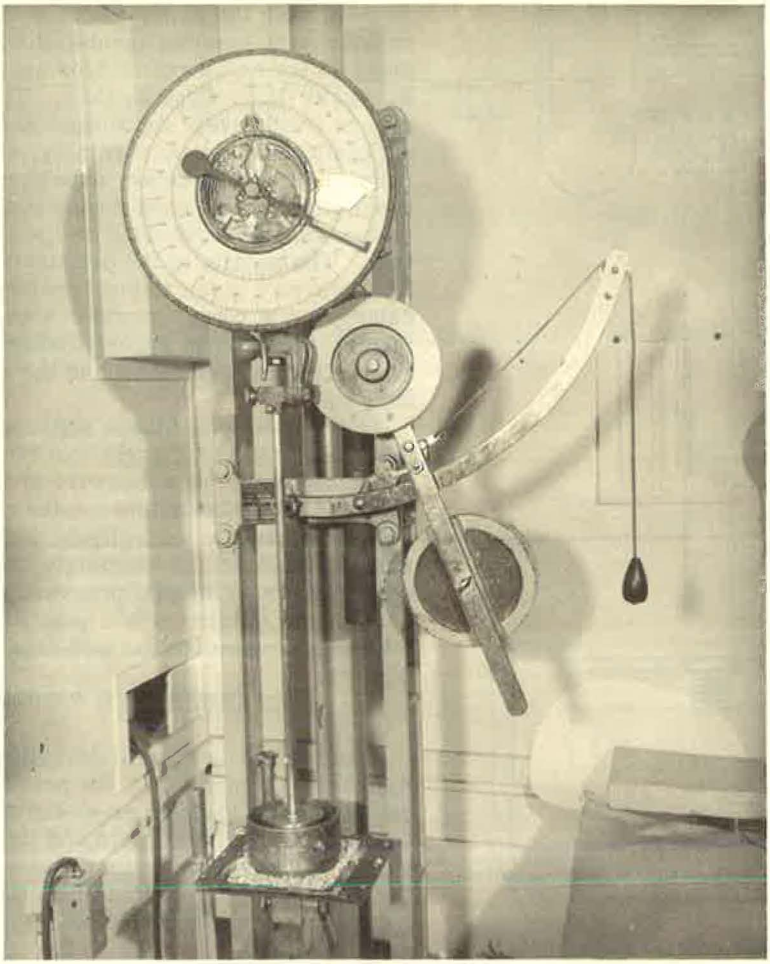

Figure 5. Assembly of test equipment with 4-in. mold.

Two base aggregates were used in this study, a slag (S62-1) and a Miami limestone (S59-19), both meeting the specifications of the Florida State Road Department for grade No. 16 modified aggregate. The gradation of this aggregate is as follows:

Passing ½-in. sieve, 100 percent;
Passing ⅜-in. sieve, 90 to 100 percent;
Passing No. 4 sieve, 30 to 60 percent;
Passing No. 10 sieve, 0 to 10 percent; and
Passing No. 16 sieve, 0 to 5 percent.

Certain other aggregates were used in the studies of the effect of size distribution, but these were derived from the slag No. 16 mentioned previously. The aggregate spread quantity applied to the samples was 20 percent greater than the spread quantity designated by the Florida State Road Manual. After pressing the aggregate under a rubber mat at a pressure of 15 psi, excess was removed from the surface by a wrist-snapping action. The mold was then placed on the roadbed. The plate, asphalt, and aggregate were weighed separately after each component had been added to record the amounts. In general, most of the studies reported in this paper refer to an

