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Pavement-Marking Materials

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Pavement-Marking Materials

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Traffic Paint Development in California

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● IT IS common knowledge that evolution plays an important role in nearly all of our practices in an industrial economy. That this premise is valid in the realm of traffic-paint manufacture and use may not be so well known, but it is abundantly true. Most of us will remember the introduction of cross-walk markings in towns with an occasional designation of parking limits near a driveway. We saw this marking extend to curves on the main highways to designate the location of the lanes of travel. We watched those lines grow into the open highway and develop into a two-color scheme and double-line system in strategic areas. Reflectorized lines soon followed, then the broken line, in some states, as an economical measure. Machines for applying the lines kept pace with this evolution as traffic demands increased. The lacquers we have been using have not maintained the rate of advancement noted in the mechanical aspects of its application.

Today in California we are not sure of the exact formulations used in the early traffic lines, but a good guess would suggest gloss oils or very short oil varnishes with the white pigments available. Drying time and durability were not so important in those days as now. Variations of the above-mentioned formulation led to the eventual development of the California formula by G. H. P. Lichthardt, which was used so successfully for many years in this state and several others. This formulation, for California, is still one of the best we have been able to devise. Oddly enough, most other states do not share our satisfaction. Experimental work in the East has shown failure of this paint within a month. Of course, this formulation gained its reputation during a time when traffic volume was merely a fraction of that of today. Time was not such a vital factor under those conditions. Even under present conditions, however, the old California formula using Manila D. B. B. resin and chinawood oil is in great favor among our paint crews. That their faith is often justified is apparent from Figure 1. The traffic line shown here was of the old California formula. It had been exposed on asphalt for over 10 months at the time the photograph was made. Summer traffic was about 6,000 vehicles per day with a probable decrease of 20 percent in winter.

The performance of this paint on concrete has not matched that observed on asphalt. Figure 2 will illustrate this to some extent. The foreground in this photograph is asphalt, the background concrete. The striping is the same as that shown in Figure 1, except that this was 7 months exposed when photographed. Traffic here was about 12,000 vehicles daily. The background striping shows failure by chipping. Although the relatively short life of this paint on portland concrete has been known for several years, it might have remained our mainstay had not national shortages of vital components driven us into other formulations.

Preliminary experimentation with numerous formulations on transverse traffic lines led to selection of a few of them for large-scale trial. An abrasion apparatus, based on a design developed by the staff of the Los Angeles City Bureau of Standards was acquired some time later. This machine consists of a 3/4-in. plate glass, 4 ft. in diameter, which acts as a track for anchorage of traffic stripes. The stripes, 0.015 in. thick, are drawn with a doctor's blade and allowed to cure for 72 hr. Weighted rubber-tired wheels set at a 2-deg. bias are then driven over the lines for a definite number of passes, dry. This is followed by a similar treat-

Figure 1.

Figure 2.

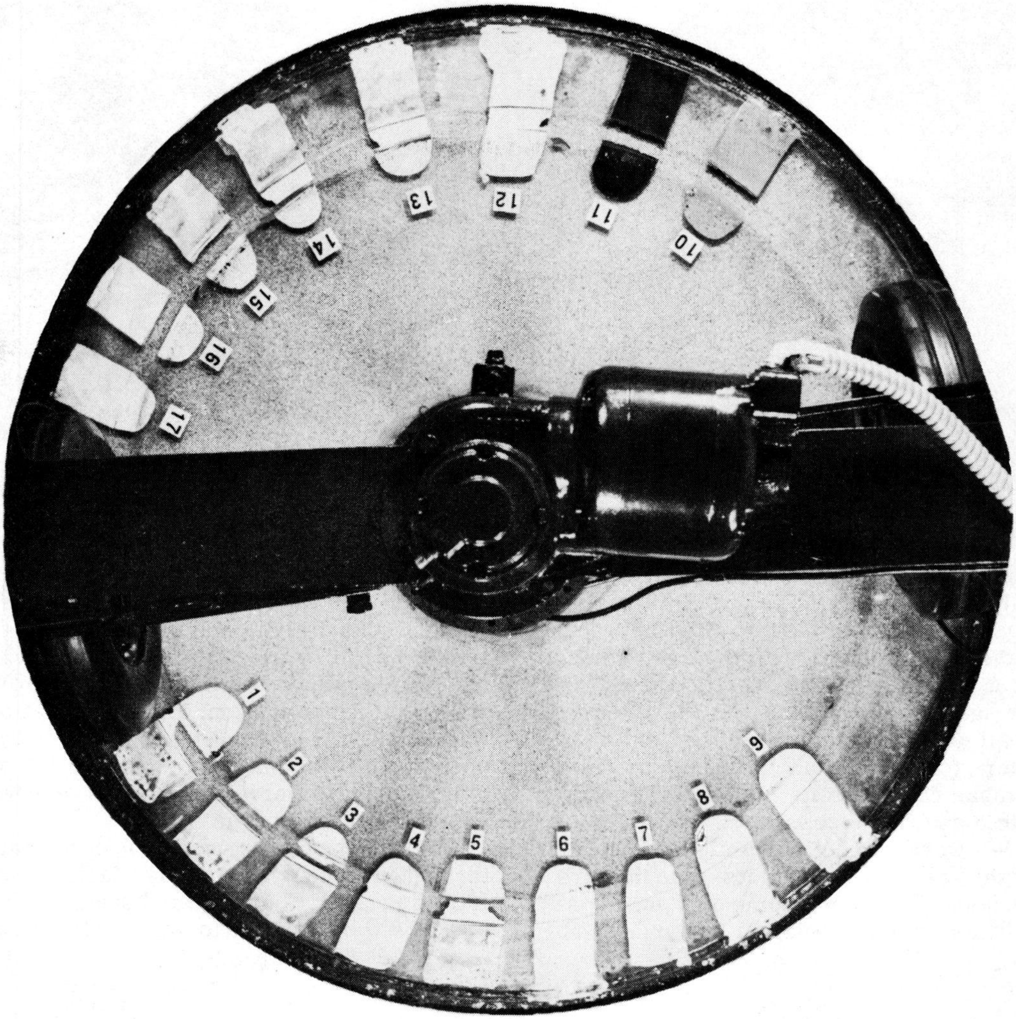

Figure 3.

ment, wet. The results obtained from this apparatus show fair correlation with those obtained on the highways (Fig. 3). All of these stripes were subjected to the same treatment. The types indicated here as II, III, IV, V, are defined below. Type I is not included in this series. Stripes 1 and 2 are Type II. Stripe 3 is Type III. Stripes 4, 6, 7, and 8 are Type V. Stripe 5 is Type V. Stripe 16 is a widely advertised proprietary traffic paint, beaded. Stripe 17 is Type IV, beaded. Stripe 9 is the paint used by the State of Washington. All others are nondescript experimental products. This series of stripes was subjected to 75,000 passes of wheels, dry, after which 25,000 passes were made wet. Transverse traffic lines exposed for many weeks prior to the acquisition of this apparatus gave results in general agreement with those that are obvious on the glass. Unfortunately, no photographic record was kept of these experiments. The results, however led to our large-scale procedure.

Last year we issued invitations for bids on five different vehicular types of traffic paint. These were: I, the D. B. B. chinawood oil; II, Alkyd; III, dispersion resin; IV, chinawood oil-pentalyn varnish-chlorinated rubber; and V, modified phenolic resin-castor oil-chlorinated rubber.

Awards were made for 10,000 gallons

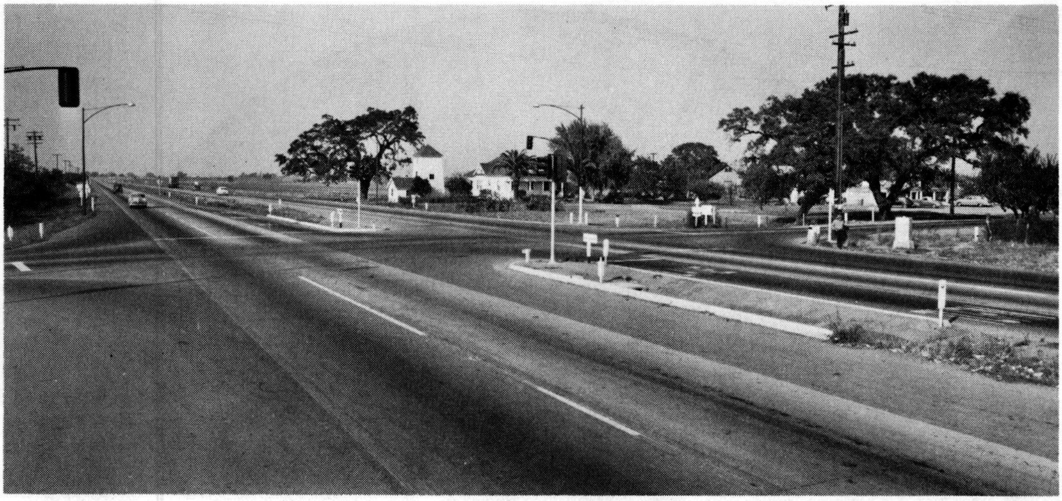

Figure 4.

Type I, 50,000 gallons Type II and 5,000 gallons each of Types III, IV and V. Pigmentation was left to the discretion of the manufacturer with the requirement for a minimum of 200 sq. ft. of coverage per gallon. We had made extensive small-scale tests on these and many other formulas and it was our intent to make comparisons on the larger scale with these five types.

We were compelled to discard Type V in the early stage of its manufacture, because of the development of incompatibilities in the container. Further observations of our small-scale tests had reduced our enthusiasm for this paint anyway. Each type was sent to all districts in the state, and an attempt was made to evaluate each at intervals following its application. The evaluation was limited, as far as possible, to the observation of one man, in order to maintain a comparable judgment on each paint in all parts of the state.

California affords varieties of climate throughout the year. This fact is of importance, not only to our booster clubs and joke writers, but to the traffic-paint

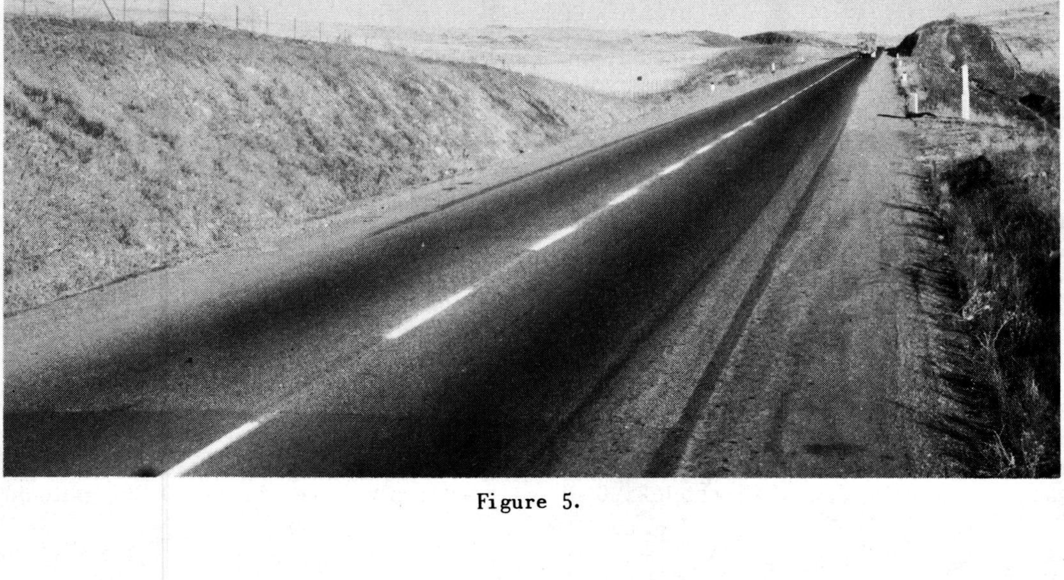

Figure 5.

engineer as well. We found a great diversity in the general acceptability of the various types of paint in different parts of the state. In the San Francisco Bay area, where the mean temperature is low and moisture conditions are annoying during a great part of the year, the alkyd formulations were disappointing, to say the least. In one case, the alkyd stripe was placed on a cold day preceding a heavy rain storm during the night. The stripe had practically disappeared within 10 days. In other cases where the alkyd was placed under favorable conditions, it has given good service for many months. It shows exceptional value as a holder of glass beads (Fig. 4). This stripe, near an intersection where wear is heavy, shows typical state of alkyds that have had favorable conditions of application after 7 months exposure to traffic of about 6,000 vehicles daily. However, its tendency to remain tacky for a long time results in a dirty film surface due to traffic and causes many complaints from the painting crews and sometimes from motorists. The surface will clear up and become comparably respectable in a few days, but the feature is still undesirable. It also has a tendency to surface dry and skin in shaded areas in the mountains and this behavior results in pickup by traffic, even after an hour or more of exposure.

