FIELD AND LABORATORY INVESTIGATION OF TRAFFIC PAINTS *

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SYNOPSIS

This paper is a progress report of a co-operative investigation between the State Highway Commission of Indiana and the Joint Highway Research Project of Purdue University Only the durability of traffic paint has been considered in this report The object of the study was to establish a correlation between field performance and laboratory tests and to determine the characteristics of the paint film necessary for good durability on the road

Samples of traffic paints representing the specification materials of eight different states, selected to cover a wide range of type and composition, were obtained and applied in the field at six different locations in the vicinity of Lafayette, Indiana Old concrete, new concrete, and bituminous surfaces of different widths were used The paints were applied with both brush and spray gun as transverse lines, as a centerline, as obedience lines on a curve, and were also applied at a location where they were subjected to the action of weather only The paints were given a durability rating on the basis of visual inspection in the field supplemented by a kodachrome-slide record The completed tests include those for the characteristics of the paint—settling, mobility, hiding power, weight per gallon, drying properties, pigment, and volatile and non-volatile content, and tests for the characteristics of the dry film—pigment volume, abrasion loss, water and alkali resistance, and degree of flexibility Special attention has been given to the abrasion and flexibility tests. The Dorry hardness abrasion test has been modified to give more reproducible results. A method is presented for determining the degree of flexibility of a traffic-paint film

It was found that there was a wide difference, amounting to several hundred per cent in some cases, in the durability performance of the specification paints In general, the durability of the paints was independent of the methods of application which were used It was observed that, in the final analysis, all paints failed on concrete by losing bond with the surface (scaling) even though some of the paints were subjected to a long period of wear before failure took place Those paints which showed early failure by scaling at one location did so at each where they were included in road tests on concrete, while the best paints of the group were consistently the best under each type of road service The modified wet abrasion and water resistance tests have shown a positive correlation with the field data The degree of flexibility of a traffic paint appears to be entirely meaningless from the standpoint of correlation with field durability on concrete pavements It is indicated that a test for adhesion, with particular attention to the loss of adhesion caused by water and other weathering factors, is desirable

Purpose of Study

This study of traffic paint was undertaken because it is generally recognized that traffic-paint specifications are not always adequate to insure a satisfactory material. In the past the formulation or composition of the paint has been stated in practically all traffic-paint specifications. Paint, however, is a complicated colloidal mixture that is very difficult to analyze, and even though the raw materials which make up the vehicle are known, it is impossible to determine what reactions have taken place in the processing. Specifications based on composition, therefore, have not been entirely satisfactory and many states have abandoned this type of specification in favor of a field service test as the basis for award of

* This study is being conducted by the writer as a research project under the direction of Professor K B. Woods, Assistant Director of the Joint Highway Research Project Acknowledgment is also made of the valuable assistance of members of the Advisory Board of the Project as well as Dr I W. Burr, Assistant Professor of Mathematics, Purdue University, for his aid in evaluating the flexibility-test data statistically

contract. This latter procedure is open to criticism since it requires several months and since there is no positive assurance that the same paint will be supplied as was tested. There also is no control of the quality of separate batches of the paint supplied by the manufacturer.

Mr. J. E. Myers, chairman, in a report of the Committee on Traffic Zone Paint, Highway Research Board (6),[1] has summed up the situation thus.

"The volume of traffic paint used on highways and streets has increased to the point that proper attention to specification and testing problems is necessary. Paint is one of the materials that cannot be purchased in its finished form for service but must pass through final operations that are subject to variables that are often beyond control Added to this the material itself is a complicated colloidal mixture of organic materials which often defies any reasonably accurate determination of quality by simple composition tests The situation is still further complicated by the fact that the research activities of the paint and allied industries are constantly making available new raw materials in new combinations with which improved service results are made possible The result is that the picture changes so rapidly that if the user is at all progressive minded he is very likely to become discouraged in his attempts to keep abreast of these new developments by means of exact composition specifications It follows that there has been increased interest in laboratory and road tests that might be standardized and give accurate information about the service life of paint and laboratory scale road tests"

In view of these considerations, it was felt that the most satisfactory basis for a traffic-paint specification would be one based on laboratory performance tests that had been correlated with road performance. This report represents the progress that has been made toward this goal. Investigations of this nature in the past (2, 3, 4) have centered mainly around some form of an accelerated wear test that simulated road conditions to some degree. Much work has been done to determine the best formulation for a traffic paint (4, 5, 8, 9). This information is of primary interest to the manufacturer, but the thought behind this research program has been that it is of secondary importance to the traffic-paint consumer. He is interested solely in how well any given paint serves its intended purpose.

It was the primary object of this study, then, to establish what properties of the paint film were necessary for good performance. As a starting point, the tests for film characteristics, which are in common use, were chosen for evaluation While many other properties of traffic paints, such as drying time, color, covering power, visibility, etc, are important characteristics, the primary consideration of this study has been durability with respect to the amount of paint remaining on the road surface. This property is of most concern from the serviceability and testing standpoints

In addition to the correlation of laboratory tests with road performance, it was a further purpose of this study to determine the effect of the type of surface and service condition on the life of the traffic paint. It was felt that if the factors affecting the service life of traffic paints were evaluated, a better testing technique could be developed in the laboratory.

Paints Acquired for Study

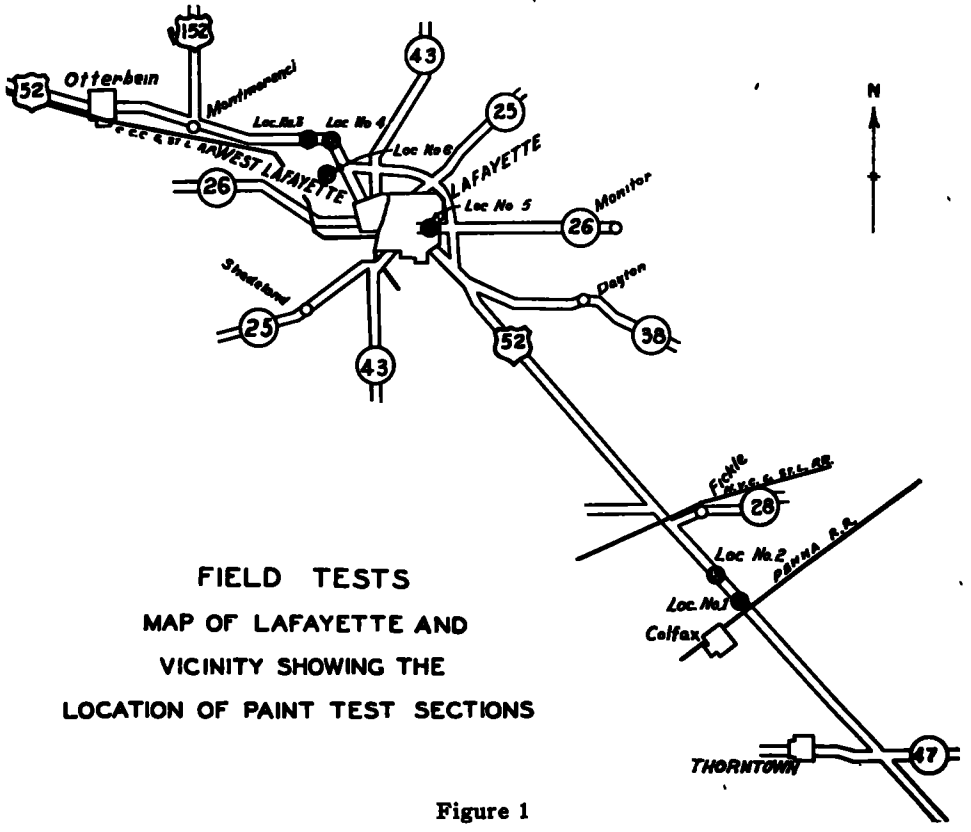
The paints acquired for study in this research program were chosen to cover the range of type and composition in common use. They were specification materials supplied by eight different States and included the two general types on the basis of the vehicle employed. One type consisted of kettle-treated, natural or synthetic gums and drying or semi-drying oils, and the other of a cold-cut, natural resin that used a drying or semi-drying oil as a plasticizer. In all, 17 different paints were submitted by the eight States Table 4 gives the color of each paint together with the type of vehicle used in its manufacture. The paints covered the range of specifications in common use

[1] Figures in parentheses refer to list of references at end.

and, in addition, were selected from States with general climatic conditions comparable to those of Indiana.

The appearance of these 17 paints varied from a dull, flat to a semi-gloss finish. The white paints varied from a pronounced yellowish tint to a bluish white. No two of the yellow paints were the same color. They varied from a bright canary yellow to a rather dirty-looking brownish color.

endure under each type of service. Transverse stripes, centerline stripes, and obedience-line markings were included Also a location was used where there was no traffic. The type of road surface to which the paints were applied was also varied to include new broomed concrete, old smooth concrete, and bituminous surfaces. The roads were also of varying widths The primary object of all the road tests was to secure a field rating for all of the paints to compare with the laboratory results.



FIELD TESTS
MAP OF LAFAYETTE AND VICINITY SHOWING THE LOCATION OF PAINT TEST SECTIONS

Figure 1

Field Tests

The 17 paints were placed in service at six locations in the vicinity of Lafayette, Indiana. These locations are shown on the map, Figure 1. A variety of service conditions was included in an attempt to determine the relative amounts of traffic and weathering action that paints must

TEST SECTIONS AND PROCEDURES

Wherever possible, the paints were placed by two different methods. In one portable spray equipment was used with a hand spray gun; in the other, the paint was spread as evenly as possible with a brush. With both methods, special care was taken that a definite volume of the

paint should be spread uniformly over the chosen area A template made from 2-in, cold-rolled strip steel was used to define the area to be painted. All paints at any given location were applied the same day to perfectly dry pavement. Each stripe was allowed to dry for at least 1 hr. before being subjected to traffic; however, the time varied over a wide range since all stripes could not be placed at the same time

All paints, with the exception of No. 8, were applied as received. Paint No. 8 was thinned at the rate of two quarts of V. M. and P naphtha per 5 gal. of paint as is specified for this paint. Each gallon sample of each paint was thoroughly mixed and put into quart cans as soon as it was received. A new quart sample of paint was then used for each day's operations. In general, it may be said, because of their rather heavy consistency, that paints Nos. 2, 8, 9, 10 and 13 were the most difficult to apply with the spray equipment used, but that satisfactory application was obtained even with these paints The cold-cut paints formulated with highly volatile solvents (paints Nos 3, 4, 7, 11, 14, and 17) were usually difficult to "brush out" into an even film because of their tendency to become tacky almost as soon as they were applied; they were very readily applied with the spray gun.