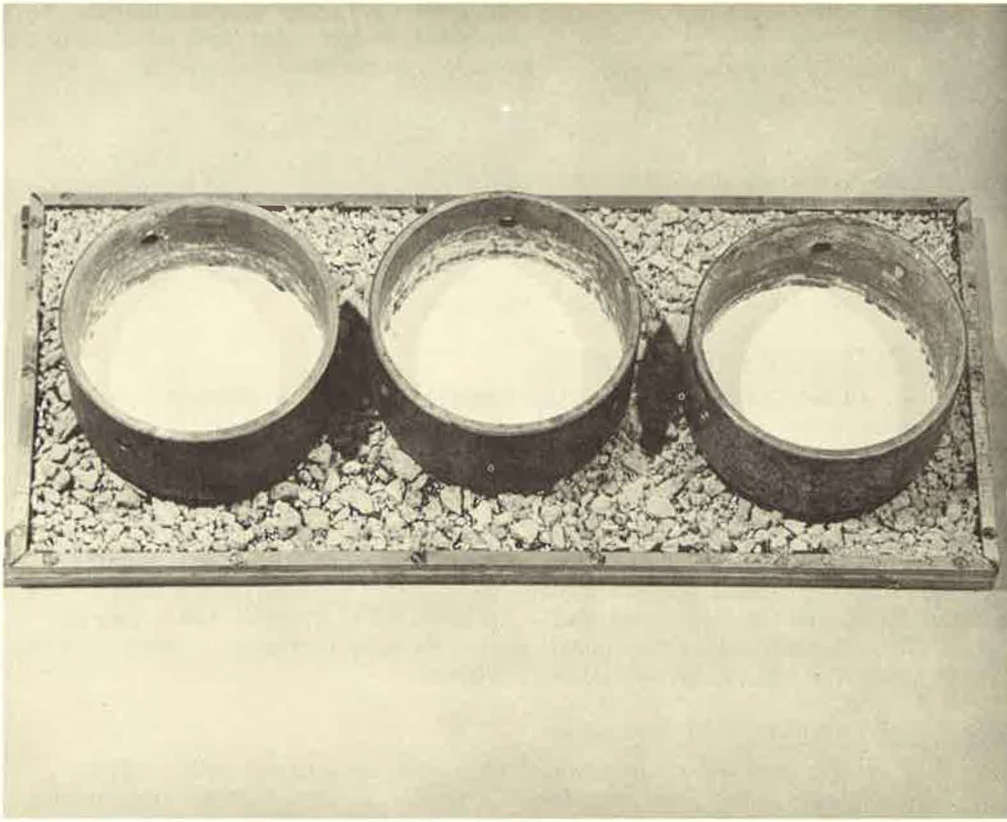

Figure 6. Samples on test plate preparatory to measuring tenacity.

asphalt spread quantity of 0.12 gal/sq yd. However, some studies were made at different spread quantities. Generally, the aggregate quantity was 0.10 cu ft/sq yd.

Testing Procedures

After the samples had been prepared and the Hydrocal poured, the assembly was allowed to set for about 1 to 1½ hr. These samples were aged at 73 F, as mentioned before. The Scott tensile tester was employed to measure the pullout force using a linear speed of 11.3 in./min on the pulling head. The total force is measured on the instrument and coverted to pounds per square inch, based on the area of the mold. The results for the experimental program are given in the form of tables and figures, but many of the details have been omitted to conserve space.

RESULTS

Effect of Asphalt Spread Quantity

The influence of the spread quantity of asphalt when increased from 0.12 to 0.30 gal/sq yd is indicated by the frequency polygons shown in Figures 7 and 8. A statistical analysis of the results for these figures is given in Table 2.

Considering the individual aggregates, the results show an increase in tenacity of approximately 5 to 10 percent for an increase of 2½ times the spread quantity of asphalt. This effect is of about the same order of magnitude as has been noted for certain field tests for Florida asphalt cements of the type used in this study. The statistical analysis indicated that only once out of 100 times would the larger tenacity

TABLE 1

ASPHALT PENETRATION AND VISCOSITY DATA

Asphalt	Penetration, 77 F (100g/5 sec)	Viscosity, 77 F (megastokes)
Gulf Coast naphthenic (S119)	Soft	0.0027
East Central Texas resid. (S120)	235	0.11
East Texas asphalt (S117)	174	0.27
Florida AC-8 (S60-17)	92	1.0

values for the higher spread quantities be attributed to chance for both the slag aggregate and the Miami limestone.

Effect of Aggregate Type

Additional study of the data in Table 2 at the same asphalt spread quantities for the two aggregates when based on asphalt spread quantities of 0.12 and 0.30 gal/sq yd indicates that there is no appreciable difference for the results obtained by either aggregate.

Influence of Size Distribution of Aggregate

The slag No. 16 (S62-1) used in these experiments was separated into a coarse and fine fraction using a No. 4 Tyler sieve (0.185-in. opening). These two fractions were compared with the tenacity results for the whole aggregate (Fig. 9, Table 3).

The data for the fine fraction are similar to those for the whole material. The null hypothesis that they are from the same populations cannot be rejected at the 0.01 probability level. However, a study of the results for the coarse fraction shows a somewhat lower value for the tenacity test. At a spread quantity of 0.12 gal/sq yd, the tenacity value for the fine and whole fractions are about 21 percent higher than for the values using the coarse fraction of the slag. As indicated in Table 3, there was an increase in the tenacity value as the asphalt spread quantity increased. Other data in Table 3 are given to complete the statistical analysis.