We have experimented with formulations which eliminate many of the undesirable features of the alkyds. One of the more interesting of these, on an experimental scale, is the use of a vehicle which develops an incompatibility in the early stages of solvent evaporation. This is done by use of a conventional alkyd of about 42 percent phthalic anhydride content, such as Reichold's solid Beckosol No. 7 with a heat bodied oil. Preferably castor, such as Bakers 403; or a Z_3 linseed, oil may be used. These oils are incompatible with the alkyd. However, in fairly high dilutions with solvents the incompatibility disappears, and an oil content of about 15 percent may be used without necessitating undesirable thinning. Such a vehicle properly com-

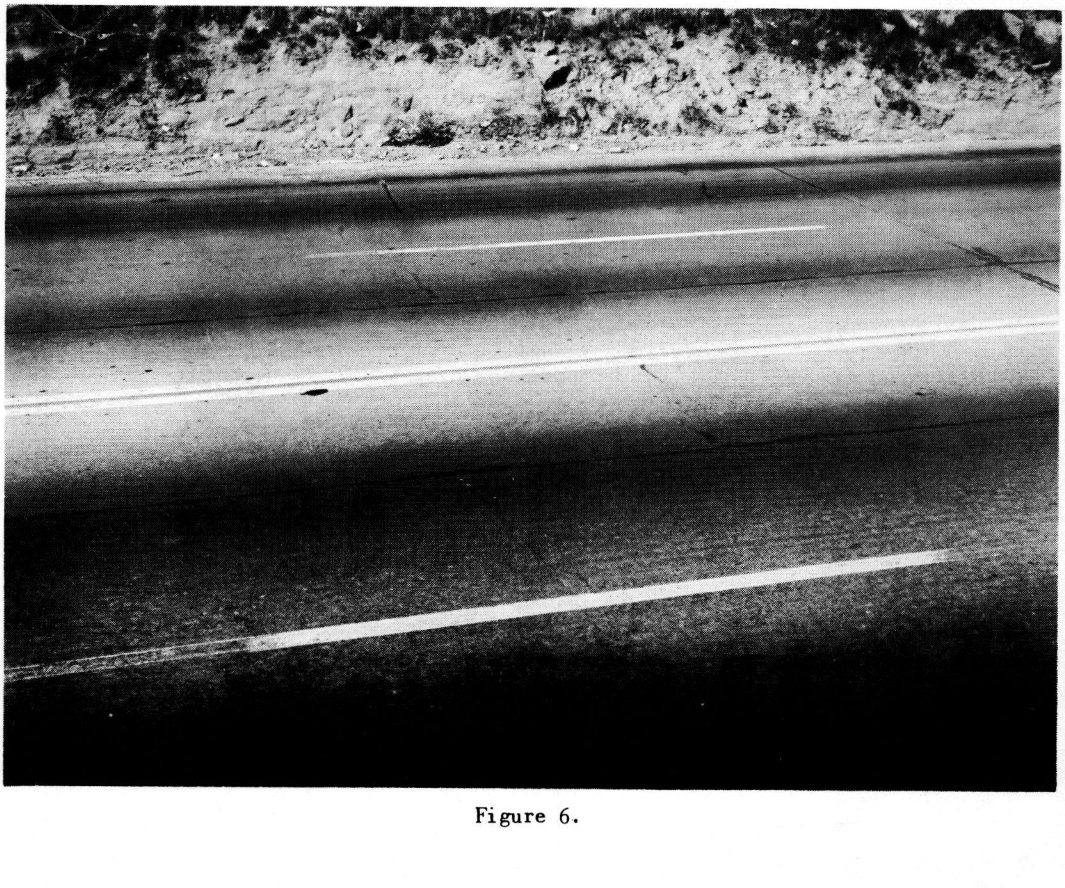

Figure 6.

pounded with pigment displays remarkable drying properties (a so-called false dry) without many of the afore-mentioned faults. The film from such compounding is relatively soft for a time and on abrasion tests has been a notorious failure. Nevertheless, when placed on highways under heavy traffic conditions, it has shown unusual durability and exceptional bead retention even through wet weather. We hope to expand our knowledge of this formulation and perhaps exploit its properties on a larger scale.

Our Type III has been dropped from consideration, temporarily at least. It had some of the deficiencies of the alkyd but was particularly criticized by the paint crew as having "no body." The resin content, the viscosity, etc. were all there, but it showed a tendency to spatter all over the highway when sprayed from the striping machine. Once down and dried, the wear and overall performance of the product has been eminently satisfactory. The comparative tendencies are shown photographically in Figure 5. The first stripe in the foreground is Type I, 10 months exposure. The background stripes are of Type III, 6 months exposure. Traffic count is approximately 6,000 vehicles per day. The pavement is asphalt. Given some time to study its peculiarities, Type III could be made quite acceptable in our opinion.

Type IV gave the best all-purpose, all-weather, all-state results we have had to date. Complaints have been practically nil and the performance so far has been highly satisfactory. It has appeared to be equally proficient on either asphaltic or concrete pavements. It dries quickly, holds beads well and shows great durability. It is not so sensitive to weather conditions as are many other formulations. Figures 6, 7, and 8 show segments of one of the more difficult highways from a traffic paint standpoint. The pavement is concrete, the traffic in excess of 30,000 vehicles daily, and the atmosphere is alternately wet and dry, bright and cloudy. The single lines of the traffic stripe are Type IV of 8 months ex-

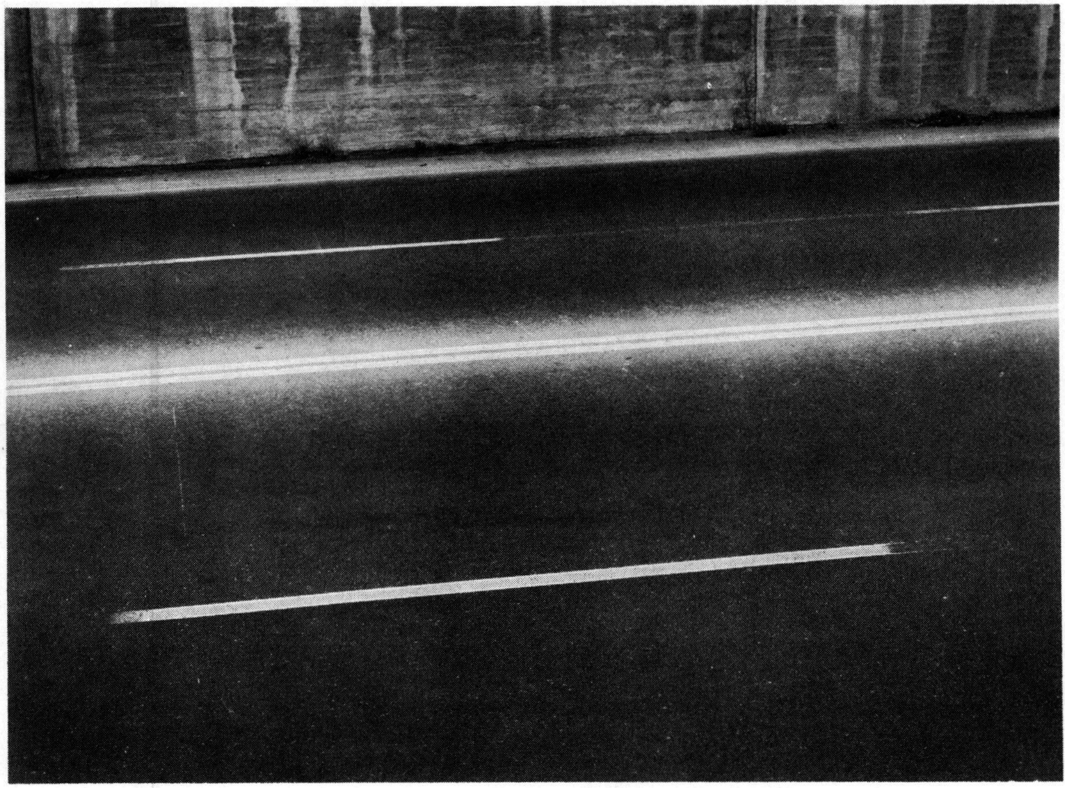

Figure 7.

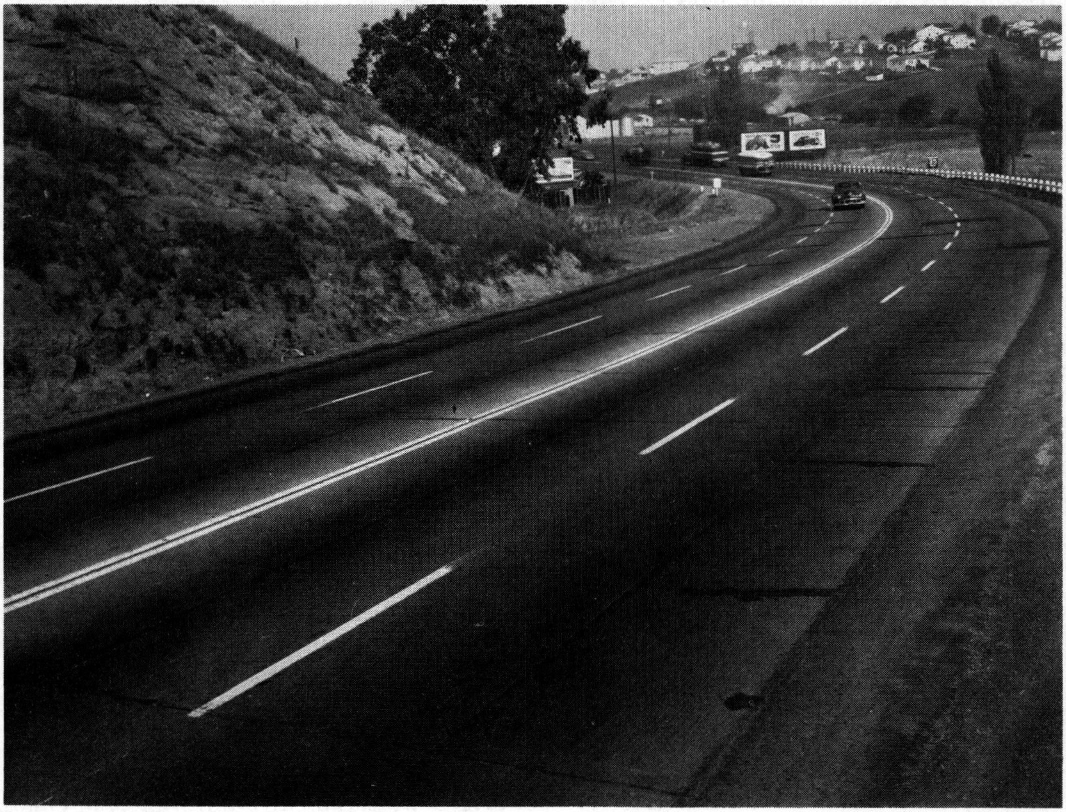

Figure 8.

posure. The double lines are of Type I of unknown exposure. The single lines are in excellent condition. Although they are badly soiled by grease and traffic dirt in some places, they glow beautifully at night and give a fine outline in moderate fog.

Because of this apparent superiority, it is perhaps not out of order to detail its composition. The vehicle was made by blending a varnish of 50 percent solids with a 25 percent solution of 10 centipoise Parlon, one to one. The varnish was composed of Hercules Pentalyn 802A, 25 gallons in oil length, 40 percent chinawood and 60 percent linseed. The pigment was composed of 10 percent minimum of titanium oxide, 5 percent zinc oxide, 50 to 55 percent lithopone, 10 percent talc, 5 percent mica, 10 percent celite 281 and 5 to 10 percent whiting with sufficient blue to overcome the yellowish tint. The pigment volume concentration was 45 percent. The solvent and thinner used throughout was essentially aromatic. The viscosity was set at 70 Krebs units with a tolerance of 5 units.

The oil in the varnish noted above is subject to wide variation in composition. It may be all chinawood or all linseed -- we have used the former with success. The latter has proved satisfactory in small laboratory batches, but we encountered some difficulties in a tendency of the finished product to thicken, especially if it contained zinc oxide. The overall compatibility is assured with 100 percent tung oil but is somewhat doubtful with 100 percent linseed. It is our opinion that a 75 to 25 ratio of tung to linseed is perhaps approaching an optimum combination. Our laboratory abrasion tests indicate a higher resistance in the blends than in either of the single-oil varnishes.

In the preparation of the varnishes we have requested that the wood oil be cooked to a gas-proof stage, while avoiding an over cook. Although gas proofing is probably not necessary to produce durability, good technology would require it to assure stability of the final product. This resin-oil-chlorinated-rubber combination is a complicated system and in the presence of zinc oxide may react in an undesirable way if any tag ends are left loose.

At the present time we have confidence in this chlorinated-rubber type of traffic lacquer. Although it is possible that this paint may not prove satisfactory, it has been successful in all parts of the state so far. We need further experience during the rainy season before stamping it with our unqualified approval. Recently one of our painting foremen stated that this new product had increased his production by 25 percent. Indications are that it will do as well in durability. We have no illusions as to the perfections of this product; we expect to improve it, especially when raw materials become available in abundance.

In an experimental way we have found several formulations that appeared to be excellent. One of these, mentioned earlier, was substituted for Type V. This was a Pentalyn A - linseed oil varnish with a pigment similar to that given for the Type IV and chlorinated-rubber content of about 3 percent based on the total paint. This product had been quite satisfactory in small-scale experiments and showed good stability in the can. A 500-gal. batch was sent to a district for trial there. A striping truck, equipped with two 80 gal. tanks, was loaded and striping started. While one tank was being used, the second was being agitated. When the first was used up and the service line switched to the second tank we found its contents to be of a consistency of a thick mayonnaise. We were never able to reproduce that phenomenon in the laboratory with small samples. The manufacturer could do it in large vats by agitation and slightly elevated temperature. He eliminated the difficulty by use of small quantities of butanol, but we abandoned the formulation.

Another formulation which has given considerable promise is Pliolite (styrenated butadiene) with a mixture of chlorinated paraffins -- better known as the Texas formula. This product has exceptional possibilities in unbeaded lines for cross walks, etc., but we have found it to be a relatively poor bead holder and have experienced some difficulties in securing proper viscosities for uniform application. However, a 20 percent pigment volume concentration (titanium and zinc oxides) in this vehicle produces an excellent cross-walk product of great durability. The vehicle is likewise readily adaptable to curb-marking paints of a highly satisfactory type, but the limited compatibility of the Pliolite resin restricts the range of its potentialities in a traffic paint.

We believe it is desirable to make a study of the PVC for each vehicle. PVC seems to exert a tremendous influence on the durability and bead retention, and it varies with radically different vehicles. Generally we find an optimum PVC which is a compromise between durability and drying time requirements. In our experience, relatively low PVC gives better durability if the stripe is allowed to dry; and bead retention is somewhat better. Beads, we find, extend the life of the stripe from 50 to 100 percent.

We are eyeing new resins appraisingly. Epon and the vinyls which are making such headway in the anticorrosive field are on our list for investigation. Possibly ethyl cellulose in combination with spirit soluble oils may offer some promise. Eventually, we hope to develop our paint technology to match the performance of mechanical applicators.

Physical Properties of Traffic Paints

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Kentucky Department of Highways

● TRAFFIC or zone paints have become a major item of expenditure for highway departments with their increasing mileages and with the increase in traffic using the highways. Extending the mileage requiring marking and increasing the traffic wear on the marking has necessitated successively larger purchases of paint and associated equipment. As this market became larger, increasing numbers of manufacturers have entered the field with a great diversity of formulations having differing properties.