The following sections describe in detail the paint stripes placed at each location and each condition of service. The rate of application in each case was such that the surface was well covered with a uniform film The amount of paint necessary to reach this condition varied rather widely with the roughness and texture of the surface.

Transverse Stripes on New Concrete: The site chosen for this test series was located on U. S. 52 about 21 miles south of Lafayette at the Pennsylvania railroad crossing. The pavement is 22 ft. wide and was constructed in 1939-40 of 36 per cent sand and 64 per cent gravel, using 1.50 barrels of cement per cubic yard of concrete It was finished with a wire broom to give a heavily corrugated surface.

The stripes at this location were made an integral part of the standard railroad marking. For this reason only white paints were included and the lines were limited to four inches in width The paints were placed the afternoon of July 30, 1940, when the average air temperature was 96° F. All stripes were placed across one-half of the pavement (11 ft. long) in the northbound traffic lane. The rate of application was 20 gal per mile of 4-in. stripe or approximately 90 sq. ft per gal

The average annual traffic on this road was 1,785 vehicles each way per 24 hr of which approximately 25 per cent were trucks During the winter months (Dec, Jan., Feb.) the traffic count was about 77 per cent of the average annual figure while during the summer season (June, July, Aug) the traffic count was about 118 per cent of the average annual figure.

Centerline Stripes on New Concrete These tests were placed on the same pavement as the transverse stripes just discussed about one mile north of that location. A white centerline was placed on a 4,200-ft. straight portion of the road lying between two wide curves. The test paints were placed in a 200-ft. strip. The individual test lines were each 10 ft. long and 4 in. wide. The painting was done the morning of July 30, 1940, when the air temperature was 90 to 95° F. Each paint was again applied twice, once by each method, at the rate of 90 sq. ft. per gal.

The pavement at this point was the same as that just described under "Transverse Stripes on New Concrete." The two locations are close enough together so that they carry the same traffic.

Transverse Stripes on Old Concrete· This test section was located about three miles north of Lafayette on the old concrete surface of U. S. 52. A yellow no-

passing line paralleled the centerline in the lane of traffic in which the stripes were placed The pavement was 18 ft. wide and was constructed, about 12 years prior to the time the paints were applied, of 36 per cent sand and 64 per cent gravel, using 1 70 barrels of cement per cubic yard of concrete. It was finished with a smooth surface.

As shown by the photographs of this section (Fig. 9), the road surface was spotted with oil and several transverse cracks had been filled with bituminous material. All of the paints (with the exception of No. 9, intended for bituminous surfaces only) were applied here by both methods at the rate of 15 gal. per mile of 4-in. stripe or about 120 sq. ft. per gal. All stripes were 6 in. wide and 8.5 ft. long. The painting was done August 13, 1940, when the air temperature was 85-90° F.

The average annual traffic on this road was 2,410 vehicles each way daily with truck traffic amounting to about 25 per cent of this figure. The variation in traffic from winter to summer was about the same as for the new broomed concrete of U. S. 52.

Obedience Stripes on Old Concrete· All of the yellow paints were used to mark the no-passing zone at the "pear orchard" curve on U. S. 52 north of Lafayette. The surface was the same as that used for the transverse stripes on old concrete; the traffic count was also the same. Since a ragged bituminous centerline existed that could not be avoided entirely, the paints were applied with the spray gun only. Four-inch stripes, 10 ft. long, were used and the rate of application again was about 120 sq ft per gal The paints were applied on August 26, 1940, when the air temperature was 80 to 85° F.

Since it was impossible to place six different paints on the same curve in such a manner that they would all be subjected to the same amount of traffic, an attempt was made to approximate this condition by placing each paint at four different locations around the curve The paints were placed at each end of the curve and on each side of the centerline at a point determined to be the approximate center of the sight distance of the curve.

Transverse Stripes on Rock Asphalt The rock-asphalt surface used for this series of tests was located within the city limits of Lafayette on S. R. 26 At the time the paints were applied, the surface was new and had not yet been opened to traffic Because the surface had not received the compacting action of traffic, abnormally large amounts of paint were required to obtain good coverage. The paints could not be brushed evenly without causing excessive bleeding and disintegration of the rock asphalt and therefore all stripes were applied by the spray method. All of the paints with the exception of No 10 (intended for concrete and brick surfaces only) were applied at this location as stripes 6 in. wide and 11 ft. long. The painting was done August 22, 1940, when the air temperature was 80 to 85° F. It was found, because of the porous nature of the surface, that the paints had to be applied at the rate of approximately 60 sq ft per gal to obtain good coverage.

The average annual traffic at this location was calculated as 1,120 vehicles each way daily. Approximately 12-13 per cent of the traffic was trucks.

Weathering Series: All 17 paints were placed with the spray gun on both a concrete and a bituminous surface, entirely free from traffic, in the form of 6-in. stripes. These stripes were placed to test the performance of the paints under weathering action only. They were placed July 25 and 26, 1940, when the air temperature was 90 to 98° F. The rate of application was 120 sq ft. per gal.

RESULTS OF THE FIELD TESTS

The road tests have been rated by visual inspection over approximately 11

months The method of visual inspection, whereby the degree of failure or the percentage of the line that has failed is judged, is certainly not ideal However, in the absence of a better method, it was used with special precautions to insure as great accuracy as possible. The paints were rated in the field periodically and, at the same time, a kodachrome record was made of the paint exposures The

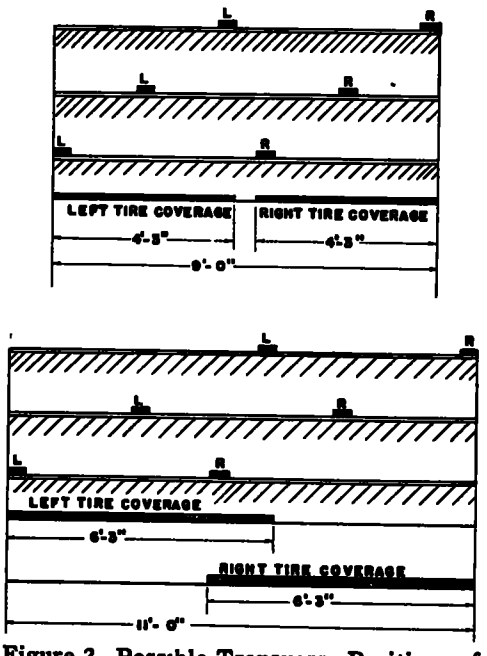


Figure 2. Possible Transverse Positions of Passenger-Car Traffic

paints were then rated by three independent observers using the color slides. This method proved satisfactory Although the individual opinions of the percentage failure of any particular line differed by as much as 20 per cent in the advanced stages of failure, nevertheless the average of these observations showed a logical and progressive degree of failure over the period that the paints were observed.

In discussing the results of the paint exposures, it is well to recall the three purposes of these tests. First, it was desired to obtain a relative durability rating for each paint Second, two different types of concrete, broomed and smooth (22 and 18 ft. wide), as well as three conditions of service, transverse lines, centerlines, and obedience lines, were included to determine the influence of these variables on the durability of the traffic paints Third, bituminous surfaces were included for comparison with concrete.

It was found, first of all, that the width of the pavement to which the paints were applied as transverse lines determined, to a great extent, the type of failure and made a direct comparison between the effects of two pavement textures impossible Figure 2 represents the possible transverse positions of passenger-car traffic on 18-ft. and 22-ft pavements. It can be seen that if the vehicle stays in one traffic lane it is not possible for the tires to cover the width of the stripe on an 18-ft. pavement In comparison, on a 22-ft. pavement each set of tires can more than cover one-half of the traffic lane. A similar situation exists with standard and semi-trailer truck traffic as shown in Figures 3 and 4 In these cases it is possible for truck tires to practically cover the entire width of the 22-ft. pavement. However about one-third of the width of the transverse stripe on 18-ft. pavement cannot be hit by the tires Added to these considerations is the fact that there is much greater tendency for vehicles to "track" on the more narrow pavement. These considerations were verified by the types of failure produced on the pavements of 18- and 22-ft widths.

The smoother concrete pavement was found to be much better adapted to traffic paint evaluation than the broomed concrete surface Besides the fact that the ridges of the concrete tended to break down under traffic, they collected dirt and dust and thereby obscured the results somewhat Also, the 6-in. lines spaced a good distance apart, as used on the smooth concrete, were much easier to evaluate

than the crowded, 4-in lines placed on the broomed concrete surface. For these reasons the attempt to rate the relative durability of the paints, after different periods of service, was confined to the transverse stripes on old concrete. The results of the other exposures have been compared with this detailed study It must be emphasized that the paints have been rated on the basis of durability only

Transverse Stripes on Old Concrete These stripes were placed August 13, 1940, and were rated for the first time on August 20, after seven days of service: The failure that had taken place on some of the paints was very pronounced at this time. Figures 5 and 6 show these results. Extensive failure was confined to paints Nos. 1, 6, 8, and 12, with paints Nos. 6 and 12 showing the greater degrees of failure. Inspection 30 days after application revealed very little new failure but did show that the failure of paints Nos 1, 8, and 12 had progressed considerably All of this failure was definitely of a scaling nature whereby the paint lost bond with the concrete. Small pieces of the paint film as large as one-half inch in diameter could be found along the shoulder of the road.