Influence of Moisture Content of Aggregate

A series of experiments were run in which the aggregate was wet with water to various degrees. When completely wet, the slag aggregate used in these experiments was found to carry about 12.5 percent water. By partially drying some of the wet aggregate, it was possible to obtain more or less uniform moisture contents for the

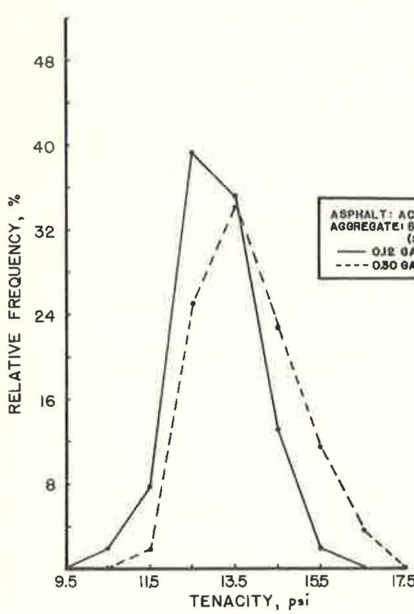

Figure 7. Effect of asphalt spread quantity on tenacity test for slag.

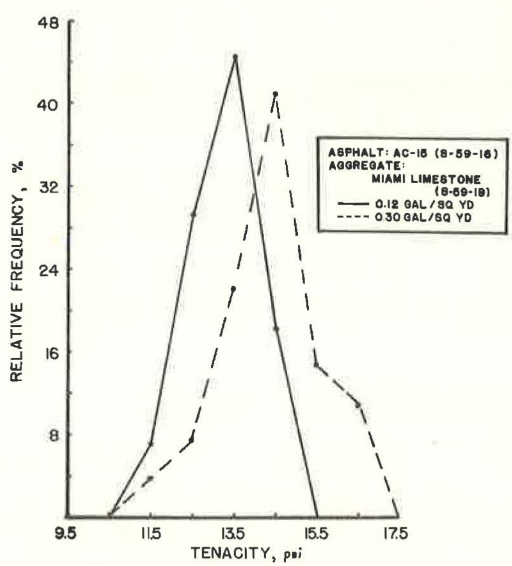

Figure 8. Effect of asphalt spread quantity on tenacity test for Miami limestone.

TABLE 2

EFFECT OF ASPHALT SPREAD QUANTITY (AC-15)

Measurement	Slag No. 16 (S62-1)		Miami Limestone No. 16 (S59-19)	
	0.12 Gal/Sq Yd	0.30 Gal/Sq Yd	0.12 Gal/Sq Yd	0.30 Gal/Sq Yd
No. of samples	51	52	27	27
Mean tenacity value at 73 F, psi	13.1	13.9	13.2	14.4
Std. dev., psi	0.88	1.21	0.89	1.27
Coeff. of variation, percent	6.72	8.71	6.75	8.80
95 percent confidence limits for mean	12.8 13.4	13.5 14.2	12.8 13.5	13.9 14.9
Mean aggregate weight per plate, gm[a]	220	262	269	310

[a]Reported here as a matter of interest to show effect of spread quantity.

aggregate at different levels, as indicated in Table 4. The statistical results, shown in Figure 10, indicate that a partially wet aggregate did not greatly influence the results, although when the aggregate was completely wet there was an appreciable change in the tenacity value.