In order to bring some order out of this situation, the research laboratory in cooperation with the Division of Traffic of the Kentucky Department of Highways undertook a study of the paints as offered by some of the principal producers. Toward this end 1-gal. samples of such paints as the producers deemed worthy of consideration were procured. The choice was left to the discretion of the manufacturer in order to assure procurement of paints which are currently in production and which the maker would like to sell. Previous experience with samples obtained from brokers and distributors has indicated that they are not reliable sources of either fresh samples or the latest formulations. This procedure, of course, leads to the possibility of obtaining hand-picked or laboratory-made paints which are better than production runs of the same formula. Any apprehension on this point can be relieved by further testing of any paints purchased in quantity to assure their compliance with specifications and performance of the original specimen.

In some instances the manufacturers have specified certain of the samples they submitted as laboratory or experimental mixes which they would like to have tested. This implies a desire on the part of the producer to make this paint, if the testing shows it to have merit, and consequently these samples were included without discrimination in the program.

Early in this project it was decided to make a comparative physical study of the paints without regard to chemical compositions, since the highway department is not interested in paint manufacture but rather in application and service of paints which can be purchased commercially. Hence, this work concerns itself only with the physical characteristics of the various paints as they manifest themselves in application with Kentucky Department of Highways machines and personnel.

Cost is a big factor in the purchase of traffic paints, but these prices vary so often that it was deemed advisable not to consider cost in this project. Thus the data are presented objectively, and the purchaser can use this information in conjunction with current market quotations to make an intelligent selection.

TRAFFIC PAINT CHARACTERISTICS

Paints designed for traffic purposes differ considerably from paints used for decoration and protection of building, machinery, etc. Since they are applied almost entirely outdoors on a horizontal plane, they must have good weathering properties. In order that there will be a minimum of interruption to traffic when paints are being applied, they must dry as quickly as possible after placement so traffic can pass over them without tracking. This is a point of particular importance when the marking is to be done in cities where traffic is heavy, constant, and cannot be blocked for more than the shortest of intervals. But conversely, this rapid drying must not be so fast as to cause skimming when the paint container is open for stirring or clogging in the nozzle of the spray machine, if such is used.

Traffic paints are thicker and more-heavily pigmented with a coarser pigment than most other paints, in order to increase their covering power and abrasion resistance even when thinned down; as a result, they dry to flat or semigloss finishes. Indeed, this rough surface is desired; it increases night visibility at the low angles of incidence encountered from vehicular headlighting. Toward this end, pumice and other inert materials are sometimes added to the paints to increase the roughness of texture of the finish, and incidentally, these materials increase wear resistance also. In the last few years the greatest strides in increasing the effectiveness of traffic markings at night have been made by reflectorizing them with minute glass spheres. Each tiny bead serves individually as a lense, backed up by a spherical mirror, and its action is to collect light falling on it and return the light in the general direction from whence it came. Collectively the effect is to make the line many times brighter than it would appear without the reflectorization. In fact, the markings seem to glow with a light all their own, which has led many drivers upon casual observation to the erroneous conclusion that the lines are luminous. The beads may be mixed with the paint before it is applied, or they may be dispersed on the wet surface by hand or mechanical dispenser.

The heavy pigmentation and inert additions of beads, pumice, and sand lead to two more necessary characteristics of traffic paints. First, the mixtures must not show too great a tendency to settle and it must be easily redispersed by stirring once it has settled. Second, it must form a good strong bond with the reflectorizing materials, so they are not easily dislodged from the stripe after it has dried in place. This same property of adhesion is also necessary if the paint is to last through a useful life on the pavement. Paints with poor adhesive properties usually crack and chip away from the surface long before their effectiveness is diminished by abrasion.

To accomplish a desirable combination of the above-mentioned properties, there are many different formulas and processes. The fact that the ultimate in all characteristics is not available in one paint is attested to by the number of manufacturers in the field, each of them offering many different mixes with differing compositions and characteristics. Indeed, it has been observed that paints meeting the same specification as to composition yield widely varying results in service. The difference probably lies in the method of mixture and cooking in the varnish kettle. For this reason, specifications based on composition do not assure the procurement of uniformly serviceable paints. Thus, the best traffic paint specification should have as its basis physical and service tests, rather than mere chemical composition data.

In general, traffic paints consist of quick-drying-varnish vehicle, pigments, ester gum or gum copals, volatile thinners, and driers. These are combined in various proportions and by various processes to achieve traffic paints with varying properties. Often one or more of the generally used components is replaced by a different substance to make a paint with special properties. Thus, rubber latex, chlorinated rubber, cold-cut resins, and cellulose laquers are often encountered as vehicles in place of the more common varnish, and thinners and driers may be any of a variety of low-boiling petroleum or coal tar fractions. Almost universally these thinners are compatible with gasoline, as this is the thinner-solvent most readily available to paint crews working in the field. Paints requiring special thinners should be avoided for highway use, unless they offer very attractive properties to compensate for the inconveniences of having to buy usually expensive special solvents and having to transport them with the striping crews.

Pigments are chosen for traffic paints on the basis of cost, hiding power, and suitability of color. For white paints, the pigments in largest use are zinc oxide, titanium-base, and lithopone, plus the aforementioned silica materials for increasing visibility and abrasion resistance. Colored paints have carbon black, organic dyes, iron oxides, or chrome yellows, depending upon the color desired. Zinc oxide is added to most of these to increase the color retention under the severe weathering conditions encountered by traffic markings.

METHOD OF TESTING

As mentioned previously, this test program has been designed and conducted as a comparative physical test of paints on Kentucky roads, under Kentucky weather, using Kentucky striping equipment and technicians. As close an approximation as possible has been made to the conditions of application and service that these paints would encounter were they adopted for use by the Kentucky Department of Highways. The striping crews were allowed to place the field test stripes exactly as they would in using the paints in general service. No attempt has been made to achieve optimum rates of application for each sample except the adjustments which the sprayer operator makes to secure the type of line desired from the different paints. This was done in order that the stripes not be put down under controlled conditions which could not be maintained in service.

The transverse field-service stripes were placed August 21 and 22, 1950, on days which were uniformly sunny with a temperature in the upper seventies and a relative humidity of near 50 percent. They were located about 3 mi. south of the Lexington city limits on US 27. At this point a divided, four-lane cement-concrete surface adjoins a divided, four-lane bituminous surface, both relatively new. Identical sets of stripes were located in the west lane on both the concrete and bituminous pavements (see Fig. 1). Immediately prior to the date of field placement, all of the paints were dispersed by shaking them in a mechanical paint-shaking machine. Thus, only minor stirring was needed to condition the paints when they were opened at the field location.

It will be noted that there are considerably more stripes than paint samples. The reason for this is that those paints which the producer designated as suitable for use with or without external bead application have been applied both ways, i. e., one stripe reflectorized and the other one not. In a few instances extra stripes were placed when the first one did not appear satisfactory.

The rate of application was determined for each of these samples by placing a previously weighed piece of brown kraft board measuring 6 in. wide and 14 in. long with a removable strip of 1-in. masking tape across the short dimension at each end (Fig. 2). The striper was passed over this and a stripe placed upon it. Then removal of the masking tape at each end left a section of stripe 1 ft. long. Weight of the paper and paint minus the original weight of the paper gave the weight of paint per foot. This information, coupled with the laboratory determined specific gravity of each paint, allowed computation of the covering power or rate of application, which is shown in Table 1 in two forms: feet per gallon and gallons per mile.

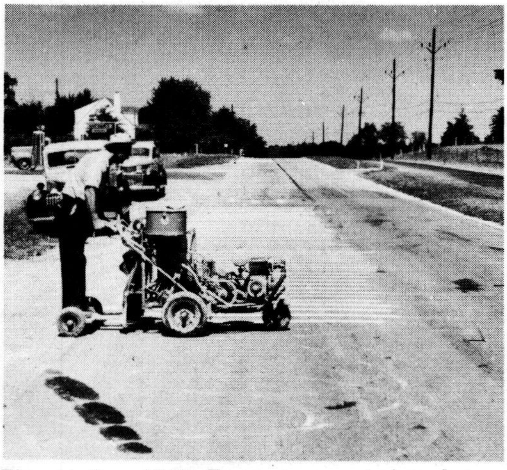

Figure 1. 1950 Transverse stripe location. Stripes on bituminous surface are immediately behind striper and on concrete surface in the background.

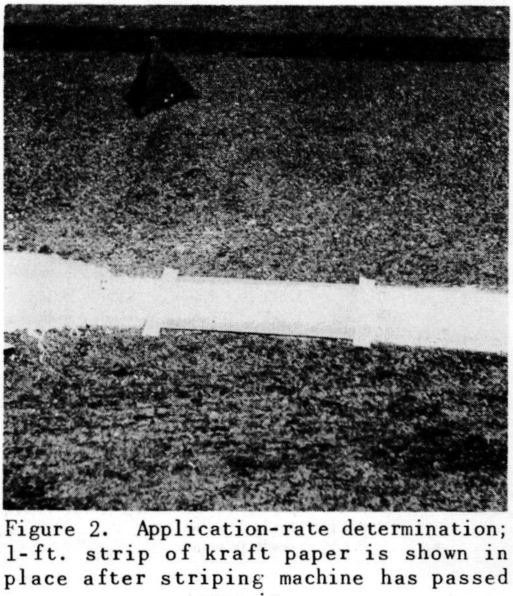

Figure 2. Application-rate determination; 1-ft. strip of kraft paper is shown in place after striping machine has passed over it.

TABLE 1

Sample and Stripe No.	Specific Gravity	Wet Weight Per Foot Grams	Feet Per Gallon	Gallons Per Mile	Loss in Weight on Drying %	Approximate Track Free Drying Time* Min.	** Type Reflectorization	*** 8-Months Transverse Stripe Evaluation	Color
1&2	1.29	6.3	775	6.82	15.8	12	1-NR 2-B.O.P.	0 & 0	W
3&4	1.751	10.4	637	8.3	16.4	9	3-NR 4-B.O.P.	0 & 0	W
5&6	1.411	9.2	580	9.12	22.8	8	5-NR 6-B.O.P	0 & 1	W
7&8	1.291	10.5	465	11.37	32.4	22	7-NR 8-B.O P.	1 & 1	W
9&10	1.448	26.4	208	25.4	20.5	21	9-NR 10-B.O.P.	3 & 3	W
11&12	1.556	12.5	471	11.22	12.0	9	11-NR 12-NR	2 & 2	W
13	1.604	10.0	607.1	8.7	9.0	14	13-NR	3	W
14&15	1.308	13.1	378	13.98	21.4	13	14-B.O.P. 15-NR	2 & 2	W
16&17	1.394	9.2	574	9.22	17.4	13	16-B O.P. 17-NR	2 & 2	W
18&19	1.351	6.7	764	6.93	15.0	12	18-NR 19-B.O.P.	3 & 3	W
20&21	1.306	11.6	426	12.41	10.4	18	20-B.O P. 21-NR	2 & 3	W
22&23	1.351	8.4	609	8.68	12.0	17	22-NR 23-B.O.P.	2 & 3	W
24&25	1.355	8.0	641.5	8.24	12.5	15	24-B.O P. 25-NR	2 & 3	W
26&27	1.353	9.8	523.5	10.1	14.2	10	26-B.O.P. 27-NR	1 & 2	W
28	1.457	9.4	587	9.0	19.2	10	B.O P.	1	W
29	1.619	14.0	437.8	12.07	23.6	15	B.O.P.	0	W
30	1.512	10.7	535	9.88	14.0	24	NR	2	Y
31	1.418	7.9	679.8	7.78	10.2	21	NR	1	Y
32	1.436	5.6	970	5.45	5.5	13	NR	1	Y
33	1.422	5.8	928.5	5.69	8.5	11	NR	0	Y
34&35	1.336	8.7	581.5	9.09	21.8	10	34-NR 35-B.O.P	4 & 3	Y
36&37	1.582	8.4	713	7.41	16.6	12	36-B.O P. 37-NR	1 & 3	Y
38&39	1.48	13.5	415	12.75	13.4	12	38-B.O.P. 39-NR	1 & 2	Y
40&41	1.389	7.0	751.5	7.04	5.7	15	40-B.O P. 41-NR	2 & 2	Y
42	1.491	7.0	806	6.55	18.6	12	B.O.P.	1	Y
43&44	1.435	9.3	585	9.04	10.7	15	43-B.O P. 44-NR	1 & 2	Y
45&46	1.316	7.8	640	8.25	19.2	24	45-B.O P. 46-NR	1 & 2	Y
47&48	1.604	12.9	471	11.22	14.6	32	47-B.O.P. 48-B.O.P.	2 & 2	Y
49&50	1.316	23.3	214.1	24.68	25.0	10	49-B.O.P. 50-NR	1 & 3	Y
51&52	1.544	13.0	449.5	11.75	22.3	15	B.I.P.	0 & 0	Y
53	1.694	12.1	529.5	9.98	5.0	15	B.I P	1	Y
54	1.706	13.8	468.5	11.29	11.6	16	B.I.P.	1	Y
55	1.831	28.6	242.3	21.8	14.4	10	B.I.P.	0	Y
56	1.573	8.3	717.5	7.37	2.4	10	B.I.P.	1	Y
57	1.579	7.2	830	6.36	7.0	15	B.I.P.	2	Y
58	1.621	7.5	817.8	6.45	4.0	23	B.I.P.	1	W
59	1.668	9.7	651	8.12	12.4	7	B.I.P.	0	W
60	1.714	12.0	540	9.79	6.6	5	B.I P.	0	W
61	1.344	10.9	466.5	11.31	11.0	18	B.I.P.	2	W
62	1.582	7.1	843.5	6.28	1.4	13	B.I.P.	2	W
63&64	1.356	3.8	1351	3.91	5.2	11	63-B.O.P. 64-NR	2 & 2	W
65&66	1.312	7.6	653.5	8.09	13.1	13	65-B O P. 66-NR	2 & 2	W
67&68	1.398	8.4	630	8.9	13.1	16	67-B.O P. 68-NR	3 & 3	W

* - Noon Temperature 79F., relative humidity 56 percent

**-B.O.P. = beads on paint
B.I.P = beads in paint

*** - Transverse-stripe evaluation scale
0 - Useless, paint barely discernible if at all
1 - Poor, traces remain but not serviceable
2 - Fair, serviceable but dim
3 - Good, still serviceable
4 - Excellent, fully serviceable

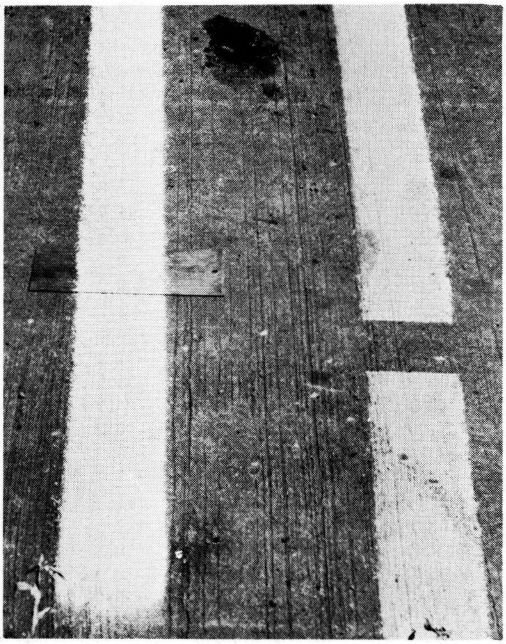

Figure 3. Weathering-reflectance panel. Panel is in place in left hand stripe after application of paint. Gap in right hand stripe was left by previous panel.