The results of the inspection of these lines after 155, 242, and 329 days of exposure are shown in Figures 5 and 6 It was evident that the method of application had very little effect upon the performance of the paints as a group Some individual differences could be found and the method of application may have had an influence on the performance in these cases. However, enough data were not available to draw any definite conclusions in this regard It is felt that paint No. 10 was handicapped by the spraying method used because of the presence of coarse sand in the paint The results on the sprayed stripe of paint No 10 therefore were discounted Also, the average results indicated that the outside wheel track at this location represented a

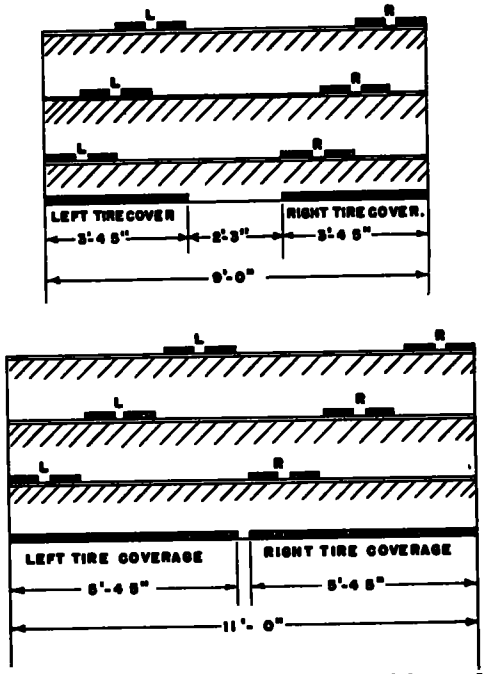


Figure 3. Possible Transverse Positions of Standard- Truck Traffic

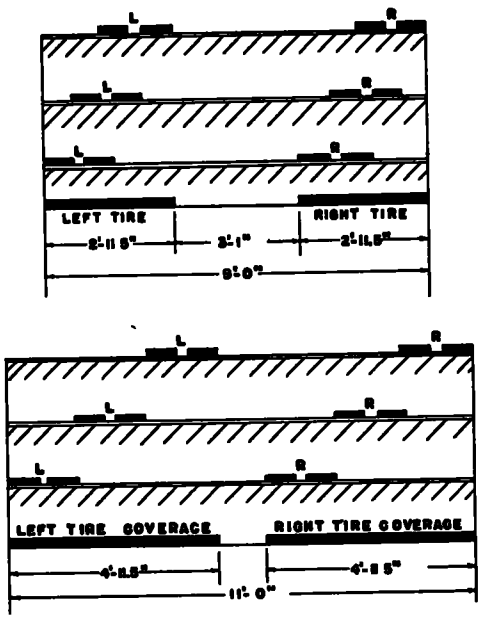


Figure 4. Possible Transverse Positions of Semi-Trailer Truck Traffic

condition about twice as severe as that of the inside track Dirt and stones along the edge of the road and in the treads of the outside tires of the vehicles may have caused this condition. The yellow paints as a group performed slightly better than the white paints, but the best white paints showed equal or better durability than the best yellow paints It is significant to note that over the entire service life of the paints most of the failure seemed to result

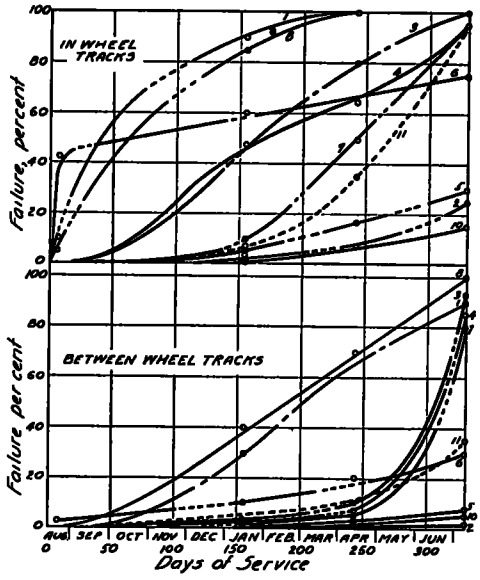


Figure 5. Results of Road Tests, White Paints, Transverse Stripes, Old Concrete

from a scaling action. No doubt much wear did take place over the length of time that the paints were exposed, but in practically every case it seemed rather conclusive that the final failure resulted from scaling.

It must be emphasized that these curves of Figures 5 and 6 are merely a representation and are not to be used to draw detailed conclusions. The results plotted are an average of the results on the sprayed and brushed lines and, for the wheel track area, are an average of the areas of both wheel tracks. Also, it should be emphasized that all ratings are based on the amount of paint remaining on the road, color changes, visibility, etc, have not been taken into account in the ratings

With regard to the white paints (Fig. 5), Nos. 2, 5, and 10 were definitely the best at the end of the 329 days of service, both in the wheel track area and in the area between the wheel tracks Paints Nos 1, 6, and 8 are definitely the worst of the group because of their early failure. However, the failure of No 6 did not

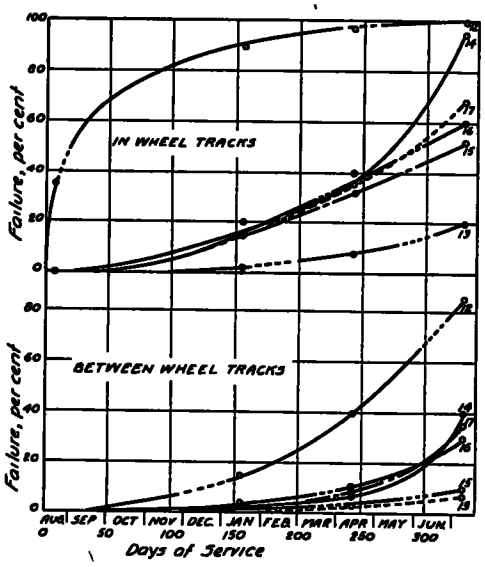


Figure 6 Results of Road Tests, Yellow Paints, Transverse Stripes, Old Concrete

progress in the same way as did the failures of Nos 1 and 8, so that it cannot be classed with these paints at the end of the 329 days of exposure, especially with regard to the area between the wheel tracks. In the wheel-track area, Nos. 2, 5, 7, 10, and 11 may be regarded as giving good service for a period of 155 days or approximately five months. In the area between the wheel tracks, Nos. 2, 3, 4, 5, 7, 10, and 11 showed good durability for a period of 242 days or approximately eight months. Nos. 3, 4, and 7, while showing good service in the area between

the wheel tracks for 242 days, failed rapidly after this time so that failure was nearly complete at the end of 329 days

With regard to the yellow paints, Figure 6 shows paint No. 13 to be definitely the best in the wheel track area. Paint No 15 is grouped with No 13 as the best of the yellow paints in the area between the wheel tracks. No 12 was definitely the poorest of the group. All paints except No. 12 gave good service in the area be-

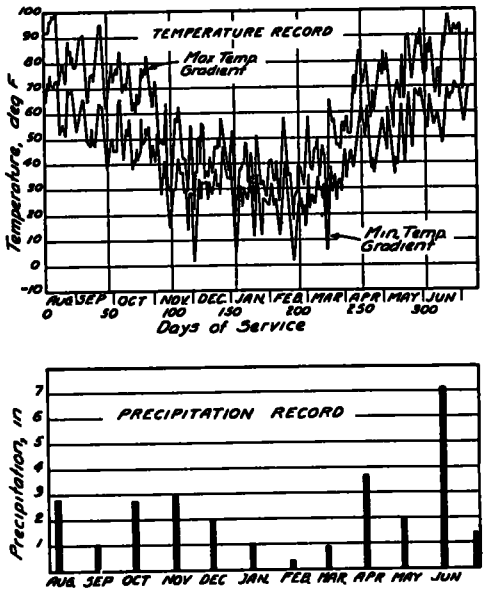


Figure 7

tween the wheel tracks for a period of 242 days, while No. 13 showed its superiority in the wheel track area over most of the period the paints were in service

The temperature and rainfall record over the period of these tests is shown in Figure 7. Analysis reveals that the paints went through changes of temperature that crossed 32° F. 88 times between November 7 and March 30, as shown by the daily maximum and minimum temperature gradients. These recorded cycles of freezing and thawing are no doubt a minimum since in any one day there may be numerous cycles, depending upon temperature, clouds and sunshine. The question immediately arises as to what would happen if these same paints had been placed at a different time of year.

Figures 8 and 9 show views of these tests after services of 155 and 329 days respectively

Obedience Stripes on Old Concrete. These tests failed to accomplish their objective because of the ragged bituminous centerline and bituminous-filled cracks previously mentioned. All of the yellow paints, with the exception of No. 12, showed fairly good service up to the time when they were largely obliterated by the bituminous material. Paint No. 12 did not fail as rapidly at this location as in the transverse stripe test. The conclusion is that this service condition in general was not so severe as the wheel track area of transverse stripes and was more severe than the area between the wheel tracks However, this did not hold true for points around the entire curve.

Transverse Stripes on New Concrete As was previously stated, these tests were very difficult to rate because of the crowded conditions and the broom marks The results are not directly comparable to the results of the smooth concrete tests because of the difference in width of the pavements. However, some general findings and conclusions are worthy of note. The results of the sprayed and brushed stripes were again very similar.

The three white paints, Nos. 1, 6, and 8, that failed early on smooth concrete by scaling also scaled early in this series of tests This failure did not start as early nor progress as rapidly as in the tests on smooth, 18-ft., concrete Paint No. 6 was an exception to this latter statement, being the first paint to show failure at this location.

Those white paints which performed best on the smooth concrete surface, Nos. 2, 5, and 10, also gave the best service in these tests.

Centerline Stripes on New Concrete: Figure 10 shows the test section after 256 days of service. As in the transverse-stripe test, early failure by scaling occurred on paints Nos. 1, 6, and 8, but in this case the failure was not nearly so marked. After 41 days of exposure for each set of stripes, the failure on the centerline amounted to only about one-third to one-fifth as much as for the transverse stripes on this same pavement.

In general, it required much longer to develop significant differences in the paints placed as a centerline than when these same paints were applied as transverse stripes. However, after some five months of service, Nos. 2, 5, and 10 again showed superiority. In these tests, No. 6 could also be included in the best group. After 256 days of exposure Nos. 5 and 10 were definitely superior as centerline paints. Nos. 2 and 6 were only slightly less durable.