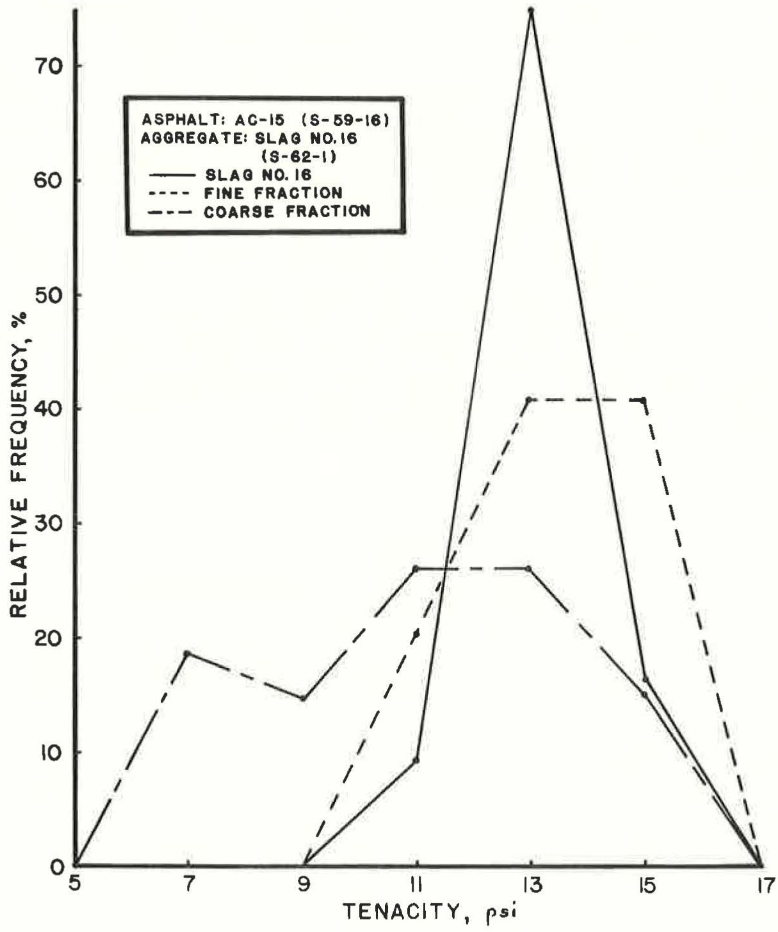

Figure 9. Effect of aggregate size distribution.

TABLE 3

EFFECT OF AGGREGATE SIZE DISTRIBUTION[a]

Measurement	S62-1 Whole	R62-23 Fine	R62-24 Coarse	R62-24 Coarse
No. of samples	51	27	27	17[b]
Mean tenacity value at 73 F, psi	13.1	13.3	10.9	12.8
Std. dev., psi	0.88	1.71	2.74	0.97
Coeff. of variation	6.72	12.8	25.1	7.58
95 percent confidence limits for mean, psi	12.8	12.9	9.8	12.3
	13.4	13.7	12.0	13.3
Mean aggregate weight per plate, gm	220	165	286	305

[a]Asphalt AC-15 (S59-16) at 0.12 gal/sq yd.
[b]These data are for an asphalt spread quantity of 0.30 gal/sq yd; the number of samples is low because the supply of this fraction of the aggregate was exhausted.

Influence of Dust in Aggregate

It was also considered desirable to test the effect of a high dust content in the slag on the tenacity value. Some of the slag No. 16 (S62-1) was ground overnight in a ball mill and that portion of the ground material which passed through a No. 200 sieve was used as a dusting agent. Certain preliminary experiments using dust without any aggregate gave a very large variability in results with tenacity values ranging from 6.2 to 16.7 psi. A study of the surfaces indicated that there was a partial and variable bond with the dust, asphalt, and Hydrocal. This would cause the variance obtained and would not be similar to the separation of the mineral from the asphalt. Certain tests were also made in which an aggregate dust combination was used, but here again there was considerable variation in the results because a uniform dusting of the aggregate could not be obtained with the small quantities involved in the mixing. One other set of experiments was carried out in which the surface was first covered with the dust, the excess removed, and the aggregate applied to the surface. This procedure resulted in a very definite lowering (approximately 33 percent) in the tenacity value. Here it is expected that the presence of dust interfered with any coherent bond between the mineral aggregate and the asphalt component.

TABLE 4

EFFECT OF MOISTURE CONTENT OF AGGREGATE ON TENACITY VALUE[a]

Measurement	Oven Dry	4.08% Moist.	8.5% Moist.	12.5% Moist.
No. of samples	27	27	27	26
Mean tenacity value at 73 F, psi	12.5	11.9	11.7	4.85
Std. dev., psi	1.48	1.22	1.73	1.00
Coeff. of variation, percent	11.8	10.3	14.9	20.6
95 percent confidence limits for mean, psi	13.1	12.4	12.4	5.3
	11.9	11.4	10.9	4.4

[a]Asphalt AC-15 (S62-9), 0.12 gal/sq yd; aggregate, slag No. 16 (S62-1).