A similar arrangement was used to obtain the sample for laboratory use in determining reflectance and weathering properties. In this instance 3- by 9-in. metal panels were placed in the path of the striper and a specimen of the paint was thereby obtained (Fig. 3). A panel can be seen in place after the striper has passed over it in the left hand stripe. The gap left in the stripe can be seen in the right-hand stripe in the photograph. These panels were subsequently taken to the laboratory and their reflectance was measured; then they were placed in an accelerated weathering chamber, where they were subjected to over 500 hrs. of strong radiation and water spray. This length of accelerated weathering is roughly equivalent to one year of exposure to normal weathering. The panels were then scrubbed with a brush and water to remove any scum or chalk and the reflectance was then a measure of the weather resistance of the paint: those paints losing the least reflectance have better weathering characteristics than those which lost more reflectance. These data are tabulated in Table 2. It is to be noted that this information is not available on a few of the samples. This was due to a lack of space in the weathering chamber for all of the panels. This limitation caused the rejection of some of the poorer panels upon which the paint was not well placed or was "splotchy" and would consequently have given unreliable results.

The track-free drying times given in Table 1 were determined by starting a stop watch when the strip was placed and stopping it when a finger run along the stripe failed to find any soft or tacky spots along the length of the stripe. This was largely a matter of judgement; but since the same person noted all of these times, it is probable that they are consistent as a relative measure of drying time and are indicative of the drying time necessary before traffic can be permitted over the stripe without tracking under these particular conditions of humidity and temperature. All drying times were determined on the concrete surface in the interest of uniformity. However, a few impromptu checks revealed that the drying times were almost identical on the bituminous surface.

The percentage volatile material given in Table 1 was determined by subtracting the dry weight of a specimen from the wet weight and dividing this difference by the wet weight, then multiplying the quotient by 100 to obtain the result expressed as a percentage. This figure is a measure of the amount of volatile thinner, drier, or other vaporizable substance in the mixture and serves to differentiate between very heavy paints and those which are diluted or cutback. In general the lower this figure the greater the covering power of the mixture assuming possible dilution in the field to the proper consistency for sprayer application.

An accelerated abrasion test has also been started on these specimens on the circular track road testing machine in the Highway Materials Research Laboratory. Briefly the installation consists of a circular track 45 feet in circumference at the centerline of the 24 in. width paved area. The pavement consists of a dense plant mix bituminous surface. A rotor, consisting of a metal framework mounting a 30 horsepower direct current motor on one end driving a pair of 7.50 x 20 truck

TABLE 2

Sample and Stripe No.	Panel No.	Type Reflectance NR.	B.O.P.	B.I.P.	Initial Reflect-ance	500 Hr. Reflect-ance	500-Hr. Change In Reflect-ance %	600 Hr. Reflect-ance	600-Hr. Change In Reflect-ance %
2	1		X		0.0701	0.0781	+11.4	.066	-5.8
4	2		X		.0906	.0960	+ 5.9	.080	-11.7
6	3		X		.0496	.0527	+ 6.2	.0498	+ 0.4
7	4	X			.0484	.0485	+ 0.2	.0437	- 9.7
9	5	X			.0484	.0517	+ 6.8	.0487	+ 0.7
11	6	X			.0484	.0527	+ 8.9	.0467	- 3.5
13	7	X			.0515	.0508	- 1.3	.0440	-14.5
14	8		X		.0647	.0681	+ 5.2	.0600	- 7.2
16	9		X		.0488	.0519	+ 6.3	.0400	-18.0
19	10		X		.1229	.1068	-13.1	.0800	-34.9
20	11		X		.119	.1129	- 5.9	.0950	-20.2
23	12		X		.0529	.0519	- 1.9	.0380	-28.2
24	13		X		.0542	.0509	- 6.1	.0582	+ 7.4
26	14		X		.0753	.0798	+ 5.9	.0883	+17.3
28	15		X		.0506	.0509	+ 0.5	.0542	+ 7.1
29	16		X		.0493	.0499	+ 1.2	.0583	+18.2
30	17	X			.0419	.0399	- 4.7	.0401	- 4.3
31	18	X			.0262	.0389	+48.5	.0401	+53.0
32	19	X			.0388	.0399	+18.1	.0400	+18.3
33	20	X			.0432	.0399	- 7.6	.0400	- 7.4
35	21		X						
36	22		X		.0432	.0409	- 5.3	.0400	- 7.4
38	23		X		.1035	.0898	-13.2	.0899	-13.1
40	24		X		.1022	.0898	-12.1	.0891	-12.8
42	25		X		.0444	.0409	- 7.9	.0400	- 9.9
43	26		X		.0481	.0477	- 0.8	.0472	- 1.8
45	27		X		.0506	.0507	+ 0.2	.0533	+ 5.3
47	28		X		.0320	.0389	+21.6	.0372	+16.2
49	29		X		.0617	.0789	+27.8	.0794	+28.7
51	30			X	.0296	.0389	+31.4	.0361	+21.9
53	31			X					
54	32			X	.0296	.0380	+28.4	.0342	+15.5
55	33			X					
56	34			X					
57	35			X	.0320	.0404	+25.3	.0387	+20.9
58	36			X	.0394	.0512	+29.9	.0509	+29.2
59	37			X	.0501	.0522	+ 4.2	.0509	+ 1.6
60	38			X	.0487	.0502	+ 3.1	.0509	+ 4.5
61	39			X	.0501	.0492	- 1.8	.0469	- 6.4
62	40			X	.0487	.0492	+ 1.0	.0469	- 3.7
63	41		X		.0638	.0619	- 2.9	.0810	+26.9
65	42		X		.0627	.0700	+11.6	.0691	+11.2
67	43		X		.0353	.0619	+75.4	.0584	+65.4

tires through a standard truck differential and a 30 horsepower direct current generator on the other end which is driven by an identical set of truck wheels and differential, is mounted on a center pedestal by a gear box which imparts an eccentric motion to the rotor. Thus the rotor is driven about the track by the motor through one set of wheels while it is "loaded" by the other set of wheels connected to the generator. In other words, one end of the rotor is driving while the other is dragging. The eccentric motion imparted to the rotor causes the wheels to cover the track surface uniformly and at an almost constant skid. The direction of motion of the wheels is tangent to the circle of rotation only instantaneously once each revolution. At all other times the wheels are skidding slightly. This, of course, imparts a great deal of abrasion to the sur-

Figure 4. Accelerated-abrasion test. Paint segments are shown on the surface of the circular test tracks.

face and hence can be called an accelerated abrasion test.

For the purpose of testing paints this apparatus is excellent in that samples are mounted on a road surface material just as in practice, and they are abraded by loaded tires just as they will be in service. It is possible with this device to add some elements of weathering if desired.

The paint samples were applied to the track immediately after they were used for the transverse stripes at the field location. The remainder of the samples was brought in and applied by brush to radial segments marked off on the track surface with masking tape. There is one of these segments for each of the paint specimens. Figure 4 shows a portion of the test area on the track before any abrasive action was started. This work is not yet completed.

INTERPRETATION OF DATA

Most of the data in Table 1 are self-explanatory. It is meant to serve as a reference table covering the physical properties of the 43 brands and formulations tested. The purchaser is usually confronted with a narrow field of selection as price quotations in hand normally dictate that the best bid of the lowest two or three be selected. A quick reference to the information in the table will probably allow the selection of one of the group as the best for the particular purposes.

The reflectance data in Table 2 must also be considered in selecting a paint. Here one must be careful to compare paints of like color and reflectorization, i.e., white premixes should be compared only with other white premixes and not with yellows, or paints designed for external bead application.

It will be noted in Table 2 that the majority of the specimens gained in reflectance with the 500 hrs. of weathering. This is doubtless the result of bleaching action of the radiation on the pigment and the roughening of the surface by chalking of the paint and also the deposition of calcium carbonate residue from the water spray. This process will of course reach a peak and then the reflectance will begin to diminish. This does not seem to have happened within the 500-hr. test. However, reference to the 600-hr. data substantiates this, in that some of the paints which had gained in reflectance at 500 hr. have started to lose reflectance at 600 hr. Those paints which have lost reflectance have done so as a result of the darkening of some of the pigments or other organic materials and some loss of beads.

In the case of premixes, the reflectance should go up as the paint film initially covering the beads wears away, bringing the reflex action of the beads into play. Paints in this category which fail to increase their reflectance with weathering and abrasion are probably either thick and the paint film is not yet worn from the beads or else the paint is so slow in drying that the beads all sink to the bottom of the paint stripe, becoming well covered by a thick coating of paint. Weathering alone would not serve to bring these premixes to their full reflectance, so each time that the panels were taken from the weathering chamber for a reflectance measurement all of them were scrubbed with forty passes of a wet brush and mild abrasive. Then they were rinsed in running water and allowed to dry before the measurements were made. All of the panels were treated in this manner, in-

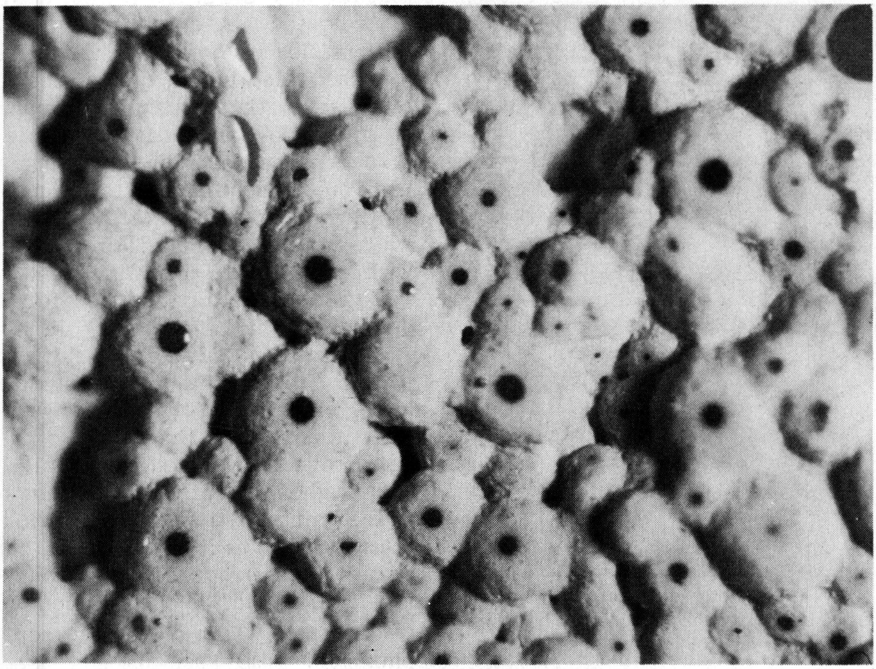

Figure 5. Photomicrograph (30X) of Sample 47 after 500 hours of accelerated weathering and mild abrasion. This slow drying paint used with external beads has allowed the beads to sink into the paint so that it appears as a premix and performs as one.

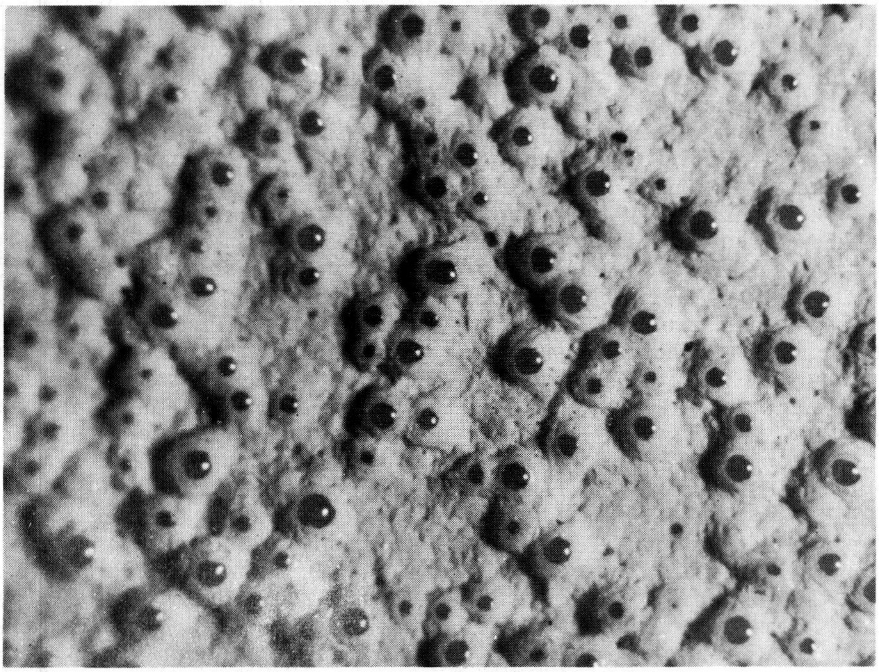

Figure 6. Photomicrograph (30X) of Sample 50 premix after 500 hours of accelerated weathering and mild abrasion. Except for smaller more uniform bead size there is little to distinguish this from the slow drying external bead paint of Figure 5.