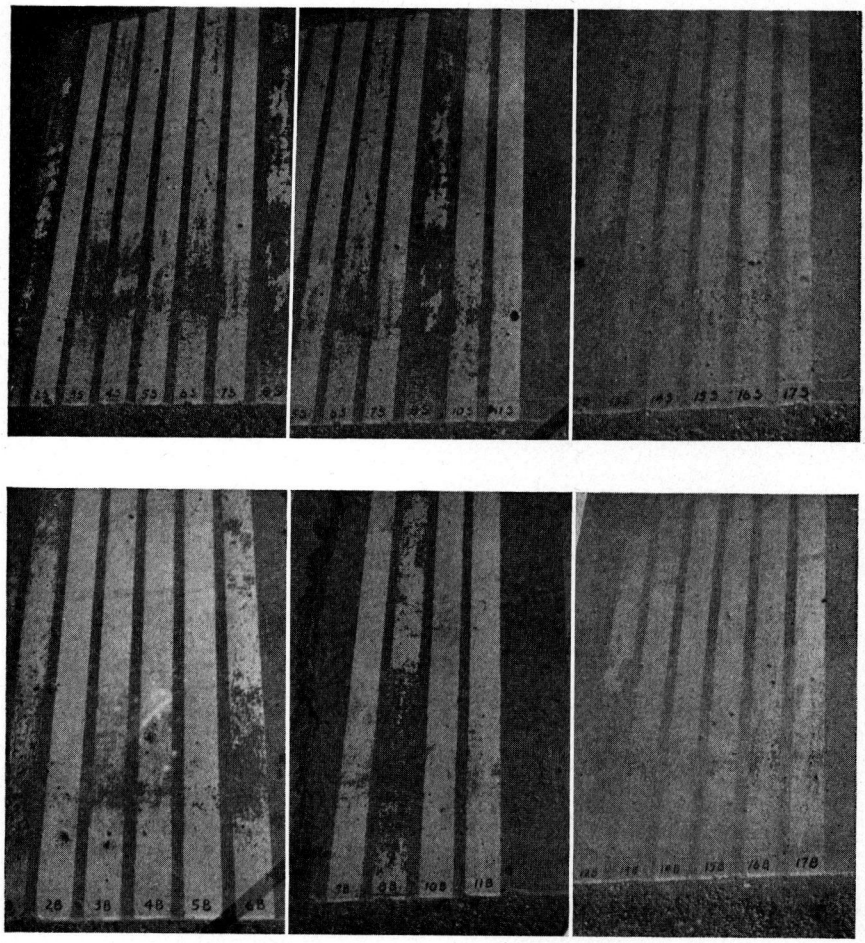


Figure 8. Transverse Stripes on Old Concrete after 155 Days of Service

Transverse Stripes on Rock Asphalt: Paints Nos. 6 and 12 cracked badly when first applied to this surface. No. 1 yel-

lowed considerably after application and Nos. 2, 3, 4, 7, and 11 appeared definitely whiter than the other white paints.

The results of these tests must be discounted in some degree because the non-uniform porosity of the surface prevented applying the paints in an even film. However, in general, the paints performed better on this surface than on concrete. Although most of the failure on this surface seemed to take place by a wearing (abrasion) action, considerable scaling was in evidence. Paint No. 6, which cracked when first applied, scaled to a marked degree. It can be said that Nos. 2, 5, and 13 (No. 10 was not included in this test—it is intended for concrete and brick surfaces only) were again among the best performers. As shown in Figure 11, Nos. 8, 11, and 16 may also be considered as giving good performance on this surface. Paint No. 9, intended for bituminous surfaces only, was among the worst of the group on a durability basis.

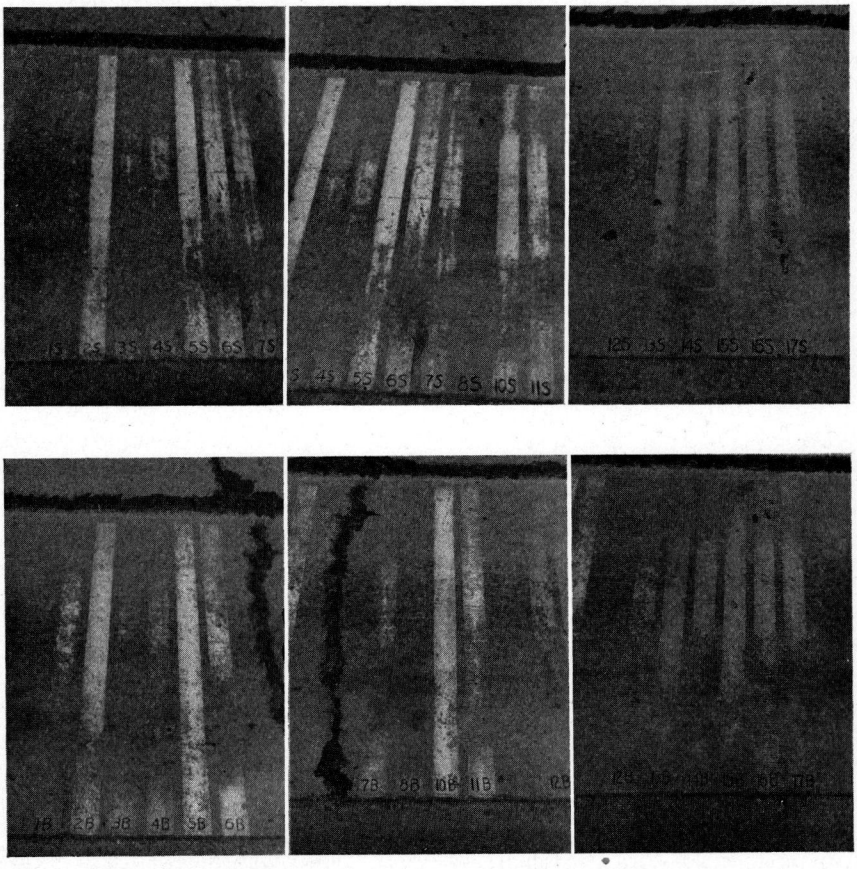


Figure 9. Transverse Stripes on Old Concrete after 329 Days of Service

Weathering Series: Even though the weathering tests have been under way only one year, it has already been demonstrated that weathering is an important factor affecting the durability of a traffic paint. In this series of tests, disintegration was apparent after only six months of exposure with some evidence being

noticed previous to that time. The effects of weathering were difficult to evaluate because there was no action present to dislodge those portions of the paint film which scaled or otherwise became loosened by the action of weather. Nevertheless, considerable scaling was in evidence, and it is possible that a longer service will reveal more definite results. The tests have shown that the weathering resistance of a traffic paint certainly has an important bearing upon its road durability characteristics, particularly if service of six months or longer is considered. Traffic paints can fail quite markedly within a year or less under the action of weather alone. The following remarks refer to the paints after one year of exposure. Figure 12 shows the white paints on concrete and bituminous surfaces exposed to weather without traffic for one year.

On concrete all of the paints showed some evidence of scaling. Nos. 3, 4, 7, 11, and 17 seem weathered to the greatest degree, showing evidence of chalking and scaling to the extent of exposing the concrete surface over a considerable portion of the painted area. The fact that these paints showed less weathering resistance on concrete may account in some measure for the sudden change in the slope of the failure curves of these paints as transverse lines on smooth concrete. See Figure 5.

On the bituminous surface, all paints were scaled to some degree. However, Nos. 3, 4, 7, 11, and 17 seemed to be scaled only where they covered the exposed aggregates and not where they came in contact with the bituminous material directly. On this surface, Nos. 8 and 9 seemed to show the least resistance to weathering.

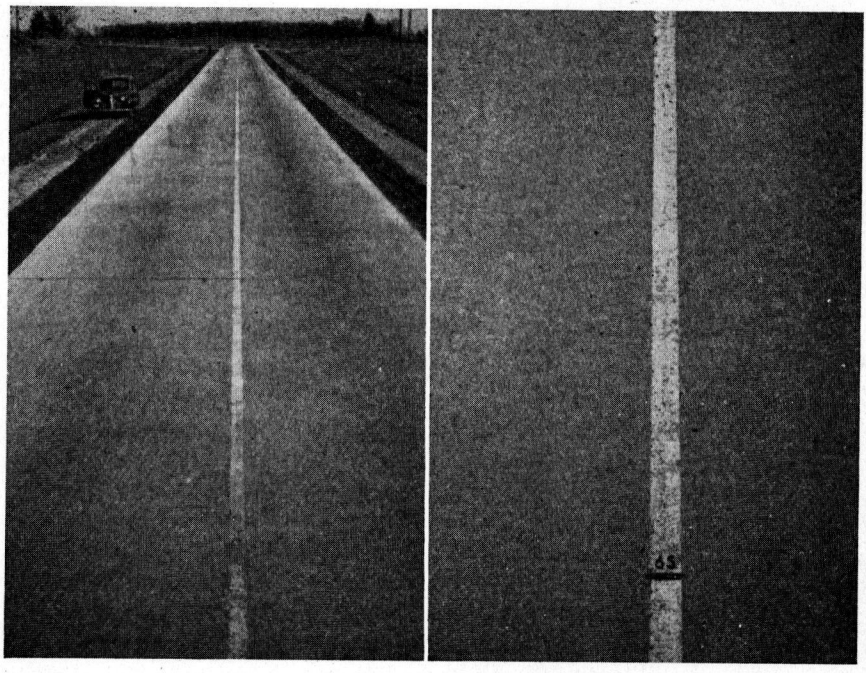


Figure 10. Centerline Stripes on New Broomed Concrete after 256 Days of Service

Laboratory Tests

The laboratory tests were made on the identical paints that were applied in the field. The object of these tests, as pre-

viously stated, was to establish test constants for the various paints which might be compared with road performance. Tests for characteristics, such as hiding power, mobility, weight per gallon, etc., were included for completeness of the record and to give those interested more complete information on the paints used. However, those tests which measure characteristics of the paint film have received prominence in this study.

The field tests indicated that a test to measure the adhesion of traffic paint for concrete surfaces would be very desirable. Work is progressing on such a test, but satisfactory results are not yet available.