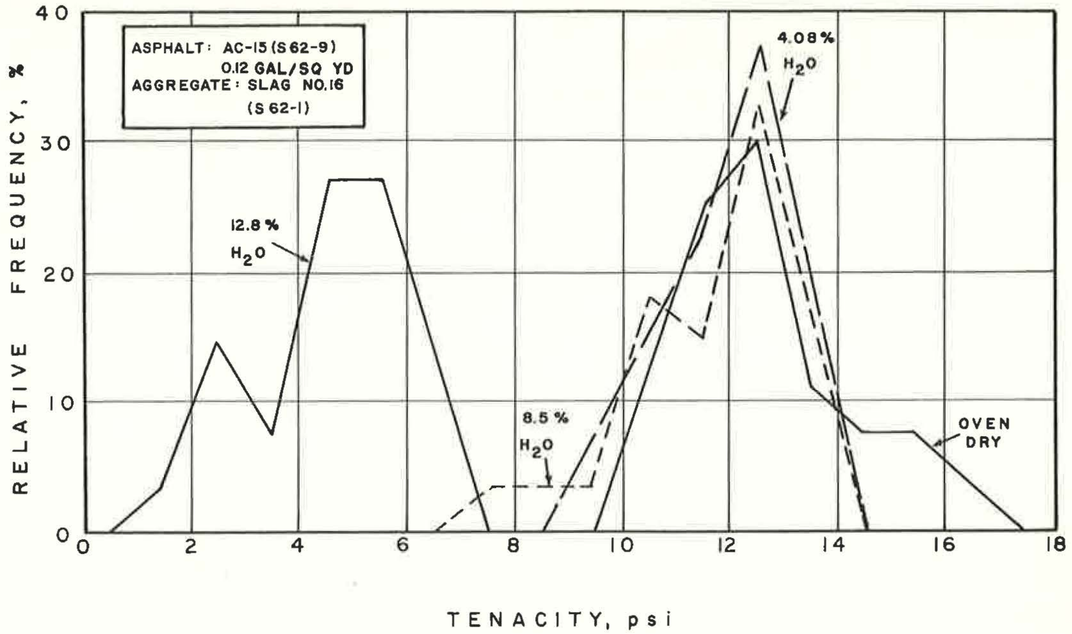

Figure 10. Effect of moisture content of slag aggregate.

Effect of Viscosity of Asphalt

During this investigation, it seemed apparent that the viscosity of the asphalt had a considerable influence on the value of the tenacity measurement. Accordingly, it was considered desirable to investigate exactly how this viscosity might influence the results. Tests were run at temperatures up to 140 F and results showed a rapid decrease in the tenacity value (Fig. 11). All tests above 73 F were performed in a special constant temperature room in which the operator actually aged the samples and performed the measurements at the test temperature (92, 104, 122, and 140 F). The

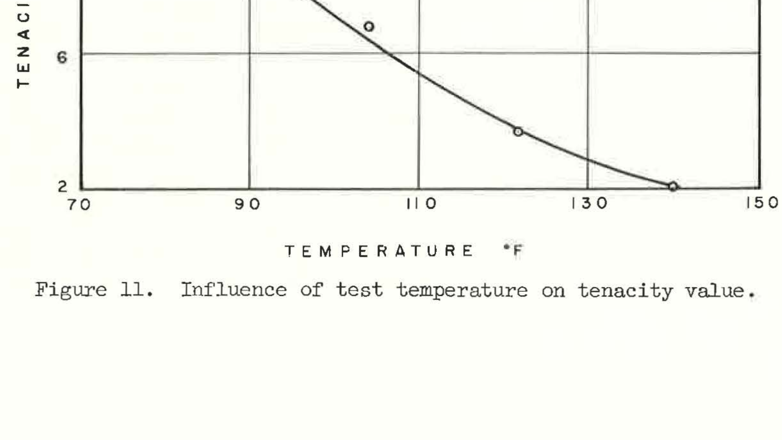

Figure 11. Influence of test temperature on tenacity value.

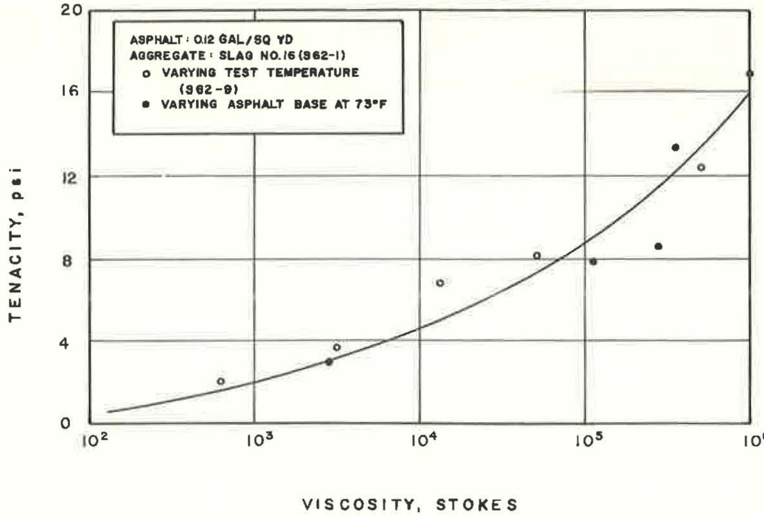

Figure 12. Relation between tenacity and viscosity for several asphalt-aggregate systems.

operator was able to remain in the room at 140 F for the time necessary to perform the test because the humidity in the room was very low. In each of these cases, at least 24 samples were run at each temperature.