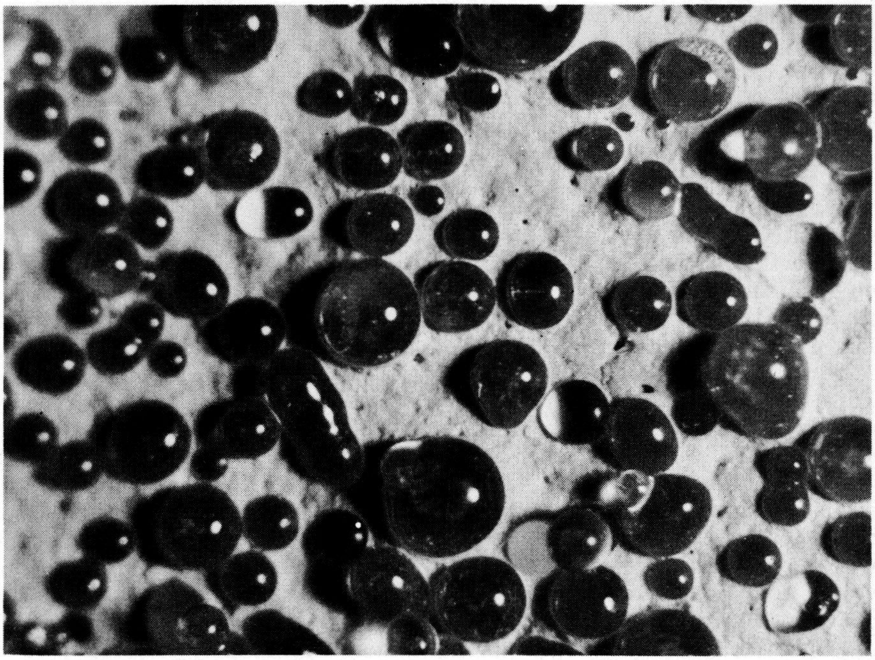

Figure 7. Photomicrograph (30X) of Sample 49 which is a rapid drying external bead paint. Note that due to the rapid drying, beads are only imbedded on the bottom and there is no paint up over the sides of the spheres.

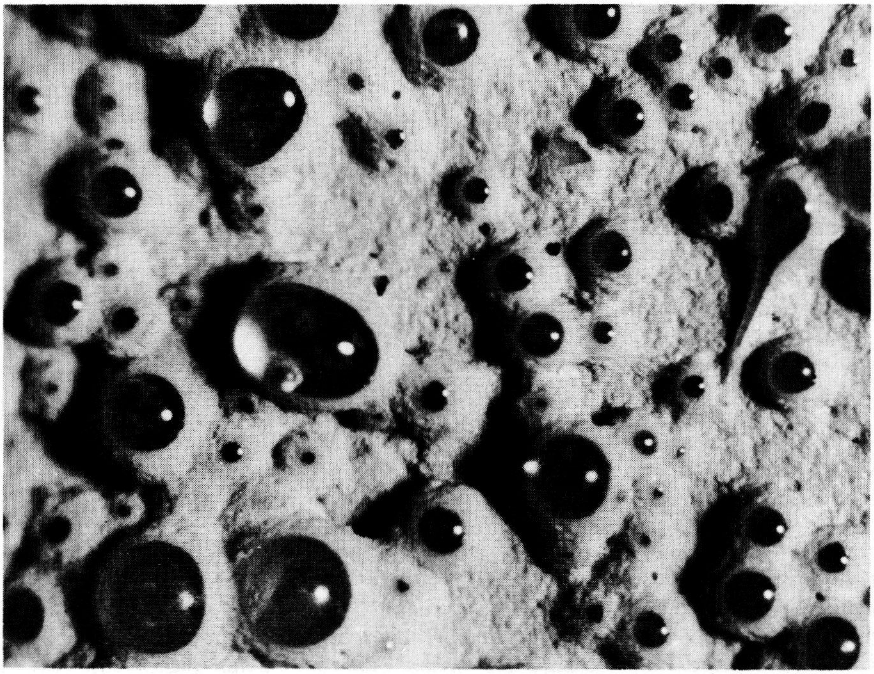

Figure 8. Photomicrograph (30X) of Sample 25 which is a medium fast drying type of paint used with external bead application. Note the pillaring of the beads by the paint extending up about half way on the spheres.

cluding the external bead and nonreflectorized specimens.

Paints which are reflectorized with externally applied beads should exhibit their highest reflectance at the initial reading, and their loss in reflectance after this is due almost entirely to beads being torn away from the paint film. As a result, paints of this type with poor adhesive properties or too-rapid drying properties lose their reflectance sooner than paints which retain their beads better. Paints of this type which gain in reflectance are usually of a slow-drying type which allows the beads to sink into the paint film and become covered by paint before drying. This is demonstrated by Samples 45 and 47 which show a large increase in reflectance with weathering. Reference to Table 1 shows these two paints to be slow driers, 24 and 32 min. respectively. As a consequence of this, they perform more as premixes, and as shown in the photomicrograph, Figure 5, it can be seen that they appear almost like premixes. Figure 5 shows Sample 47 after 500 hr. of accelerated weathering and mild abrasion. Note the similarity to Figure 6, which is a premix after the same treatment.

Figure 7 represents the opposite condition to Samples 45 and 47. In this case the drying time is so fast (10 min.) that the beads have no opportunity to sink into the film. In fact, a skin probably forms so fast that the beads are held up and are unable to sink into the paint. One would expect in this situation that the beads would not adhere. However, in this particular instance the adhesion seems good, and there is little noticeable loss of beads after the 500 hr. of accelerated weathering and mild abrasion. Reflectance of this specimen was high initially and dropped off only slightly with weathering, due probably to darkening of the yellow pigment and some slight loss of beads. It is worthy of note that this type of paint does not impart its characteristic yellow color to the markings at night as well as one in which the beads are surrounded more completely by the paint film. At the low angles of incidence and viewing encountered at night, these markings reflect the color of the light source. Thus, although they do appear as yellow at night, it is a diluted yellow as compared to their color under daylight conditions.

Figure 8 represents a median condition between the above two extremes. The drying time of 14 min. lies between Samples 47 and 49, and it will be noted that the beads have penetrated the film about half way, and upon drying and shrinking this has left each bead at the top of a little pillar of paint. This, of course, makes for an excellent light intercepting and reflecting position for the beads. Because of the lower half being surrounded by the paint, more of the pigment color is imparted to the low angle light at night, and the light reflected is more nearly identical to the daytime color. This pillar effect is also noted in Figure 5, which is the slow-drying external-bead paint and also in the premix of Figure 6; but as might be expected, the beads are more deeply imbedded in these instances. It is possible that wetting agents may be added to some of the paints to lower the surface tension of the paint film, allowing the beads to become more deeply imbedded. This possibility has not been explored, and there is little cause to in a comparative physical-performance test program such as this one.

Figure 9 is a photomicrograph of Sample 60, which is a type of premix not exhibiting this shrinkage and consequent pillaring effect of the beads. In this specimen, the beads are deeply imbedded in the film beneath a smooth top surface. Only a small top sector of the uppermost beads is exposed by abrasion, and little reflection could be expected at low incidence angles. Also visible in the photograph are some of the cracks which have developed as a result of weathering. These are general over the surface and would contribute to dulling of the markings by becoming filled with road scum.

Figure 10 shows Sample 1, which is nonreflectorized. Note the porous nature of the finish which would quickly become filled wirh road scum and darken to a dull nonreflecting gray. This is the likely result of a paint which is too thin, even though the percentage of volatiles is not excessive. This paint has the lowest specific gravity of any of the samples tested.

Figure 11 represents a much-better

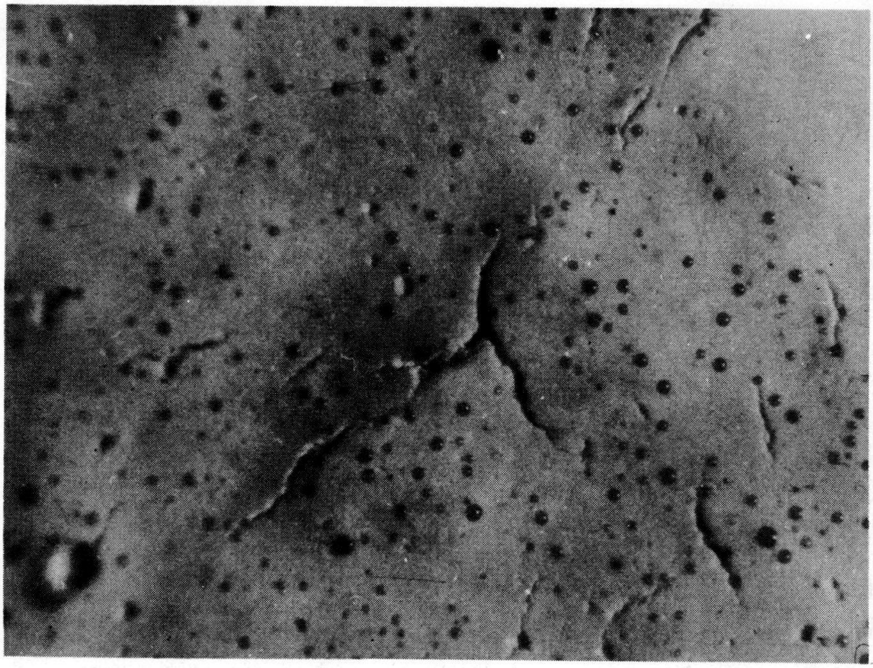

Figure 9. Photomicrograph (30X) of Sample 38 a premix which does not shrink differentially on drying and thus presents a smooth top surface with only the top sectors of the beads being uncovered by abrasion. Cracks are the result of accelerated weathering.

type of surface for nonreflectorized service. The surface is closed but, nevertheless, rough enough to offer a fair reflective surface at night. This condition is probably brought about by the addition of inert granular materials, as discussed earlier in this report. This particular photo is of Sample 7.

The size and quality of beads will, to a certain extent, determine the reflectance of a specimen. In this test all the beads used for external application are the same-taken from the stock of the Kentucky Department of Highways Traffic Division. Since these are the beads currently used by the department, it was deemed advisable to use them on all the samples designed for external bead application. If different beads are purchased in conjunction with paint supplies, some variation can be expected from the data contained in this report. Since no specific study of various bead types and their properties has been included in this report, only some general statements can be made without substantiating data. More complete analysis will be presented with the data in the second part of this report.

Smaller bead sizes (120 to 200 mesh), such as are used in the premix to inhibit settling of the mix and clogging of the spray nozzle, offer wide-angle reflective properties, good adhesion properties, and a homogenous reflectivity, due to the breaking down of the marking into very small reflective units. But this small size contributes to a diminishing of the reflectance of the line when the surface is wet. It takes only a slight film of water to immerse these small spheres, preventing their being effective as reflex reflectors. The larger bead sizes are not so easily covered and can be expected to be more effective on wet roadways. The larger sizes (40 to 80 mesh), are subjected to easier stripping away from the film, in addition to being unsuitable for premix use because of settling and clogging considerations.

In general, the smaller-sized beads have higher refractive indices, which is very desirable. But these higher indices

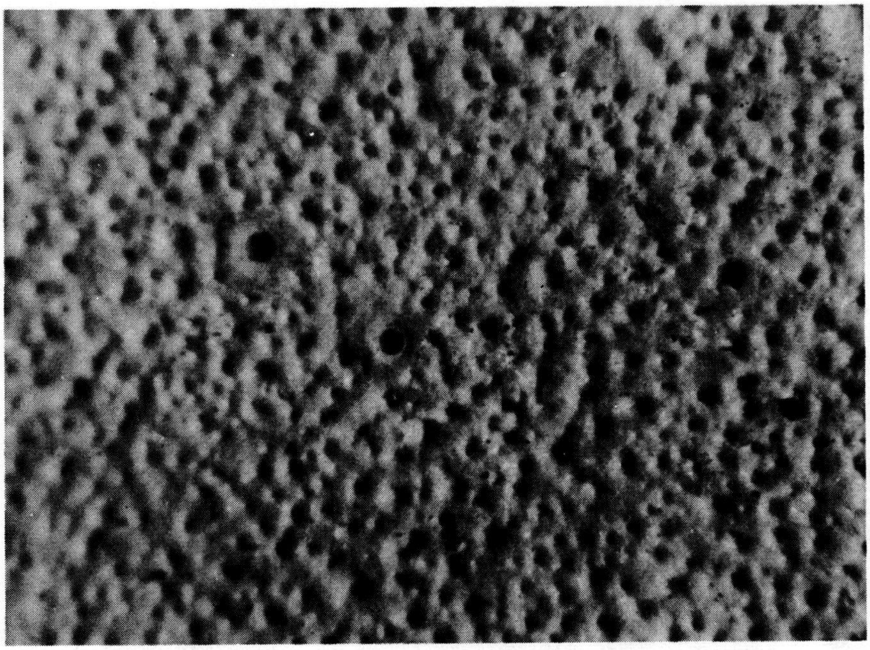

Figure 10. Photomicrograph (30X) of Sample 1 which is a nonreflectorized paint which was too high in volatile materials and dried to this honeycombed surface which would soon become filled with road scum.

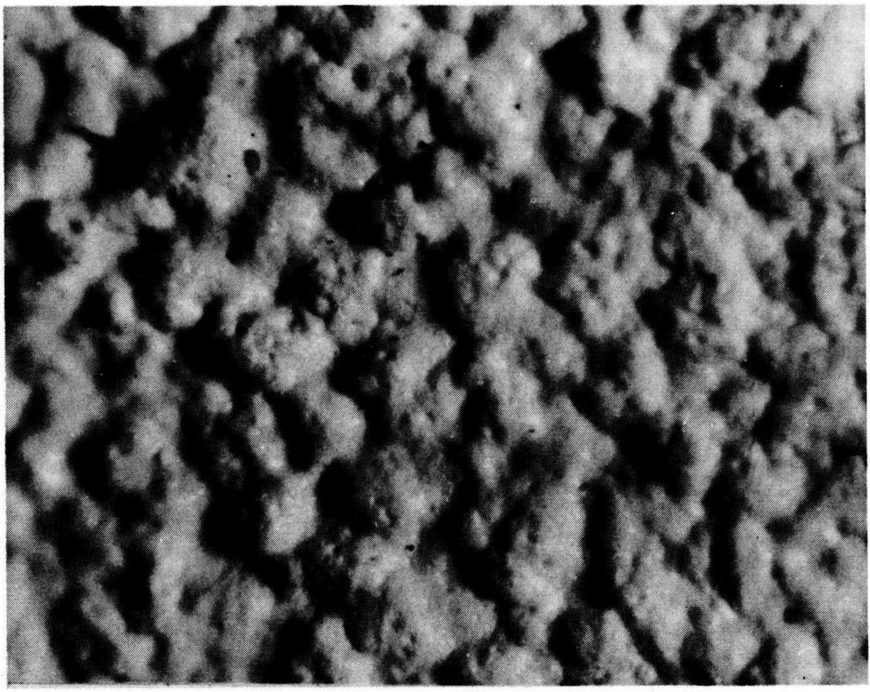

Figure 11. Photomicrograph (30X) of Sample 7 showing a nonreflectorized surface which is closed to dirt, but is made rough enough by inert additions to give it a fairly good reflecting property.