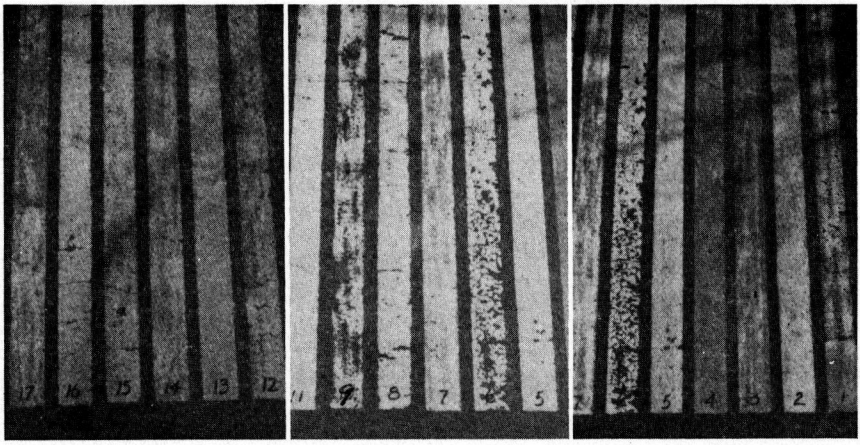


Figure 11. Transverse Stripes on Rock Asphalt after 233 Days of Service

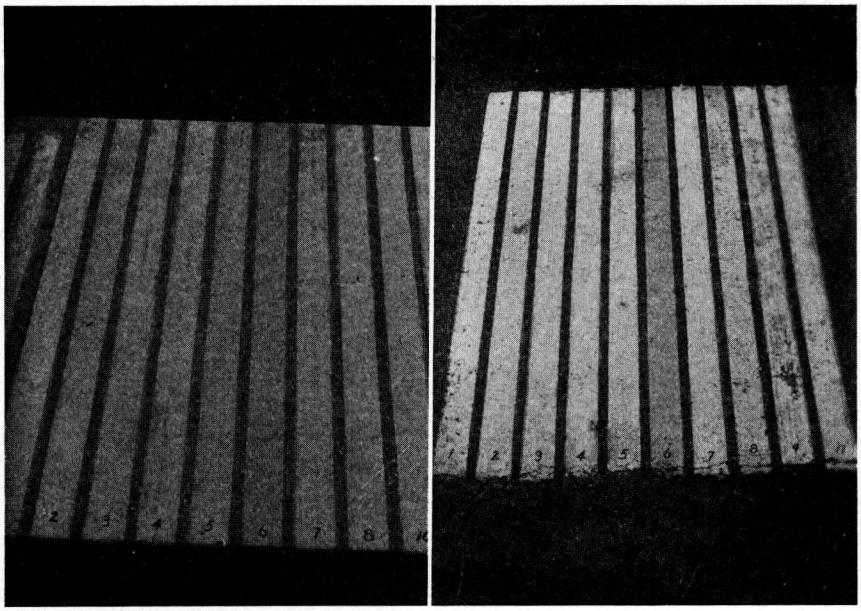


Figure 12. Weathering Series after One Year of Exposure

Also, it seems from the field tests that it may be necessary to determine the effect of weathering agents on the test constants of these paint films. This work is contemplated for the future.

For a complete discussion of methods of paint testing, the reader is referred to the book of Gardner (10). The methods of tests for traffic paints in use by several state highway testing agencies are discussed in the extensive series of articles by Shuger (7)

The final results of all laboratory tests made to date are recorded in Table 4.

CHARACTERISTICS OF THE PAINT—METHODS OF TEST

Each gallon of paint, when received, was thoroughly mixed and divided into quart samples, two of which were then set aside for the laboratory tests. Standard procedure was followed whenever a standard existed

Settling Characteristics The settling characteristics of these paints were determined by a method supplied by the Krebs Pigment and Color Corporation (from written communication). The test as used by them is applied to the pigment cake in a quarter-pint can, using a 6-in tapered spatula As used by this laboratory, the test was applied to the pigment cake in a quart can, using an 8-in spatula, 1 in. wide. The degree of caking is determined as follows.

C-10+	Perfect dispersion—no sedimentation whatever apparent
C-10	Gives practically no resistance to spatula No deposit brought up with spatula, however, pigment may even be rather well settled out.
C- 9	Well defined but very soft cake offering a slight but definite resistance to sideways motion of spatula (Flat side of spatula foremost)
C- 8	Spatula readily drops through to bottom of can under its own weight. Cake has toughened slightly so that portions can be removed with spatula
C- 7	Just possible to move spatula through cake sideways. Slight but definite edgewise resistance to spatula This is the important point of initial "failure" by caking, i e, where caking begins to become truly objectionable
C- 7—	Practically impossible to move spatula sideways through cake
C- 6	Well defined resistance to spatula when moved edgewise with one hand
C- 5	Just possible to move spatula edgewise with one hand
C- 4	Necessary to use both hands to produce edgewise motion of spatula
C- 3	Barely possible to move spatula edgewise through cake
C- 2	Impossible to move spatula edgewise when once inserted in cake

Mobility The mobility or consistency was measured by means of a Gardner Mobilometer using the 51-hole disc, a total moving load of 100 g., and a distance of 10 cm. "The cylinder is filled to a depth of 20 cm with the material to be tested. The cylinder is levelled by means of the adjusting screws The disc end of the plunger is then introduced into the cylinder and the bracket attached. The time required for two marks 10 cm apart on the stem of the plunger to pass through the collar is then recorded" (10). The test temperature was 25° C.

Hiding Power The relative hiding power of the paints was determined by the checkerboard brush-out method. The hiding-power board was glass covered and met the requirements for the proposed tentative definition for hiding power suggested by Sub-Committee VIII of Committee D-1, American Society for Testing Materials, which is as follows:

"The hiding power of a paint is measured by that quantity of a paint that must be applied to a given area of an impervious black and white background, the white portion of which has a brightness of 80 per cent plus or minus 2 per cent, and the black to be less than 8 per cent brightness, so as to bring the brightness over the black background to within 98 per cent of that over the white background and shall be specified at 'wet.'"

Quite obviously, when this test is applied to traffic paints, the term "wet" loses its meaning. The test is difficult to use with these paints because, in general, they are not easily brushed out and it is therefore not as accurate as when applied to oil paints The method of using the hiding-power board was to weigh the quart can and a one and one-half inch clean brush to plus or minus one-half gram The paint was then applied to 1 sq. ft of area on the board and brushed out as evenly as possible until the black and white squares could not be distinguished in diffuse light. The can and brush were then reweighed and the results expressed in square feet per gallon, using the weight per gallon of the paint for the conversion. The results are given in Table 4, reported to the nearest 10 sq. ft. per gal.

Weight Per Gallon The weight per gallon of the paints was determined with a calibrated weight-per-gallon cup holding exactly 83.3 cc. The weight (in grams) of paint required to exactly fill the cup at 25° C. was determined with an accuracy of 0.1 g. This figure divided by 10 then gave the weight of one gallon of the paint expressed as pounds per gallon

Composition of Paint The percentage of pigment in the paint was determined by the standard method of chemical analysis of white linseed oil paints, A S T.M. Designation D 215-37 (11), except that in some cases it was necessary to change the extraction mixture. The non-volatile portion of the paint was determined as specified in the standard method of testing oleoresinous varnishes, A S.T.M. Designation D 154-38 (11), except that a 3-5 gram sample of the paint was used.

Solids in Paint: The percentage of solids by volume, pigment plus non-volatile matter, in the paint was calculated from the weight per gallon and volatile-matter data A weight of 6 3 lb. per gal was assumed for the volatile constituents of the kettle-treated paints, while a weight of 6 65 lb. per gal was assumed for the volatile constituents of the cold-cut paints. The percentage of solids was used to calculate the resulting film thicknesses of the paints and is included in Table 4. Quite obviously, if the same volume of each paint is applied as was done in the road tests, paints having the greater proportion of solids by volume will produce the greater film thicknesses.

The calculations for determining the percentage of solids in the paint by volume are illustrated by the following example·

Weight per gallon = 12 6 lb.
Volatile content by weight = 29 1%.
12.6 lb per gal. × 0 291 = 3.67 lb. volatile per gal. of paint.

$$\frac{3\ 67 \text{ lb.}}{6.3 \text{ lb. per gal.}} = 0\ 58 \text{ gal. volatile per gal. of paint.}$$

1.00 − 0 58 = 0 42 gal solids per gal. of paint or 42% by volume.

Drying Properties The drying properties of the paints were determined in the laboratory by brushing an even film on tin plate and noting the time taken to dry to touch and to dry firm The paint film was considered dry to the touch when no paint adhered to the finger and no more than a slight tackiness was felt under a light touch. The film was considered firm when rubbing with a firm pressure of the finger did not produce disruption The hardness after 24 hr air drying was determined by the ease with which the film could be scratched with the finger nail.

CHARACTERISTICS OF THE PAINT FILM—DISCUSSION OF TEST PROCEDURE

In this study particular attention has been paid to those laboratory tests which measure the characteristics of the paint film. Paint technologists consider the pigment volume of the film to be important and these data have therefore been calculated when sufficient information was

available The water and alkali resistance of the paint films has been determined by qualitative means The abrasion and flexibility tests, tests which have received a great deal of emphasis and which are often included in traffic-paint specifications, have been given the most weight in this study to date.

Pigment Volume The pigment volume of the dry film was calculated from the results of the composition tests using the pigment analysis as supplied by the various states or, if this was lacking, the pigment analysis as given in the specifications When this information was not available, the pigment volume could not be calculated. It was necessary to assume a weight per gallon for the volatile and non-volatile constituents of the paint vehicle (the same as assumed for the calculations of percentage of solids in the paint) It is felt that the results of the calculations are accurate to at least plus or minus 2 per cent. The accuracy of the necessary assumptions was checked by comparing the calculated with the actual weight per gallon for each paint.

The pigment volume calculations for one paint follow·

Basis—1000 lb of paint
Pigment=58%=580 lb
Vehicle=42%=420 lb

Pigment—580 lb total			
80 0% Lithopone	=464 lb	@ 0 0279 gal. per lb.	=12 95 gal
20 0% Asbestine	=116 lb.	@ 0.0421 gal per lb.	= 4 88 gal.
	580 lb.		17.83 gal.
Vehicle—420 lb total			
30 6% Non-volatile	=128 5 lb.	@ 8 6 lb per gal	=14 94 gal.
69 4% Volatile	=291 5 lb.	@ 6 3 lb per gal	=46 27 gal
	420.0 lb.		61 21 gal

Pigment volume of dry film $=\frac{17\ 8}{32\ 8}=54\ 3\%$

Calculated wt per gal $=\frac{1000}{79\ 0}=12\ 66$ lb per gal

This figure of 12 66 lb per gal checks very well with the actual weight per gallon of 12 6 lb., showing the assumptions to be reasonable.