The results indicated that the viscosity of the asphalt greatly influenced the tenacity value; accordingly, a chart was made up, as shown in Figure 12, in which the tenacity values at different temperatures are plotted against the viscosity of the asphalt AC-15 (S62-9) at the same temperatures. In addition, as indicated by the solid dots, data were also included for some additional asphalt base materials having a different range of viscosity from the AC-15 used in most of the work reported here. These different asphaltic materials ranged from a soft fluid Gulf Coast naphthenic residuum to a Florida AC-8 asphalt cement. The line drawn in Figure 12 represents an estimated smooth curve through all of the data that were available. The viscosity data at different temperatures for the asphalt cement AC-15 used in most of the experiments were obtained by plotting experimental data on the standard ASTM viscosity chart and reading off the values at the temperatures used for the tenacity test measurement.

Influence of Aging

There was some indication that the test values were affected by the length of time between the preparation and the testing of the samples. This phenomenon was not totally unexpected since it is well known that there is an aging effect on asphalt in many physical tests because of the colloidal nature of the asphalt which sets after it has once been melted. Apparently this effect has also shown up in this tenacity test. To obtain quantitative data on the influence of aging, certain experiments were run as indicated in Table 5.

Samples aged up to 170 hr displayed a steady increase in the tenacity value which, when plotted against the log of time,

TABLE 5

EFFECT OF AGING ON TENACITY[a]

Measurement	Roadbed Age			
	2 Hr	22½ Hr	92 Hr	170 Hr
No. of samples	27	9	9	9
Mean tenacity at 73 F, psi	12.5	16.3	19.4	20.1
Std. dev., psi	1.48	1.7	0.58	1.6
Coeff. of variation, percent	11.8	10.7	3.0	10.1

[a]Asphalt S62-9, 0.12 gal/sq yd; aggregate, slag No. 16 (S62-1).

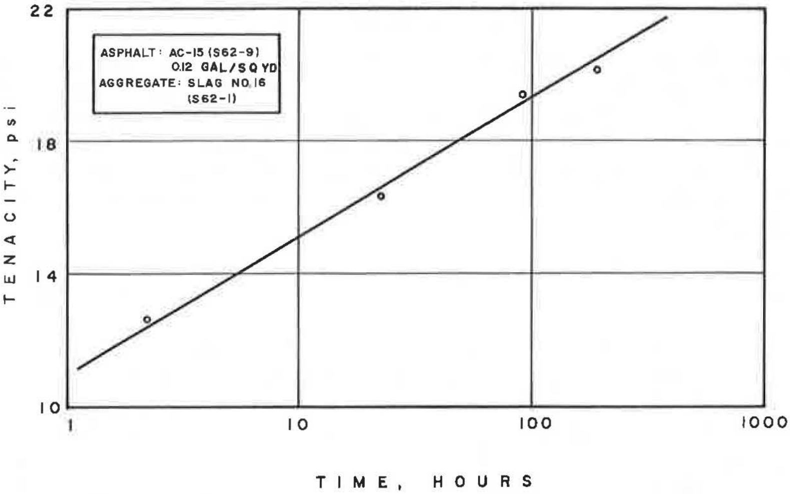

Figure 13. Change in tenacity value with aging of samples.

showed essentially a straight line (Fig. 13). For these samples, as indicated in Table 5, the number of samples was somewhat limited because the quantity of materials was limited. However, the trend is significant and is perhaps one of the most important results obtained in this study. If the correct relationship between time and tenacity value is a semilog plot as shown, the tenacity value increases with aging at a rate which decreases as an inverse function of time.

Variance for Two Operators

A brief survey was made of the effect of using two different operators for performance of the tenacity test. The results are given in Table 6. The data in the table include results for a new sample for AC-15 (S62-9) which is compared with the results obtained on the AC-15 used for the earlier work. As noted earlier, the viscosity of the asphalt had an appreciable effect on the results and, therefore, any variation in the viscosity of the asphalt for a given asphalt cement specification would be expected to affect the tenacity value. The range of data shown for S62-9 with two operators was from 12.5 to 13.9 psi, which is considered an acceptable agreement. Refinements of the test procedure probably could reduce this difference, but no further work was done in this direction.