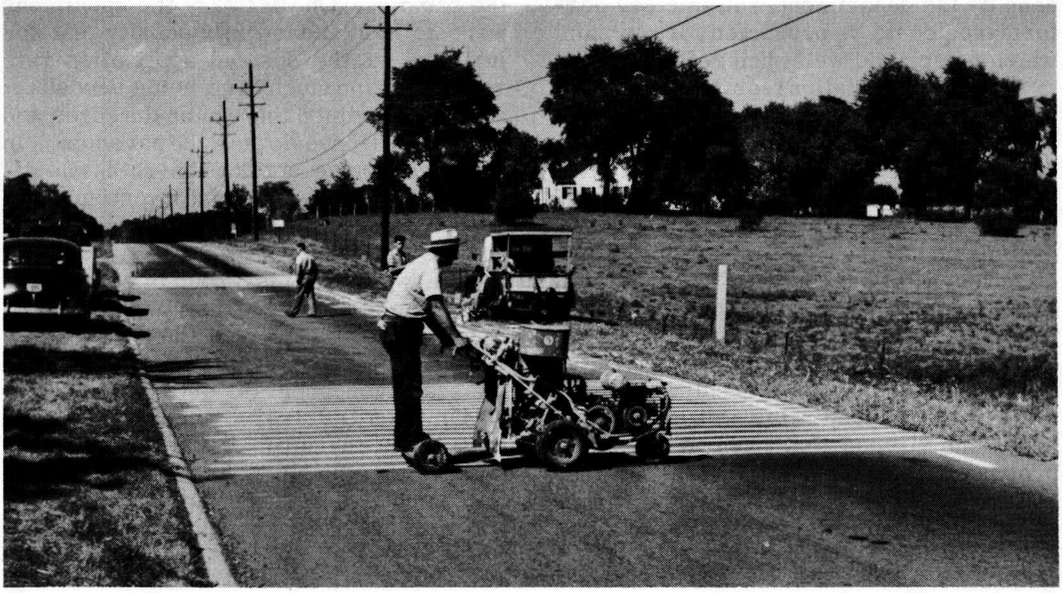

Figure 12. 1951-transverse-stripe location. The set of stripes in the foreground are on bituminous surface while the identical set on concrete surface is visible in the background.

are also indicative of softer glass, which makes the bead more susceptible to crushing. Thus a balance must be achieved between acceptable hardness and the highest refractive index consistent with this desired degree of hardness. This can be tied down in a specification by including specifications and tests of the refractive index, silica content, and size gradation.

The uses of these diminutive beads for increasing the night visibility of traffic markings have not yet been fully explored. There appears to be some promise to their use in black, bituminous paints for cement-concrete-pavement markings. It seems likely that such a paint could be devised which would yield a black line in daylight and a white one at night. Also, with the increasing use of formed white-cement curbing and centerline of special conformation to increase reflective properties, there is some room for experimentation in addition of glass beads to the white mortar to increase its reflective efficiency.

Other attempts to make traffic markings of greater permanence than paints include colored plastic discs cemented and nailed to the road surface. Clear plastic discs of similar design containing sheets of beaded reflective material inside the body of the disc are being tried. Asphalt-composition blocks inlaid in the surface are now coming into wide-spread use for crosswalk markers, and in England plastic centerline stripes have been inlaid in some roads. Only time will tell if this offers a solution to the problem of annual remarking of pavements.

1951 PROGRAM

The continuation of this testing program in 1951 was slightly modified in the light of the previous year's experience. The selection of paints was somewhat smaller, seven manufacturers supplied 24 formulations. This was not a conscious effort to dimish the scope of the investigation but was the result of the suppliers narrowing their own submissions voluntarily to those formulations which they felt would make the best showing.

Another point of difference was that the duplication of transverse stripes, one reflectorized and one nonreflectorized, side by side, was eliminated. Since the current policy of the traffic division is to reflectorize all centerline stripes, it was felt that any paint purchased should be considered on the basis of its performance as a reflectorized stripe, and for the small amount of nonreflectorized painting done by the department, satisfactory performance could be presumed for any paint which performed well when reflectorized.

The major deviation from the procedure of the previous year was in the application-rate control. Whereas in the 1950 application the rate was merely measured after the spray machine operator had adjusted for the optimum stripe he could obtain with each paint, in the 1951 program the application rate was set at 15 gal. per mi. of solid stripe, and the machine was adjusted at this rate plus or minus 5 percent, except in a few instances where the consistency of the paint prevented achievement of the desired rate. One mix was so heavy and viscous that even at maximum pressure and nozzle opening the desired rate could not be forced through the sprayer. No thinning was permitted with any of the samples. One or two of the specimens were so light and low in viscosity that adjustment to the desired application rate resulted in too much paint being deposited; as a result, the paint ran at the edges and puddled in depressions in the pavement. In these cases the application rate was diminished until a satisfactory stripe was achieved and the altered rate was recorded.

The work on this group of samples is not complete, since they were applied August 22, 1951, and the transverse stripes are being evaluated according to the scale and program outlined in ASTM Designation D 821-47, which will be continued until the ultimate failure of all the transverse stripes. The laboratory data and service-evaluation data will be presented in a subsequent report on this work.

TABLE 3

1951 TRAFFIC PAINT EVALUATION PHYSICAL PROPERTIES

Sample and Stripe No.	Specific Gravity	Wet Weight Per Foot Grams	Feet per Gallon	Gallons per Mile	Loss in Weight on Drying %	*Approximate Track Free Drying Time Min.	** Type Reflectorization	Color
1	1.542	20.6	324.2	16.3	14.2	11	B.O.P.	W
2	1.447	21.4	331.9	15.9	15.0	9	B.O.P.	W
3	1.506	24.7	387.7	13.8	2.2	19	N.R.	W
4	1.412	21.7	305.4	17.3	10.5	13	B.O.P.	W
5	1.538	24.7	368.4	14.3	8.5	16	B.O.P.	W
6	1.481	21.0	309.7	17.0	16.4	12	B.I.P.	W
7	1.604	20.9	430.5	12.3	3.1	11	B.I.P.	W
8	1.438	23.4	409.2	12.9	9.2	9	B.I.P.	W
9	1.412	22.4	321.9	16.4	12.9	22	B.I.P.	W
10	1.313	22.9	376.5	14.0	15.4	17	B.I.P.	W
11	1.383	23.0	422.1	12.5	12.1	16	B.I.P.	W
12	1.398	24.4	350.4	15.1	8.8	15	B.O.P.	W
13	1.490	25.7	343.9	15.3	13.5	12	B.O.P.	Y
14	1.611	19.5	417.6	12.6	7.4	10		Y
15	1.497	22.3	327.5	16.1	9.4	14	B.I.P.	Y
16	1.304	24.8	376.8	14.0	8.9	16	B.I.P.	Y
17	1.692	27.0	349.9	15.1	7.1	10	B.I.P.	Y
18	1.586	24.0	438.2	12.0	8.7	18	B.O.P.	Y
19	1.090	26.1	338.1	15.6	10.4	9	N.R.	Y
20	1.710	25.9	249.9	21.1	13.9	18	B.I.P.	Y
21	1.434	25.6	313.7	16.8	13.6	16	B.O.P.	Y
22	1.550	22.8	388.5	13.6	8.1	14	B.O.P.	Y
23	1.883	26.2	272.0	19.4	16.4	17	B.O.P.	Y
24	1.813	SPOILED SAMPLE						

* Noon Temperature 79°, Relative Humidity 56%

** B.O.P. = Beads on Paint

B.I.P. = Beads in Paint

Review of Traffic-Paint Research

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SYNOPSIS

IN THE early years of the present century it became apparent, with increasing demand for traffic stripes, that paints must be developed which had certain special properties. This paper is an outline of the recorded research for the formulation and testing of traffic-marking paints. Consumers' and manufacturers' opinion on improved properties of traffic paints point the way for additional research.

● IN THE early years of this century, the production and use of motor vehicles increased and construction and improvement of highways expanded so rapidly that it soon became evident that a method for traffic-lane markings must be devised. Centerlines of white concrete, stones sealed with asphalt, reflector buttons, brass spots, plastic inlays, etc., have been tried at various times but none of them have proven as satisfactory as the painted stripe.

It is not definitely known when and where the first traffic line was used, and many claims have been advanced for credit of originating the idea, but the B. F. Goodrich Company, after investigating many claims, presented Edward N. Hines, Road Commissioner for many years of Wayne County, Michigan, with a plaque (1) designating him as "Father of the Center Traffic Line."

In 1925, when the use of traffic paint for highway markings was becoming generally accepted and the volume of such business increasing, Mattimore (2) listed seven properties of a traffic paint which, in his opinion, governed the quality of the paint and for which laboratory tests should be developed.

The paint properties which he discussed and for some of which he gave methods of tests are: (1) consistency, should be suitable for machine application; (2) spreading rate, for the type of spreading apparatus used a paint giving the slowest uniform flow without clogging is desirable; (3) opacity, a thin paint of high hiding power used in a machine that restricts the flow (or operates at a higher speed) would make an ideal combination from an economic point of view; (4) drying time, tests should preferably be made at low temperature and high relative humidity; (5) light resistance, accelerated testing by exposure to the ultra-violet region of the spectrum; (6) visibility (day and night), description of a photometric apparatus is given for testing visibility; and (7) durability, accelerated weathering and abrasion to indicate durability.

The formulation and testing of traffic paints was investigated by Nelson and Werthan (3). The properties of paints designed for traffic-marking purposes, which they considered in more or less detail, are consistency, drying time, hiding power, color and color retention, visibility (day and night), and durability (resistance to weather and abrasion).

By proper formulation the consistency, spreading rate, and opacity are so balanced that complete hiding will result. For drying time the usual requirements of 1/2 hr. to no pickup and thoroughly dry in 1 hr. must be met. Any of the various white pigments may be used except lead compounds, which have a tendency to discolor. If lithopone is desired, the light-resistant variety must be used. To give additional visibility, coarse inerts passing No. 35 sieve and retained on No. 48 sieve are most suitable.

Apparatus is described for testing visibility and accelerated weathering with abrasion is used to determine durability.

No comparative road test was made on the 19 paints formulated but test results of the samples submitted by the Pennsylvania State Highway Department were in relative accord with road tests.

When it became apparent that the increasing demand for traffic stripes would, in time, require a considerable expenditure of money, the California Division of Highways (4) began the search for a satisfactory traffic-paint formula. The goal to be achieved was a paint having such characteristics as rapid drying, no bleeding on asphalt pavements, no brittleness, color retention, and resistance to abrasive action. To meet the drying time requirements, a lacquer-type paint was needed.

At that time no standard specifications for such a paint had been drawn up; therefore, an extensive research program was undertaken to develop a paint formula.

The investigation covered the use of commercially available gums and the solvents to be used with them. The different lacquers developed were subjected to an abrasion test on a machine constructed in the laboratory. Further investigations were conducted in devising an apparatus for measuring relative visibility.

To pass the specifications as finally drawn up, the lacquer was required to pass a severe abrasive test, to dry in 15 to 30 min., have good flowing and covering properties, pass a bend test, a water-resistance test and a nonbleeding test.

Hickson (5) reported the work done on traffic paints by the National Bureau of Standards in cooperation with officials of the District of Columbia. The district officials determined the working properties of many paints in a road distributing machine and the "mileage" per gallon of 4-in. stripes, while the bureau determined physical properties, such as hiding power, reflectance, consistency, drying time, bleeding tendencies, and relative durability in road-service tests. In addition to many commercial brands, eight different types of experimental paints were applied on both concrete and bituminous surfaces.

Hickson found that the paints generally did not wear as well on concrete as on bitumen; however, some paints wore better on concrete. Some were satisfactory on concrete but caused the bitumen to bleed. Even though there were wide differences in durability, weathering was of minor importance as compared with wear under the conditions of testing

In repeated trials, one brand of paint was consistently the best of the commercial paints. This paint was used as a control in comparing the durability of other brands and of all experimental paints.

Two of the best experimental paints contained 65 percent pigment and 35 percent vehicle by weight. The pigmentation of the two paints was different, both vehicles contained 40 percent nonvolatile matter but were of different proportions of chinawood oil, linseed oil, and modified phenolic resin.

It was observed that several commerical paints, all passing the same specification based on composition, gave different results during wear tests. Thus, a specification for traffic paint should be based on physical and performance tests rather than on a formula which purports to describe the composition.

In order to test resistance to abrasion, a machine, originally developed to measure relative wear of sole leather, was adapted to test wear resistance of traffic paints. It was essentially a weighed wheel with a rubber tread containing an abrasive which rotated against a movable circular roadbed to which the test paint was applied. A brake device permitted increasing the shearing action if desired. It is suggested that a weathering cycle be introduced into such test for better correlation of results with actual road wear.

A specification for a white traffic paint is given, together with a table of results of examinations of paints submitted under this specification.

As progress was made with traffic-paint formulation, the consumer's problem of choosing the best product increased, and tests for wear resistance were proposed. In addition to apparatus and tests developed by the Bureau of Standards and the New Jersey Zinc Company, several others were suggested.

Sweatt (6) developed a machine which consisted essentially of a circular table to the concrete surface of which the traffic paints to be tested were applied, this surface being rotated against a tire which functioned as an abrading wheel.

Power was applied from a 1/2-hp. motor by means of a wheel with a tire that served as one of the supporting bearings for the table. The abrading wheel was set at a slight angle to simulate the action of a skidding car.

The New York Department of Public Works (7) modified the Standard U. S. Dorry Hardness Machine slightly, so that the holders would be equipped with open, 12-oz., seamless tin cans. Bottoms of the cans, which had to be perfectly level, were painted and left to dry in the laboratory. The cans were accurately weighed, and enough sand placed in the cans to bring the total weight to 100 grams. After being placed in the holders and subjected to 500 revolutions, using double crushed quartz as the test abrasive, the empty cans were again weighed. The loss in weight was considered a measure of the abrasion loss. The test was repeated on the dried paint soaked in water for 18 hr.