Abrasion Loss: The abrasion loss of a traffic paint is generally considered to be an important factor affecting durability and several abrasion or wear test machines have been developed A test developed by the University of Maine (3) utilizes a standard automobile tire as the abrading wheel. The paints are placed on a concrete table which is rotated against the abrading wheel E F Hickson (4) of the National Bureau of Standards has developed a wear test in which an abrading wheel, made of a special erasure stock, drives a table on which the paint panels are placed. This machine has been modified by the laboratories of the Baltimore Paint and Color Works, Inc. and is fully described by L. Shuger in his articles on traffic paint (7). Regarding the correlation between road durability and wear as measured by this machine, Shuger says, "These results indicate that those paints which possess durability exhibit good abrasion resistance. However, it is possible that a paint with poor durability can show excellent results on an accelerated wear test. This serves to show that an abrasion machine cannot be used as a sole indicator for durability" (7)

All of the tests mentioned compare the abrasion or wear resistance of the paint under test with that of some standard paint. The New York State Division of Highways has developed an abrasion test, utilizing the Standard U. S. Dorry Hard-

ness Machine, which measures in grams the abrasion loss of both dry and wet paint films. This test, with modification, has been adopted by the State of Indiana and therefore was chosen for evaluation in this study The New York version of this test, together with some comparative results, is reported in the publications of Shuger (7). With regard to this test, Shuger states, "What has been previously cited as to the value of the abrasion test may be applied to this method as well. As a sole means of predicting durability, it has the inherent weakness of an abrasion test; but as a requirement in a specification, it can prove of definite value" (7).

The abrasion method specified by the State Highway Commission of Indiana is as follows:

"For this test the Standard U. S. Dorry Hardness Machine, which has been slightly modified so that the holders will take an open 12-oz seamless tin can 3¼-in diameter by 2⅜-in deep, is used The bottom of the can is painted and allowed to dry for 7 days in the laboratory The tin can is then accurately weighed (A), and enough sand added to bring the total weight to 100 g The weighted tin can is then placed into the holder and subjected to 500 revolutions using double 0 crushed quartz as the abrasive The can is revolved one-quarter turn, by the operator at the end of each 125 revolutions of the Dorry Machine. The empty tin can is then accurately reweighed (B). The difference between weight A and weight B is a measure of the abrasion loss.

"The same test is repeated on the 7-day dried paint which is soaked in water for 18 hr. Towel dry for weight A

"NOTE Only such tin cans are used in the abrasion test as show perfectly level bottoms with no bulge This can be easily ascertained by placing a straight-edge over the bottom of the can"

This test is essentially the same as developed by New York State, Division of Highways, but two rather important modifications have been adopted by the Bureau of Materials and Tests of the State Highway Commission of Indiana. The method of forming the film on the bottom of the can has been changed from one in which the can is rotated by hand to a method whereby the can is placed in the holder of a hand centrifuge and whirled at moderate speed. Also, the test as used by New York State does not provide positive means of controlling the depth of abrasive on the rotating plate The State of Indiana has added a scraper to each holder that can be adjusted to maintain a uniform and controlled depth of abrasive over the entire area of the plate

In adapting this test to the variety of paints studied in this investigation, the merits of the Indiana modifications of the test were first checked. It was found that they aided in increasing the duplicability of results, and they were therefore adopted for this investigation Some of the paints, especially those with the cold-cut base, flaked readily from the tin when tested, and it was therefore necessary first to coat the tin with a better adhering paint in order to obtain an abrasion result. Close control of the film thickness is necessary for good results. If the film is too thin, the metal is exposed and the test is therefore nullified. If too thick a film is used, it does not dry through in seven days and therefore wrinkles under the heat developed in the machine. Even with these precautions, the difference in hardness of the paint films after seven days produces different kinds of wear

Both the New York and Indiana versions of the wet film test specify that the film be towel dry for weight A. However, it was found that much more consistent results could be obtained if weight A were determined before placing the can in water. Weight B was then taken after the film had dried to constant weight, usually 18 to 24 hr. after test. It was ascertained that no other losses other than loss of water from the film occurred during the drying period after test by subjecting a specimen to the same moisture conditions without abrasion

The abrasion test results are given in Table 4. It was found that even with all

of the precautions that were taken, duplicate results were not too easily obtained. It was therefore concluded that the flatness of the bottom of the can was an important variable. The flatness can be easily determined with a straight-edge, but it was found difficult to secure cans with absolutely flat bottoms.

Alkali and Water Resistance· Test tubes 1 by 6 in. in size were dipped in the paint, closed-end down, withdrawn, and immediately inverted and allowed to dry for seven days in this inverted position. One tube was placed in 0.1 per cent (by weight) sodium hydroxide for 2 hr.; another was placed in hot distilled water (about 200° F.) for 2 hr ; and still another was placed in cold distilled water for 24 hr. Other concentrations of alkali, 0.5 per cent, 1 per cent, and 3 per cent (by weight), were also used, but the 0.1 per cent solution was found to be strong enough to show differences in the resistance of the paints.

After the appropriate length of time in the liquid the tubes were removed, washed under a gentle stream of tap water, and allowed to dry for ½ hr. before being examined. At the end of this time the films were checked for discoloration, softening, blistering, peeling, cracking, loss of adhesion, swelling, or disintegration In the alkali resistance tests the paint was considered to have very good resistance if there was no effect other than perhaps slight discoloration, good resistance if it softened only slightly; fair resistance if there was only a slight amount of blistering or loss of adhesion; poor resistance if softening, blistering, swelling, and loss of adhesion were at all pronounced; and very poor resistance if the paint film disintegrated.

Resistance to hot and cold water was considered very good if there was no apparent effect; good if there was only a slight softening or hardening (more brittle) effect; fair if the film was much softer, developed slight loss of adhesion, or perhaps developed very small blisters, and poor if the film wrinkled and swelled badly, and lost all adhesion.

Flexibility· In these laboratory studies of traffic paints, special attention has been given to the flexibility test because it is the performance test most often included in traffic-paint specifications and because there seems to be no general agreement as to the degree of flexibility that a traffic-paint film must possess for good performance on the road Shuger (7) states, "Flexibility tests on hundreds of traffic paints . . . . show that the bend test alone cannot be used as a guide for evaluating durability. However, the need for flexibility must not be overlooked, and a moderate bend test will assure a certain amount of resilience. Poor formulations which employ brittle resins and little oil and which give poor durability will be detected by their failure when subjected to a moderate bend test. . . . . paints which pass a severe bend test do not necessarily give better road performance." Shuger also remarks that "The severity of a bend test increases with film thickness, pre-oven drying period, time and temperature of bake, and decreases as mandrel size increases" (7).

In none of the specifications applying to the paints herein described is the film thickness of the bent paint film specified exactly. In one case, limits are established to be used in case of dispute Some States specify that the panels should be brushed while others specify that the paint shall be flowed onto the tin. The specified methods of drying the panels may be divided, on the whole, into two classes, one in which air drying for 72 hr. is used, and the other which specifies air drying for 18 hr. and baking in the oven at 105-110° C. for 5 hr. Either a ½- or a ⅛-in. mandrel may be specified. The method of viewing the panel may be with the naked eye, a low-power glass, or observation by smearing the bend with lamp black or red ink Quite obviously this variety of test

method passes or fails a paint with respect to one degree of flexibility only. In no case is there an attempt to measure the degree of flexibility or elasticity which a paint possesses. The flexibility results, determined by a standard flexibility test in which the paint film is brushed on the tin panel without regard for film thickness, are given in Table 4. It is felt that these results are meaningless because the film thickness was proved to be important in the test for degree of flexibility now to be discussed.

In an attempt to clarify this rather confusing situation and to determine the degree of flexibility necessary for good performance, the flexibility tests on this series of paints were set up to include the confusing variables and to measure the degree of flexibility. The tin panels used were those ordinarily specified for this type of test, being cut from bright tin plate weighing not more than 25 g. and not less than 19 g. per square decimeter (0 39 to 0.51 lb. per sq ft). They were 3 by 5 in. in size and were thoroughly cleaned with benzol immediately before using

The controlled variables were film thickness, method of drying, degree of bend, and method of viewing the panel for cracks. Two film thicknesses, 0 002 and 0.001 in. were used. An endeavor was made to keep within a tolerance of 0.0002 in. These film thicknesses were attained by a control of the viscosity of the paint using the Gardner Mobilometer and adding varying amounts of a compatable solvent. This procedure was quite lengthy with the range of paint types tested but would be relatively simple for any one particular type of paint. After the paint had been brought to the proper consistency to give the desired film thickness, it was flowed on the panel and the panel allowed to drain in a position making an angle of 60 deg. with the horizontal. The added thinner did not change the character of the dried film because it was completely volatile Check specimens formed from these paints without thinning established this fact. The film thickness was measured with an Ames dial which measured to 0.0001 in.

The test procedure was to bring the paint to the proper consistency for the 0 002 in. thickness, flow four test specimens, bring the paint to the consistency necessary to give the 0 001 in. thickness and flow four more test specimens. Two specimens from each group were air-dried for 72 hr. and two from each group were air-dried for 18 hr and baked in an oven, maintained at 105-110° C, for 5 hr After drying, four of the specimens were bent rapidly over a ½-in rod and the others were bent rapidly over a ⅛-in rod The baked specimens were allowed to cool in the laboratory for ½ hr before bending Each specimen was examined for cracks with the naked eye, with a ten-power glass, and under the microscope at 50 and 100 magnifications The specimen was said to have failed under each method of viewing if any definite cracks were visible A typical data sheet for one paint would then have the form shown in Table 1.

Thus, in reality, 32 flexibility tests were made on each paint. Besides the 17 paints included in this series, nine other traffic paints were included in the flexibility data, so that the maximum number of paints that could pass each of the 32 tests would be 26. The results on the 26 paints gave the number that passed for each of the 32 tests as in Table 2.

Statistical analysis of these data has shown that, on the basis of the limited number of tests, there is no significant difference between the two methods of drying. There is an indication that the baking method is slightly more severe, but this cannot be established as significant statistically from the data. A much larger number of tests would be necessary for this determination. Eliminating the method of drying as a variable, then, and considering the film thickness and size of

mandrel as variables with any one method of viewing, it can be shown statistically that there are really four significant tests (with any one method of viewing) ranging in severity from least to most severe as follows:

1. Film thickness 0.001 in., ½-in. mandrel.
2. Film thickness 0.002 in., ½-in mandrel.
3. Film thickness 0 001 in., ⅛-in. mandrel.
4. Film thickness 0.002 in , ⅛-in. mandrel.