TABLE 6

COMPARISON OF DATA BY TWO OPERATORS[a]

Measurement	Asphalt S59-16, Operator A	Asphalt S62-9	
		Operator A	Operator B
No. of samples	51	27	50
Viscosity at 77 F, megastokes	0.33	0.32	0.32
Mean tenacity at 73 F, psi	13.1	12.5	13.9
Std. dev., psi	0.88	1.48	2.34
Coeff. of variation, percent	6.7	11.8	16.8
95 percent confidence limits for mean, psi	12.8 13.4	11.9 13.1	13.4 14.5

[a]Asphalt AC-15, 0.12 gal/sq yd; aggregate, slag No. 16 (S62-1).

CONCLUSIONS

The studies conducted on the tenacity of aggregate according to the procedures used in this research have resulted in the following conclusions and inferences. Not all of the data have been reported here, but the major points are covered and indicate some of the problems involved in developing a laboratory test suitable for evaluating mineral surface treatments with respect to the tenacity with which the aggregate is held. In general, these conclusions confirm the work of Benson and Gallaway (2) whose evaluations were made by a different procedure.

1. The tenacity test as developed appears to give a quantitative measure of the retention force holding the aggregate, but the data are subject to a relatively high variance.
2. There is a complex interrelationship among the variables influencing the tenacity with which the aggregate is held; any of these may be a critical factor in a particular evaluation. Based on the results for Miami limestone and slag, which are somewhat different in surface characteristics, it appears that the type of aggregate is not too critical a factor.
3. A moisture content below a certain threshold value of approximately 8 percent did not appear too critical, but since this was based on slag No. 16, such a generalization should be used with caution.
4. A generalized relationship among tenacity and viscosity, where the viscosity is altered either by changing the temperature or by changing the asphalt, has been shown based on the results for a single aggregate.
5. The variance for the tenacity test as now run shows a high value with different operators, although it is believed that this could be reduced by refinements of the test procedure.
6. A definite relationship between the tenacity value and the aging of the samples before testing was indicated. It was shown that even for short periods of time there was an appreciable effect on the tenacity value. This might be one of the most important considerations in reducing whipoff and one of the most important conclusions of this research. Thus by prohibiting traffic for somewhat longer periods during general surface-treatment operation, it might be possible to reduce the whipoff if the results of this research can be translated into field performance.

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Appendix

TEST PROCEDURE

This is an abbreviated statement of the test procedure used in obtaining the results reported in the paper. To conserve space, not all of the details of the procedure have been included.

Test Equipment

A simulated roadbed of ⅛-in. thick aluminum plate is made, having the dimensions of 15.5 by 6.23 in. A steel form surrounding the edges of the roadbed has steps corresponding to specific spread quantities of asphalt, assuming that the asphalt has a density of unity. These steps are used as guides for a doctor blade so that the proper amount of asphalt is retained on the roadbed. The roadbed will take three molds approximately 4 in. in diameter with an inside cross-sectional area of 12.8 sq in.

Preparation of Roadbed

The clean tared test plate is heated to about 375 F, and sufficient asphalt to provide 30 percent excess of the desired spread quantity is heated to about 300 F and poured on the plate. The plate is manipulated to spread the asphalt uniformly over the surface and then the assembly is permitted to cool. When the plate is cooled to about 110 F, a heated doctor blade is used to wipe off the excess quantity of asphalt so that the desired spread quantity remains on the plate. The plate and asphalt are weighed and the weight of asphalt is recorded.

While the asphalt is still warm, a properly dried quantity of aggregate sufficient to give a 20 percent excess over the desired spread quantity is spread over the asphalt surface. After cooling, a 1-in. thick foam rubber mat is placed on the aggregate and the entire assembly pressed at about 15 psi. Excess aggregate is shaken off by a wrist-snapping action and the plate is again weighed to determine the amount of aggregate retained. Four-inch molds are then arranged down the center line of the plate and pressed into the roadbed by means of a press.

Preparation of Bonding Material

Hydrocal A-11 or B-11 quick-setting cement (U.S. Gypsum Co.) is used as a bonding agent to bind the aggregate to the molds. The material is prepared by thoroughly mixing 125 gm of cement and 67 ml of water for each mold to be prepared and pouring the slurry into the mold. The aggregate should be completely covered. The completed roadbeds are placed at a desired test temperature and allowed to stand for about 1.5 hr.

Test Conditions

The normal testing of the tenacity was carried out at a temperature of 73 F, using a Scott tensile tester with a pulling head speed of 11.3 in./min. In most cases, the tenacity test used an asphalt spread quantity of 0.12 gal/sq yd and an aggregate spread quantity of 0.10 cu ft/sq yd which are the minimum spread quantities specified by the Florida State Road Department for this type of treatment with the aggregate used.