The American Gum Importers Association, Inc. adopted a long-range program dealing with research and development work on traffic paints, which was reported by Skett and Holzberger (8). Work was done on both spirit vehicles and cooked-oil vehicles with the California traffic-lacquer specification as the basis of all spirit vehicles. The prime object was the investigation and improvement of paint vehicles; therefore, pigmentation was held constant, with the exception of some comparison between titanium-barium and titanium-calcium pigments.

Eight series of paints were prepared, and in each series one or two of the raw materials were varied in such a way that any differences in results could be attributed to the changes.

The paints were applied on a concrete road on Long Island in transverse stripes with a graph instrument using a calibrated 4-oz. veterinary's syringe for measuring quantities.

The most important conclusion of the preliminary work was that the manila-resin spirit-type paints were best formulated with blown castor oil as plasticizer and using 63 percent titanium-barium and 37 percent magnesium silicate pigment at about 40 percent pigment volume optimum. Titanium-calcium pigments gave very flat paints and better packaging than titanium-barium.

The second part of the work covered a wider range of resins and a wider range of amounts of plasticizers with pigment volume and pigment composition maintained. Further comparison was made between titanium-calcium and titanium-barium pigments and some comparison between magnesium silicate and china clay as inert materials.

In the third part of the program, 193 paints were tested, including spirit paints of Manila, Batu, and pale East India types and cooked paints of various types. Batu was used in place of modified phenolic resin and linseed oil and dehydrated castor oil in 10 to 15 gal. oil length in paints based on the Bureau of Standards formula of 15 gal. chinawood oil, linseed oil, modified phenolic resin. Three different roads were used as test locations.

Based on their investigation, Skett and Holzberger arrived at the following general conclusions: As far as durability is concerned, Batu cooked paints are superior and those containing chinawood oil are more durable than those prepared with other oils.

Batu-linseed paints of about 10 gal. oil lengths compare favorably with modified phenolic resin chinawood- linseed oil paints. All types of pigmentation may be used with Batu-linseed oil vehicle.

Only slightly inferior in durability to the best Batu cooked paints are the best Batu spirit-type paints.

Manila paints require the use of alcohols as solvents, and if due to scarcities Manila paint can't be used, it is recommended that Batu cooked paints be used at a sacrifice of color and nonbleeding characteristics but with better durability.

By 1939, the volume of traffic paint used on highways and streets had increased to the point where proper attention to specification and testing problems was necessary. It followed that there had been increased interest in laboratory and road tests that might be standardized to give accurate information about the service life of paint. However, the satisfactory correlation of laboratory and service results is time consuming, and it is a field where cooperative effort is desirable. Toward this end the Committee on Traffic Zone Paint of the Highway Research Board (9) sent questionnaires to all state highway departments, the District of Columbia, and six cities. Replies were received from 45 of the 55 questionnaires sent out. The pertinent information and the comments of the committee, based on the replies, are:

1. The idea of a complete composition specification still predominates. A few organizations are working on the basis of performance specifications, but experience with them is relatively limited.
2. The use of laboratory tests, either in the form of chemical tests to check composition or laboratory tests to indicate some special service quality, is quite universal.
3. The use of small-scale road tests has become general.
4. Very few depend on practical road service alone in judging the quality of traffic paints.
5. Aside from checking composition by chemical tests, which is quite generally done, at least 14 tests for different properties receive more or less attention in the laboratory. In order of popularity, the most important are: drying time, consistency, bleeding, flexibility, water resistance, hiding power, color stability, spreading qualities, weather and wear resistance, and visibility.
6. In making road tests, parallel and cross lines are almost equally popular, and most organizations put these tests on both concrete and bituminous surfaces. Hand brush, machine, and spray applications are also almost equally used. Four-in. lines are most popular, and the spreading rates most used range from 90 to 175 sq. ft. per gal. of paint (1/10 to 1/20 mi. per gal.).
7. Given in order, drying time, wear resistance, visibility, weather resistance, and color stability are the factors generally used in grading road service tests. Of the organizations that report the use of definite rating schedules, the majority give wear resistance first consideration, followed by drying time, visibility, weather resistance, and color stability.
8. Experience with laboratory wear and weathering tests is not yet very general. However, it is noted that the organizations reporting actual experience with these tests show a marked majority opinion in their favor.

The Highway Research Board (10), in cooperation with the Committee on Research Activities of the American Association of State Highway Officials, has prepared an index of the research activities of organizations interested in the development and improvement of the many phases of highway transportation. Some of the projects have been completed and others are still in progress. Reports of several investigations are available, and information about a few more may be obtained by inquiry to the research agency.

Traffic-paint subjects under study include abrasion tests, accelerated tests, drying time, durability, formula development, lacquer studies, night visibility, and performance tests.

A report on natural resins in quick-drying traffic paints was made by Kopf and Mantell (11). Their study covered natural resins in quick-drying traffic paints, the effect of chinawood and other oils in quick-drying vehicles, and formulations and performance tests of quick-drying vehicles.

Starting with the California vehicle formula, they made changes in resin, oil, ratio of resin to oil, ratio of pigment to binder in the dry film, addition of elemi to improve adhesion, and to a small degree, the volatility of the solvents.

Eight series of paints containing more than 30 formulations were given different tests in addition to the road-performance test. Performance-test results in relation to resin changes, pigmentation, oil changes, and volatiles are discussed for the different series of paints.

From their work the conclusion is drawn that the California specification, although popular among the states, can be improved.

Goetz (12) made a progress report of a study to establish a correlation between field performance and laboratory tests and determine the characteristics of the paint film necessary for good durability on the road.

Samples of traffic paint 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, and 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 settling, mobility, hiding power, weight per gallon, drying properties, pigment, volatile, nonvolatile, pigment volume, abrasion loss, water and alkali resistance, and degree of flexibility. Special attention was 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 percent 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 long periods of wear before failure took place. 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, 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.

In a report by Skett and Herbert (13) on accelerated testing of traffic paints, the results of laboratory and road service tests are given. Nine paints were used in the investigation, six white and three yellow. The paints were applied on roads in 12 localities for service tests, and the relative service durability of the paints in the various localities was determined by observation at the end of approximately 20 weeks.

There was not complete agreement on the service results as reported by the different cooperators. The lack of perfect agreement in the service-durability tests was explained by the variation of weather conditions in the localities in which the paints were applied.

Eight laboratories cooperated in laboratory tests of the paints. The tests used were various methods of abrasion and flexibility tests. Five laboratories used both the abrasion test and the flexibility test in evaluating the paints. Two laboratories used only the flexibility test, and one laboratory used only the abrasion test.

The abilities of the laboratories to rate the paints on the basis of the laboratory results, in the order of relative durability as determined by the prevailing service results, were not in agreement. With very few exceptions the laboratories were able to differentiate between the good paints and the poor paints but were not able to exactly classify the paints in order of their relative durability as determined by the service results.

In general, the abrasion tests gave more reliable information on durability than did the flexibility tests.

The general conclusion that can be drawn from this investigation is that no one laboratory test, or combination of laboratory tests, is sufficient to evaluate correctly the relative durability of traffic paints. However, the tests used do differentiate between paints that would be classed good and paints that would be classed as poor.

Additional work on accelerated testing of traffic zone paints was reported by Dawson and Skett (14) in 1943. Ten white paints differing widely in durability characteristics were applied on nine roads in New Jersey, New York, and Pennsylvania. They were observed throughout their life and graded by several observers. Observations were made over 15- to 18-month periods.

The same paints were submitted to seven cooperators for tests, with particular emphasis on the use of abrasion tests and overall ratings and using a variety of laboratory testing methods.

Generally satisfactory reproducibility was obtained in the road-service tests. One of the abrasion-testing methods showed fair correlation with the service tests and warranted further investigation. The abrasion-testing method previously thought to be of interest showed less satisfactory correlation in this series of tests than in the series of tests reported on by the committee in 1941.

Two cooperators rated the durability of these paints fairly well, using testing methods based on weighings of abrasion, adhesion, and flexibility measurements.

Exposure of these 10 paints to the weather on concrete and under circumstances where practically no wear due to traffic was involved resulted in evaluation of the paints in approximately the same order as road service tests. Need for further study of accelerated-weathering tests as applied to traffic-zone-marking paints was indicated.

Some effects of pigmentation upon the durability of traffic paints were studied by Herbert (15). In order to get reliable evaluations, he decided to subject each paint to exactly the same conditions of test as far as practically possible. The evaluations were made on cross stripes instead of centerlines, and the tests were conducted on fairly uniform, smooth roads in the middle of long, flat, straight stretches over which the motorist travels at uniform speed. For this work a smooth concrete road and a fairly rough macadam road were selected.

All paints were applied at 80 Krebs unit consistency with a graph instrument. The quantity of paint applied for each line was governed by measuring with a veterinary's syringe.

For this study four different vehicles were used: (1) Bureau of Standards specification; (2) California clear traffic lacquer; (3) California formula with the chinawood oil replaced by blown castor oil; and (4) 15 gal. chinawood-oil--ester-gum varnish.

The problem of studying the effect of pigmentation upon the durability of traffic paints was divided into four parts: (1) effect of various inert extenders; (2) effect of pigment volume; (3) effect of white prime pigments; (4) effect of colored pigments.

From the results of the road exposure tests the following conclusions were drawn: (1) Of the six extenders investigated, magnesium silicate and micaceous talc are the best (whiting also gave good results). (2) A pigment volume of 40 percent appeared most desirable in the four vehicles studied. (3) Titanium-barium pigment was the best of five widely used pigments with titanium dioxide plus extender second. (4) There is little choice between chrome-yellow light and chrome-yellow medium; "Hiway" Red (lead molybdate), though not previously employed in traffic paints, showed the most outstanding durability performance of any of the prime pigments in the study.

During the years of World War II, many of the raw materials for paints were not available or required high priorities. This necessitated relinquishing of composition requirements and accepting available substitutes with consequent decrease of essential qualities. Under these circumstances it was Werthan's (16) opinion that, when evaluation methods for use by both consumer and supplier were being considered, they should be limited to properties of direct practical interest to the consumer. For instance, while the resistance of a traffic paint to wear undoubtedly depends upon a proper balance of such properties as film hardness, distensibility, adhesion, and resistance to moisture and temperature changes, a customer should not be confused or burdened with tests covering these individual properties if there is a single test for determining the wear resistance of the paint.

Description of apparatus and methods of test are given for three important properties of paints, namely, night visibility, drying time, and resistance to wear. Tables are given showing good agreement between the abrasion test and road-service test for paints of different formulations.

Laboratory tests showed that cold-cut zinc resinate and Z-bodied linseed oil in a 1 to 1 ratio made paints of equal durability to those prepared from solutions of natural gums. Abietate and terpene vehicles can also be used to formulate durable paints.

In the search for substitutes during the war period, zinc resinate with heavy-bodied, blown soya oil (17) in the vehicle was tried as a substitute for the more costly chinawood, oiticica, and other oils. Zinc resinate (18) was used in spirit-formula paints and also with linseed cooked varnishes.

The Federation of Paint and Varnish Production Clubs prepared a consolidated report (19) of formulations of traffic paints made with available raw materials that could be applied to different types of roads for camouflage purposes.

Slate (20) made a study to find the causes of failure of the concrete paints then in use and to find paints and painting methods to overcome these causes.

Both laboratory and field tests showed that paints fail principally by scaling, due to loss of adhesion between the paint film and the concrete in the presence of water. The water, coming from the moist soil beneath the pavement travels upward through the concrete and evaporates from its surface. The water traveling upward carries soluble salts with it; these salts are deposited upon evaporation of the water. The paint film offers resistance to the passage of the water vapor and to the growth of the salt crystals, and the resulting forces may break the bond between paint and concrete. The surface of the concrete itself may be disintegrated by the growth of these salt crystals. The thickness of the paint film, which governs its resistance to the passage of water vapor, has a marked influence on the rate of scaling of some paints.

Laboratory and field tests, designed to compare the durability of standard and proposed concrete highway paints, showed that the thermosetting and thermoplastic synthetic-resin paints tested had far better water, alkali, and abrasion resistance than standard paints. It was concluded that the baking-type paints and the strongly polar, thermoplastic-resin paints tested were suitable, satisfactory, and superior for concrete highways.

The American Society for Testing Materials started its work on traffic paints in 1942 by appointing Subcommittee IV of Committee D-1. In a progress report of Group 2, Allen (21) presented work done on tests for abrasion, adhesion, flexibility, and hardness of traffic paint. The purpose of the study was to determine, if possible, the value of these tests in estimating the behavior of traffic paint in service and possibly to recommend to ASTM methods of tests that proved to be of value.

In June 1942, eight samples of traffic paint from eight different producers were distributed to each member of the group for testing. The paints were also included in the 1942 Ohio field-service tests on portland-cement concrete, bituminous concrete, and brick-pavement. These paints were widely different in both pigment and vehicle composition, and considerable difference in service was anticipated.

No attempt was made to standardize the procedure to be followed in each type of test, and each cooperator was at liberty to choose the method of test he felt would give best results.

No correlation could be drawn between the hardness, adhesion, and flexibility tests investigated and abrasion tests or field-service tests. Close correlation was found between the abrasion results of two cooperators and the field-service tests and fair correlation between several others.

For further study, six additional samples, which had been included in the 1943 Ohio field-service test and which represented a wide range of durability, were submitted to three cooperators for abrasion tests. The results of these abrasion tests showed close correlation with field-service behavior of the samples of traffic paint examined.

Various groups of subcommittee IV have developed the following methods of test for traffic paints: Dry to no-pick-up time; light sensitivity; conducting road service tests; evaluating degree of resistance to abrasion, erosion, or a combination of both, in road-service tests; evaluating degree of resistance to bleeding; evaluating degree of settling; evaluating degree of resistance to chipping; laboratory test for degree of resistance to bleeding, and night visibility.

Custer and Zimmermann (22) have made a progress report of a long-range program for field evaluation of traffic paints.

A Kelly-Creswell traffic-painting machine has been modified so that the rate of application can be controlled by changes only in the paint tank and atomizing pressure, and a field laboratory checks the amount of each paint applied before actual road striping.

The effect of various pigment compositions with comparable pigment volume concentration and vehicle composition, the effect of pigment volume concentration with both alkyd and oleo-resinous vehicles, and the comparison of alkyd and oleo-resinous vehicle binders were studied.