TABLE 1

Film thickness	0 002 in				0 001 in			
Method of drying	Air — 72 hr		Air — 18 hr Bake — 5 hr		Air — 72 hr		Air — 18 hr Bake — 5 hr	
Size mandrel — in	½	⅛	½	⅛	½	⅛	½	⅛
Eye	Pass	Fail	Pass	Fail	Pass	Pass	Pass	Pass
10X	Pass	Fail	Pass	Fail	Pass	Pass	Pass	Fail
50X	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail
100X	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail

TABLE 2

Film thickness	0 002 in				0 010 in			
Method of drying	Air — 72 hr		Air — 18 hr Bake — 5 hr		Air — 72 hr		Air — 18 hr Bake — 5 hr	
Size mandrel — in	½	⅛	½	⅛	½	⅛	½	⅛
Eye	16	6	10	2	24	15	20	12
10X	13	1	10	0	18	8	19	5
50X	7	0	5	0	12	0	11	0
100X	5	0	4	0	10	0	7	0

A statistical analysis of the method of viewing the bent panels for cracks revealed that there is a statistically significant difference between all methods except between the 50- and 100-power magnifications. Combining this information, then, with the previous tests established as significant, it may be considered that in reality 12 significant tests were made.

Further analysis of these data by the statistical method has shown that the degree of flexibility of a traffic paint may be measured quite satisfactorily by considering only the film thickness of 0.001 in., air drying, the ½- and ⅛-in. mandrels, and three methods of viewing (including the naked eye, the 10-power glass, and the 50-power magnification). In this simplified scheme there are, then, six significant tests which may be used to determine the degree of flexibility. The 26 paints tested showed the number of paints that passed each of the six tests as in Table 3.

The relative severity of the six tests are shown by the numbers in Table 3. The

TABLE 3

Film thickness — 0 001 in , air dry — 72 hr		
Size mandrel	½ in	⅛ in
Eye	24	15
10X	18	8
50X	12	0

17 paints tested in this study have been rated on the basis of 12 significant tests and also on the more limited basis of six significant tests. The results are given in Table 4. It can be seen that the relative flexibility of the paints is the same by each

TABLE 4

Summary of Test Results

	White paints											Yellow paints					
Paint number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Settling characteristics	Fair	Fair	Very good	Good	Fair	Fair	Very good	Good	Good	Fair	Very good	Good	Fair	Very good	Very good	Good	Very good
Degree of caking, 3 mo	C-8	C-7	C-9	C-9	C-7	C-7	C-9	C-10	C-8	C-8	C-10	C-8	C-7	C-9	C-8	C-8	C-9
Degree of caking, 6 mo	C-6	C-5	C-9	C-7	C-6	C-7	C-9	C-7	C-7	C-6	C-8	C-7	C-5	C-8	C-8		C-8
Mobility, sec (25 C)	7	11	84	5	13	29	10	Very thick	88	Sand in paint	5	14	21	7	22	16	4
Hiding power, sq ft per gal	220	280	200	240	320	290	220	270	240	No test	240	260	330	260	340	330	210
Weight per Gallon, lb	12 6	13 7	11 3	11 6	14 9	13 4	11 6	14 1	13 3	13 1	10 8	12 2	13 6	10 6	12 9	13 6	9 9
Composition of Paint																	
Pigment, per cent by wt	58 0	60 9	43 1	43 8	67 6	60 6	43 7	63 1	61 0	61 6	38 7	56 3	61 1	36 1	57 6	62 1	30 0
Nonvolatile, per cent by wt	12 9	18 4	25 0	26 8	13 2	15 3	27 5	18 3	16 0	16 3	27 9	13 3	17 7	29 6	17 0	16 4	31 7
Volatile, per cent by wt	29 1	20 7	31 9	29 4	19 2	24 1	28 8	18 6	23 0	22 1	33 4	30 4	21 2	34 3	25 4	21.5	38 3
Composition of Vehicle																	
Nonvolatile, per cent by wt	30 6	47 1	44 0	47 7	40 6	38 9	48 9	49 6	40 9	42 5	45 5	30 3	45 7	46 3	40 1	43 3	45 2
Volatile, per cent by wt	69 4	52 9	56 0	52 3	59 4	61 1	51 1	50 4	59 1	57 5	54 5	69 7	54 3	53 7	59 9	56 7	54 8
Type of Vehicle[a]	KT	KT	CC	CC	KT	KT	CC	KT	KT	KT	CC	KT	KT	CC	KT	KT	CC
Solids in Paint, vol per cent	42 0	55 1	48 0	48 6	54 4	48 6	49 6	58 3	56 0	54 1	46 0	40 5	54 3	45 3	47 8	53 6	42 9
Pigment Volume of Dry Film, per cent	54		29	28			28	46	52	52	26	53	49	22		51	18
Drying Properties																	
Set to touch, min	5	20	5	5	20	15	5	10	5	15	5	10	15	5	10	5	5
Dry firm, min	20	35	10	10	35	30	10	30	15	40	15	40	25	10	20	10	15
Hardness After 24 hr Air Drying	Hard	Soft	Hard	Hard	Soft	Soft	Hard	Very hard	Hard	Soft	Hard	Hard	Soft	Hard	Soft	Hard	Hard
Abrasion Loss																	
Dry Film, g																	
Test No 1	0 076	0 046	0 053	0 037	0 030	0 025	0 058	0 144	0 182	0 019	0 046	0 043	0 068	0 042	0 056	0 060	0 026
Test No 2	0 069	0 042	0 051	0 040	0 035		0 045	0 149	0 225	0 016	0 048	0 053	0 068	0 046	0 065	0 048	0.025
Test No 3	0 076	0 047		0 037	0 041	0 040	0 044	0 159	0 209	0 011	0 049	0 059	0 064	0 038	0 053	0 055	0 030
Average	0 074	0 045	0.052	0 038	0 035	0 033	0 049	0 151	0 205	0 015	0 048	0 052	0 067	0 042	0 058	0 054	0 027
Wet Film, g																	
Test No 1	0 119	0 055	0 103	0 084	0 062	0 049	0 083	0 168	0 252	0 034	0 086	0 138	0 063	0 051	0 077	0 058	0 042
Test No 2	0 123	0 068	0 097	0 079	0 064	0 053	0 098	0 150	0.239	0 036	0 082	0 120	0 072	0 060	0 077	0 077	0 045
Test No 3	0 111	0 051	0 100	0 086	0 054	0 053	0 103	0 173	0 239	0 035	0 094	0 117	0 069		0 073	0 054	0 044
Average	0 118	0 058	0 100	0 083	0 060	0 052	0 095	0 164	0 243	0 035	0 087	0 125	0 068	0 056	0 076	0 063	0.044
Alkali Resistance, 0 1%, 2 hr	Poor	Very good	Very poor	Very poor	Very good	Fair	Very poor	Very good	Very good	Very good	Very poor	Poor	Very good	Very poor	Very good	Very good	Very poor
Water Resistance																	
Hot water, 2 hr	Poor	Good	Fair	Good	Very good	Poor	Fair	Fair	Very good	Very good	Good	Poor	Very good	Fair	Good	Good	Good
Cold water, 24 hr	Poor	Good	Fair	Good	Good	Fair	Fair	Very good	Very good	Very good	Good	Poor	Very good	Good	Very good	Good	Good
Flexibility	Pass	Fail	Fail	Fail	Pass	Pass	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Fail
Brushed panels																	
Air Dry—72 hr																	
½-in mandrel																	
Degree of Flexibility																	
On Basis of 12 tests—No of tests passed	8	2	1	0	8	9	1	4	1	9	2	8	5	1	7	7	0
Air dry—72 hr																	
Film thicknesses of 0 002 and 0 001 in																	
½-in and ⅛-in mandrel																	
Naked eye, 10x and 50x																	
On Basis of 6 Tests—No of Tests Passed	5	2	1	0	5	5	1	4	1	5	1	5	3	1	5	4	0
Air dry—72 hr																	
Film thickness—0 001 in																	
½- and ⅛-in mandrel																	
Naked eye, 10x and 50x																	
Field Rating																	
Durability on Concrete	Poor	Very good	Fair	Fair	Very good	Poor to good	Fair to good	Poor		Very good	Good	Poor	Very good	Fair to good	Very good	Good	Good
Class	IV	I	III	III	I	III	II	IV		I	II	IV	I	II	I	II	II

[a] KT—Kettle-Treated. CC—Cold-Cut.

method of rating The highest degree of flexibility possible under each system of rating would, of course, be equal to the number of tests considered in each rating system, or 12 and 6.

Summary and Correlation of Field and Laboratory Results

This summary includes the results obtained by testing 17 specification paints from eight different States. At the time the paints were obtained they represented a fair sampling of commonly used traffic paints. The field and laboratory test results and conclusions are listed separately and are then followed by a correlation of the field and laboratory data. The actual laboratory test results and road durability ratings are given in Table 4.

Field Tests

The results and conclusions which have been obtained from the field tests are as follows:

1. There was a wide difference, amounting to several hundred per cent in some cases, in the durability of the 17 specification paints secured from eight different States (Figs. 5, 6, and 9).
2. With the limited number of paints studied, there was no definite correlation between the type of specification and the durability of the paint.
3. In the final analysis, all paint failures on concrete appeared to have taken place by scaling rather than by a wearing action, even though some of the paints were subjected to a long period of wear before failure took place.
4. The best paints of the group were consistently the best under each type of road service.
5. In general, those paints which showed early failure by scaling at one location did so at each location where they were included in road tests on concrete.
6. In general, the durability of the paints was independent of the two methods of application which were employed.
7. The quantity of paint necessary for good coverage is dependent upon the type and texture of the surface.
8. The width of the pavement to which the transverse line is applied has an important bearing on the amount and extent of failure produced.
9. It is possible to rate traffic paints satisfactorily by the use of transverse lines. This is particularly true when the paints are placed on narrow pavements, and different portions of the line are subjected to extreme variations in the amount of traffic.
10. The most severe service condition under which the paints were tested was one in which successive vehicles passed over essentially the same portion of the traffic stripe—in these tests, the wheel-track area of the transverse stripes on the 18-ft. pavement.
11. The attempt to rate the performance of the six yellow paints when they were applied as an obedience line on a curve was not satisfactory because the several portions of the line received much different amounts of traffic and because a ragged bituminous centerline obscured the results. Obedience lines on curves are subjected to service conditions differing widely in severity, but if paint is to show consistently good service as an obedience line for all types of curves, it should be capable of

showing good durability under the most severe condition of test (see conclusion No 10).