In general, three plates of nine molds were run in one group and three of these groups were run in 1 day to give a total of 27 test values, provided none of the mold and bonding setups were defective. Twenty-seven values were considered sufficient for a statistical analysis.

Comments

The desired spread quantity of approximately 0.10 cu ft/sq yd was sought in these experiments, but it turned out the actual value was about 10 percent less as reported in some of the tables.

The spread quantity of asphalt, theoretically, is the amount filling the spaces between the aggregate particles up to a thickness or embedment t. The total voids volume, therefore, is A· t, where A is the total area over which the aggregate is spread.

As shown in Figure 14, the Kearby embedment chart indicates the fraction of total embedment that should be used for an average mat thickness t in inches. This is a design chart to determine the amount of asphalt to be used for aggregates of different sizes, since the size of the aggregate determines the average mat thickness t. The average mat thickness is computed from Eq. 2, which follows, or from some physical measurement of the average particle size of the aggregates.

The following information relates the embedment and the amount of asphalt that should be used for a given operation.

1. Embedment is that fraction of the average mat thickness that should be filled with asphalt or bitumen. This is determined empirically as a function of the average mat thickness t using the chart in Figure 14.

2. Spread quantity of aggregate, S:

$$S = S'/D_L, \text{ cu ft/sq yd} \tag{1}$$

where S' is spread quantity (lb_m/sq yd) and D_L is loose-packed density (lb_m/cu ft).

3. Average mat thickness, t:

$$t = 1.33S = 1.33S'/D_L, \text{ in.} \tag{2}$$

also sometimes given as $t = \sum G_f d_f/100$ in. where G_f is percent of mean size d_f from sieve analysis.

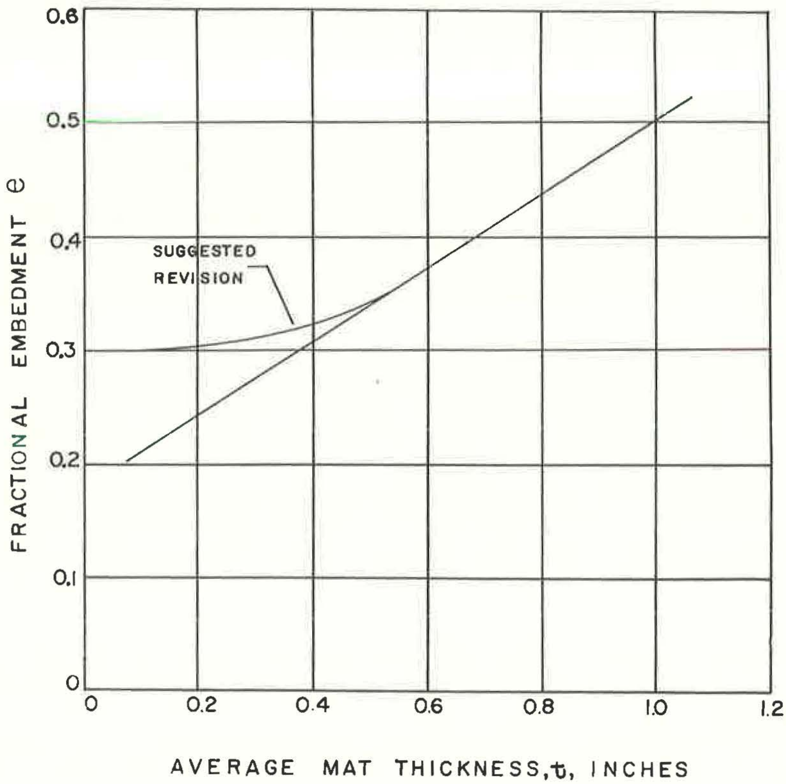

Figure 14. Kearby embedment chart (2).

4. Spread quantity of bitumen or asphalt B:

$$B = 5.60etV = 5.60et\,(1 - D_L/D_A),\ \text{gal/sq yd} \tag{3}$$

where V is total void space in the loose-packed aggregate, e is fractional embedment, and D_A is apparent density of aggregate equal to 62.4 times its specific gravity (lb_m/cu ft).

5. Material weight for area A (sq yd):

$$wt = Bp_bA = \text{lb of bitumen} \tag{4}$$

$$wt = Sp_aA = \text{lb of aggregate} \tag{5}$$

where p_b is lb/gal for bitumen and p_a is lb/cu ft for aggregate randomly packed.