12. A number of traffic paints may be successfully rated when applied as a centerline if a relatively long straight portion of the road is used and each paint is applied to a short section of the pavement.
13. According to the data from the tests on the 22-ft pavement, centerline stripes on a straight portion of the pavement are under a service condition which is much less severe than transverse stripes on the same pavement.
14. The tests in which the 17 paints were exposed for one year to the action of weather without traffic showed that weathering resistance of a traffic paint has an important bearing on its road durability characteristics.
15. Nos. 2, 5, and 10 of the white paints and Nos. 13 and 15 of the yellow paints were superior to the others after a period of exposure of about eleven months as transverse lines on an old 18-ft. concrete pavement (see Fig. 5).
16. Paints 2, 5, and 10 were superior as transverse lines on the 22-ft. new concrete (Nos 13 and 15 were not applied on this pavement.)
17. Paints 2, 5, 6, and 10 were the best of the group of white paints when tested as a centerline on the 22-ft new concrete pavement
18. Nos. 1 and 8 of the white paints and No 12 of the yellow paints showed the poorest durability when applied as transverse lines on the old 18-ft concrete pavement No. 6 showed poor durability initially, but failure did not progress in the same manner as on Nos. 1, 8, and 12 (see Fig. 5).
19. In general, the paints showed better durability on the bituminous surface (rock asphalt) than on cement concrete, however, pavement width and amount and speed of traffic were variables

LABORATORY TESTS

Those laboratory tests which measure the durability characteristics of the paint film have been given emphasis in this research program. The following conclusions have been drawn from the abrasion, flexibility, and alkali and water resistance tests—the tests for film characteristics which have thus far been studied

20. The modifications of the New York State Dorry Hardness Abrasion Test which have been made by the Indiana Bureau of Materials and Tests have merit in that they make the test more reproducible. The added technique of weighing the specimen dry, both before soaking and after subjecting to wet abrasion, is desirable.
21. The hardness of the paint film has an important bearing on the test results obtained with the abrasion machine. The abrasion losses of two paint films—one of which dries hard while the other remains comparatively soft —do not have the same meaning.
22. The accuracy of the abrasion test could be improved by using a surface more uniformly flat than the bottom of the seamless tin can now used.
23. The degree of bending which a given traffic-paint film will undergo without cracking is de-

pendent to a large degree upon its thickness.

24. It is possible to determine the degree of flexibility of a traffic-paint film by controlling film thickness and by using the ½- and ⅛-in. mandrels and three methods of viewing. The three methods of examining the bent panel for cracks, by the naked eye, 10-power and 50-power magnifications, have been shown to produce results which are statistically significant.
25. The water and alkali resistance tests would be much improved if the degree of failure could be measured by some quantitative means.

CORRELATION OF FIELD AND LABORATORY DATA

On the basis of the road tests on concrete, where durability characteristics were more pronounced, the paints may be divided into four general durability groups, namely · class I—very good (Nos 2, 5, 10, 13, and 15); class II—good (Nos. 7, 11, 14, 16, and 17); class III—intermediate (Nos. 3, 4, and 6); class IV—poor (Nos 1, 8, and 12). Paint No. 9 was not tested on concrete.

The test results of the paints tested on concrete, varying greatly in type and composition, showed that the poor paints of the group could be separated from the good ones on the basis of the modified wet abrasion test and the water resistance test. These two tests, showing direct correlations with field durability, are concerned with the effect of water on the paint film. The fact that there is positive correlation between the wet abrasion loss and field durability, even though the types of failure are not comparable, is probably due to the ability of the test to measure in some degree the resistance of the paint film to water. More data are needed on the measurement of the effect of this and other important weathering factors on the paint film. The need for data on the effect of water and other weathering factors on the adhesion of the paint film to the road surface is indicated from the road tests as being particularly desirable.

The one test in common use that appears, from these test data, to be entirely meaningless as a criterion of field durability on concrete is the test for flexibility.

By considering the four general classes, the following may be said regarding a correlation, positive or negative, between the field performance (durability) on concrete and the results of the laboratory tests on the paints studied.

26 There is a positive correlation, without exception, between the performance of class I paints and class IV paints and the wet abrasion loss as determined by the modified procedure
27. There is positive correlation between the road durability of the yellow paints and the resistance of these paints to water. The correlation between the road performance of the white paints and their water resistance is good except for paint No. 8.
28. It is significant to note that all of the best and all of the poorest paints are in the kettle-treated-vehicle class.
29. The results of the modified wet abrasion test show that, of the 16 paints tested on concrete, the three poorest paints (class IV) have the three highest wet abrasion losses, the lowest wet abrasion loss for these three paints being 0.118 g. The five best paints (class I) are within the group comprised of the lowest nine in wet abrasion loss, the highest wet loss of paints in this group being 0.076 g. The results

of the modified wet abrasion test on the 10 white paints tested on concrete show the two poorest paints to have the two highest losses, the lowest loss being 0.118 g. The three white paints classed as very good are within the group comprised of the lowest four in wet abrasion loss, the highest loss of paints in this group being 0 060 g. Of the six yellow paints tested, the modified wet abrasion test shows the one poor paint to have a loss of 0.125 g. with the next highest loss, 0 076 g., being for a paint rated as very good in the field

30 The results of the modified dry abrasion test on 16 paints show no positive correlation between test constants and road performance. When the results of the modified dry abrasion test on the 10 white paints tested on concrete in the field are considered, they show that the two worst paints of this group had the two highest losses, the lowest of the two being 0.074 g. and the highest loss for classes I II, and III (white only) being 0.052 g. When compared with field durability, the results of the modified dry abrasion test on the six yellow paints show entirely negative correlation. However, all of the 16 paints, with the exception of No 8 and possibly No. 1, show good resistance to dry abrasion; thus, these data verify the observation of Shuger (7) who states:

"These results indicate that those paints which possess durability exhibit good abrasion resistance. However, it is possible that a paint with poor durability can show excellent results on an accelerated wear test This serves to show that an abrasion machine cannot be used as a sole indicator for durability"

31. Although the water resistance test is not a quantitative one, the results are significant in that the six yellow paints show perfect correlation between resistance to water and road durability. Also, there is good correlation between resistance to water and road durability for the white paints with the exception of paint No. 8.
32. In general, the correlation between alkali resistance and road durability is negative. The alkali resistance test shows positive correlation with two of the three poorest paints, paint No. 8 being the exception, and may be of use if limited to the kettle-treated class of paints.
33. Although the pigment volume calculations show a rather narrow range for each class of paints (kettle-treated and cold-cut), it is significant that two of the three poorest paints have the two highest pigment volumes, the one exception to this correlation being paint No. 8. It would seem that pigment volume for any one vehicle would be important, but it is not necessarily indicative of good and poor paints in itself.
34. The calculated percentage of solids in the 17 paints shows a rather narrow range in general, but again it is worthwhile noting that two of the three poorest paints showed the lowest values, the exception to the correlation being paint No. 8. Likewise, the five best paints have the five highest percentages of solids by volume if paint No. 8 is not considered.
35. All five of the paints that were

rated as very good (class I) air-dried to a comparatively soft film in 24 hr. There is no apparent correlation between pavement durability and the time required for the paint film to set to touch and to dry firm.

36. The degree of flexibility measured by 32 test variations shows no correlation whatever with road durability on concrete pavements. In fact, the results show class IV paints to have a greater degree of flexibility in general than do the class I, II, and III paints.

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DISCUSSION ON TRAFFIC PAINT

MR. ANTHONY SKETT, *American Gum Importers Association, Inc.:* I am under the impression from discussion in committee that sufficient leeway is allowed in the interpretation of abrasion loss data so that two paints having losses of, say 0.050 g and 0 070 g., would be considered equal. If this is true, I believe that the data presented in the slide show no correlation between wet abrasion loss and road durability. Groups I, II, III, and IV are exactly the same.

MR. W. H GOETZ, *Purdue University:* It is true that in our discussion in committee sufficient leeway was allowed in interpreting abrasion loss data that differences in abrasion resistance of the order of magnitude you mention were not considered especially significant. However, it must be remembered that the information presented in this paper represents independent research in which one of the objectives was to evaluate the abrasion test used. Therefore, the resulting data should not be interpreted in the light of previously formed opinions of the abrasion test, but should be judged on their own merit.

As previously mentioned, the average, the maximum, and the minimum losses increase from left to right or as we go from very good paints to poor ones. It is true that there is overlapping between the maximum and minimum values of groups I and II, II and III, and I and III. However, there is a definite range between the minimum value for group IV paints and the maximum value of any of the other groups with the range increasing as we

progress from fair to very good paints. Thus, the 16 paints tested on concrete could be divided into two groups of durability which might be termed satisfactory and unsatisfactory, the first three classes forming the satisfactory group. In this sense, the data do show positive correlation with road durability on concrete, and it is indicated that the wet abrasion test would have merit in a specification by eliminating unsatisfactory paints. Data on a greater number of paints are needed, however, to definitely establish the value of the test.

Table 1 gives the wet abrasion data which were presented in the slide.

TABLE 1

CORRELATION OF ROAD DURABILITY WITH WET ABRASION LOSS

Road durability	Very good	Good	Fair	Poor
Class	I	II	III	IV
Number of paints	5	5	3	3
Wet abrasion—Average	0 059	0 069	0 078	0 136
Loss, grams—maximum	0 076	0 095	0 100	0 164
Loss, grams—minimum	0 035	0 044	0 052	0 118

MR. SKETT Is there any relation between the road durability results as you obtained them and plain weathering?

MR. GOETZ· The relationship is difficult to establish because the weathering tests without traffic are not easily evaluated. However, some of the paints were still in good condition after being subjected to both traffic and weathering for a period of one year, while others showed failure in this same time when exposed to weathering alone.

MR. M. S HERBERT, *Krebs Pigment and Color Corporation:* I wonder if the effect of pavement texture played a part in the failure of the paints rather than the theory which was proposed about the position of truck and passenger-car tires? That struck me as being a very significant point.

MR GOETZ. The texture of the pavement to which the paints were applied undoubtedly was a factor in the failure of the paints Unfortunately, no roads were available where these factors, texture and pavement width, could be isolated and their effect determined The thoughts in regard to position of passenger-car and truck tires are theoretical considerations and were presented to show why we might expect to have more concentrated traffic on the more narrow pavement and therefore valid reason to expect concentrated areas of failure on transverse stripes placed on narrow pavements, as did happen in this series of tests. We intend to measure the actual transverse position of vehicles on these roads with equipment that we now have available

MR LEROY W SHUGER, *Baltimore Paint and Color Works, Inc:* I would like to come to the defense of Mr. Goetz on this question of wet abrasion as related to durability As I examine his paper, I find that his results indicate a definite correlation and I believe that his statement of that fact, which is based solely on his findings, is entirely in order I think that this point should be clearly understood.