With paints based on rutile titanium-calcium pigment and alkyd-resin vehicle, further studies are contemplated with pigment extenders and on the use of this type of paint for glass-bead application.

In a report of questionnaire replies received from 34 states and 174 manufacturers of traffic paint, Ashman (23) listed the relative order of emphasis proposed for paint properties. The properties listed are improved service life, rate of dry, night visibility, storage stability, cost per gallon, bleeding resistance, and day visibility; however, manufacturers and consumers do not give the same relative importance to each of these properties. The consumer is concerned about better service properties in the paint film and the manufacturer about better liquid paint properties at lower cost.

There is opportunity for both producer and consumer for further study and research on traffic paint, the producer to attempt to improve the quality of traffic paint with the raw materials now in use and to seek new materials to increase durability, decrease drying time, and improve night visibility and suspension. The most important problem for the consumer is to develop an accelerated test which will definitely indicate relative durability. Such a test would permit specifications to be written in general rather than detailed terms as to composition and would give the progressive producer a better chance to supply a superior product.

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Principles of Glass-Bead Reflectorization

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● IT HAS been estimated by Ashman (1) that the 48 states used nearly $2\frac{1}{2}$ million gallons of traffic paint of all kinds in 1950. On the basis of returns from 33 states to the same author, nearly half of all white paint and two thirds of the yellow, totaling almost $1\frac{1}{4}$ million gallons, were reflectorized with glass beads in 1950. At normal application rates, this means a total consumption of more than 6 million pounds of beads for that year, and a most significant trend is revealed in the fact that these figures represent an increase over the previous year of 67 and 59 percent respectively in the amount of white and yellow paint so reflectorized. This is fairly big business, and its rapid growth in recent years gives definite notice that glass beads have become an important highway material whose functioning must be thoroughly understood and properties carefully evaluated in order to realize maximum benefits from their use.

It is the purpose of this paper to discuss some of the more important principles governing the use and performance of glass beads in traffic paint to serve as a basis for the design of adequate tests and interpretation of their significance. Fortunately, the application of theory to practice is so direct in most instances that laboratory tests can easily be devised to faithfully predict performance in service. Moreover, the intelligent application of these principles to the whole problem of bead reflectorization brings immediate and substantial dividends of a very practical nature.

The subject matter of the discussion which follows is divided among three major topics: (1) effect of chemical composition on properties of the glass; (2) effect of physical properties of the beads on performance; and (3) principles of application. The main object is to point out how the recognition and utilization of certain fundamental principles and physical laws can be made to advance the art of glass-bead reflectorization and thus serve the best interests of all concerned.

CHEMICAL COMPOSITION ON PROPERTIES OF GLASS

Glass has been defined by Morey (2)[1] as "an inorganic substance in a condition which is continuous with, and analogous to, the liquid state of the substance, but which, as the result of having been cooled from a fused condition, has attained so high a degree of viscosity as to be for all practical purposes rigid."

It is important to understand that glass is, in effect, an undercooled, highly viscous liquid. When properly compounded and processed, the melt solidifies on cooling to form an amorphous, vitreous solid in which crystallization has been inhibited or prevented by the high viscosity of the liquid at temperatures near the melting point. When crystallization, or devitrification, occurs on cooling, the glass is ruined. Devitrification is probably the most important factor which limits the range of composition of commercial glasses, and may be caused by errors in either composition or heat treatment. Other compositions, satisfactory with respect to devitrification, are unsuitable because of enormously high viscosities in the temperature range above the freezing point, which makes working extremely difficult.

Most glasses can be considered as composed of oxides, the acidic oxides most commonly used being silica, SiO_2; boric oxide, B_2O_3; and phosphorous pentocide, P_2O_5. Vanadium pentoxide, V_2O_5; arsenious oxide, As_2O_3; and germanium oxide, GeO_2, are also glass-forming but of limited use. Germanium oxide is ex-

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[1] This standard work includes an extensive and thorough treatment of the effect of chemical composition on all of the important properties of glass Together with some of the more recent publications of the National Bureau of Standards, it constitutes the principal basis for the present discussion of glass chemistry

cellent, but too expensive. Phosphorus pentoxide does not have as marked glass-forming properties as either boric oxide or silica, and is not used much. Boric oxide is widely used, but only in silicate glasses, since when used alone or in too large amounts the resulting glass lacks chemical durability. Almost all commercial glasses contain silica, which has the essential qualities of chemical durability and freedom from devitrification to a marked degree; in fact, if it were not so difficult to melt and work, silica glass would be the best type for most ordinary uses. Such glasses have a relatively low refractive index, however, which handicaps their effectiveness in beads for pavement-stripe reflectorization.

Because of the difficulty and cost of making silica glass, and in order to secure glasses having certain special qualities, other oxides are added to flux the silica and make it workable. A great many different metallic oxides are used for this purpose, the particular ones selected depending on the properties desired in the glass. Most of the common ones will be mentioned in specific applications a little later. A point that should not be overlooked in interpreting the significance of chemical tests is that comparatively small amounts (less than 1 percent) of some of the constituent oxides may greatly affect the chemical and physical properties of the glass. Whether these small quantities are added deliberately, or whether introduced as an impurity in materials or by interaction of the glass with the refractory container during melting, they should be taken into account when attempting to relate composition with physical properties.

For the present purpose, properties of primary interest related to composition are chemical durability, refractive index, density, strength, and color. The discussion of these topics which follows will also include some remarks on the significance of applicable tests for glass beads.

Effect of Composition on Durability

Chemical durability, or resistance to attack by the atmosphere and corrosive solutions, is a matter of prime importance in the utilization of all glasses. Most optical glasses are exposed to air throughout their service life and are subject to the corrosive action of chemical constituents in the atmosphere, carried by the water which is always present. Even pure water may attack certain glasses more severely than many strongly acid or alkaline solutions.

Sodium oxide is the best flux for silica, but the resulting silicate is soluble in water, and other oxides must be added to give chemical durability. Lime is most commonly used for this purpose, and the resulting product is the familiar soda-lime-silica glass that makes up the bulk of commercial production. If too little lime is added, the glass melts easily but has poor chemical durability; if too much, the glass is hard to melt and sure to devitrify. The best composition for pure soda-lime-silica glass is in range: SiO_2, 73-74 percent; CaO, 7-13 percent; Na_2O, 13-20 percent.

Magnesia and zinc oxide can be advantageously substituted for part of the lime, and aluminum oxide, Al_2O_3, gives better chemical durability and freedom from devitrification, but too much makes the glass hard to melt and work. Potassium, barium, and boric oxides all increase chemical durability and prevent devitrification, but also increase viscosity. They are helpful in small amounts, but a large proportion of any one of them has some unfavorable effect.

Glasses containing a high percentage of the acidic oxides, such as silica and boric oxide, are resistant to acid solutions, but less so to water and alkalis. Conversely, glasses containing small amounts of these oxides are subject to considerable attack by acid solutions; in fact, some of the extra-heavy lead and barium glasses can be decomposed sufficiently for chemical analysis by digestion with hydrochloric or nitric acid.

Durability versus Serviceability

While the ability of a glass to maintain an optically clear and polished surface is a measure of its serviceability, it is also true that some optical glasses of relatively poor chemical durability give excellent service (3). It has long been known that the formation of films on optical glasses in certain cases actually improved performance by reducing external reflection, and the discovery of this fact was the basis for the present practice of lens coating (4). When water of aqueous solutions attack glass, the action is not one of ordinary solution, but rather one of progressive hydrolysis and hydration, resulting in a breakdown of the silicates and preferential solution of the reaction products, somewhat analagous to the hydration and leaching of portland cement. In certain glasses this preferential solution of alkali and other metal ions by water leaves a surface film rich in silica, which has a considerably lower refractive index than the base glass. Although this film is not as effective as one of controlled thickness and refractive index, it is sufficient to give noticeable improvement in transmittance and reduction of external reflection.[2]

The foregoing should not be construed to mean that all dull surfaces and evidences of poor durability are beneficial to optical performance. Etched, pitted, and otherwise damaged surfaces are in an entirely different category. It is intended to emphasize the fact that serviceability and chemical durability are not synonymous terms, but represent destinctly different properties. For this reason, a laboratory test for chemical durability based only on weight loss by extraction with water or apparent dulling of surface luster may wrongly condemn a perfectly satisfactory glass. Optical tests before and after exposure to attack are the only reliable method of distinguishing serviceable glass beads. In our own laboratory it has been observed that weight loss of a glass-bead sample by extraction bears no evident relation to dulling of surface luster, and neither criterion is an infallible indication of subsequent optical performance. In one case, reflectivity of the glass beads was improved after refluxing for 90 hr. with distilled water in spite of a substantial weight loss in the process.

Long life is not an essential quality of pavement marking beads. It is only necessary that the glass beads retain their reflective power through the effective life of the pavement stripe, which in turn is regulated chiefly by the performance of the paint. Chemical durability, then, is not as significant as serviceability in evaluating glass beads for pavement reflectorization. A test for hygroscopicity of glass as a measure of service-ability has been used and described by Hubbard (3), but photometric tests are more practical and direct for glass beads when equipment for making such tests is available.

Effect of Composition on Density and Refractive Index

Because of the nature of glass, its density is approximately an additive function of its composition, a relationship which is generally true of all liquids (2). Silica and boric oxide are the lowest in density, followed by the oxides of aluminum, sodium, potassium, magnesium, iron, calcium, zinc, barium, and lead. The factors used to compute the density of glass from percentages of its constituent oxides are not greatly different for the common ingredients of ordinary soda-lime-silica glass, so that the composition can vary within rather wide limits without greatly affecting density. Appreciable quantities of barium and lead in the heavier crown and flint glasses have a marked effect on density however.

Density is of interest largely for three reasons: (1) it determines the relative amount of reflective surface furnished per pound of beads of a given size; (2) it affects application procedures through its effect on the sedimentation rate of beads in paint; and (3) it is related closely to refractive index. As a general rule, the refractive index increases as the density increases, but the relationship is not linear. Refractive index is a very important property indeed, and its significance will be discussed in some detail a little later, in connection with the effect of physical properties on bead performance.

Effect of Composition on Crushing Strength

There is little published information on the relation of glass composition to crushing strength and still less on strength as determined in current methods of glass-bead testing. The results of compression tests by Gehloff and Thomas on a series

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[2] For optimum results, the refractive index of the film should be the square root of that of the base glass, and its thickness one fourth the wave length of the incident light

of glasses derived from a two-component soda-silicate glass by the substitution of various metallic oxides for part of the silica are given by Morey (2). These tests were performed on very small glass prisms and indicated that the alkali oxides reduced strength most. The order of effect of the various oxides is given as: Al_2O_3, (SiO_2, MgO, ZnO), B_2O_3, Fe_2O_3, (BaO, CaO, PbO), Na_2O, K_2O, the oxides in parentheses having about the same effect. No correlation was found between crushing strength and tensile strength.

More recently, the work in Missouri reported by Lyon and Robinson (5) also shows generally greater strengths for the high-silica beads, but the effect of composition is clouded somewhat by considerable variation in physical characteristics, such as surface condition, internal milkiness, etc. Experience in testing beads from various sources in our own laboratory has given further evidence of the same general relationship between strength and silica content.

Effect of Composition on Color

When light enters glass, some of it is absorbed and some transmitted. If the absorption is small and uniform for all wavelengths of visible light, the glass appears clear and colorless. As the overall absorption increases, the glass becomes greyish in color. When the glass selectively absorbs light of any given wavelength, the hue of the transmitted light perceived by the eye is the composite of the remaining colors of the visible spectrum. In short, the apparent color of the glass is the complement of the absorbed color when the incident light possesses a continuous spectrum.

For the most part, colors encountered in beads for paint reflectorization are those incidental to the compounding of the glass and are not added intentionally. Iron oxide is usually present as an impurity in commercial glasses, giving either a greenish color or a weak yellow, depending on whether the oxide is ferrous or ferric. The addition of other oxides as so-called decolorizers masks or neutralizes the color but results in a reduction of transmission. High-grade optical glasses are produced with transmissions of more than 99 percent, but ordinary window glass has a transparency of only 85 to 90 percent. The presence of much lead or barium oxide in the optical glasses of higher refractive index also decreases the transparency. The two oxides of vanadium, V_2O_3 and V_2O_5, give colors similar to those of ferrous and ferric iron respectively.

There are two aspects to the problem of color in glass beads. One, of course, is the fact that selective absorption weakens the intensity of reflex-reflected light, since the incident beam must pass through the bead twice before being returned to the driver's eye. The other is the possibility of an objectionable color modification of the painted stripe by the beads. So far, the decision as to what constitutes objectionable color has been made on a purely subjective basis. There appears to be no necessity for a "water white" color specification, however, since a noticeable color of the beads in bulk may be totally imperceptible when they are applied to the paint in the required quantities. Some variation in color should be permitted as long as there is no appreciable alteration of the color of the paint stripe, and color specifications which are unnecessarily restrictive may hamper the development of glasses superior in other respects.

Eventually it may be feasible to use a yellow bead with yellow traffic paint. Such a practice may help prevent the washing out of the background color by the more brilliant beads, which is noticeable in most yellow-reflectorized signs of high specific intensity. The desirability of using colored beads will no doubt receive increasing consideration as the reflective efficiency of pavement stripes approaches that of present beaded highway signs.

PHYSICAL PROPERTIES OF THE BEADS ON PERFORMANCE

In the preceding section, the relation between chemical composition and certain significant properties of the glass was brought out, and it was shown how some of these properties, such as chemical durability and color, directly influence the service performance of the beads as such. The purpose of the discussion which now follows is to explain the influence of the important physical properties of the beads themselves, namely, refractive index, particle size, and flaws of various kinds, on performance in a reflectorized stripe.

While refractive index is not a property of the bead, but of the glass composing it, its significance is so intimately related to physical form that it may properly be included here for more detailed discussion.

Refractive Index on Distribution of Reflected Light

Refractive index is one of the most important properties of glass beads, since it determines to a large extent the amount and distribution of reflected light. The proportion of incident light reflected from the bead-paint interface is a function of the difference in index of the two materials, while the pattern of the reflected beam depends on the focal length of the bead lens, which is determined in turn by the refractive index of the glass. The subject of interrelation of beads and paint in reflex reflection will be taken up in a little more detail after first explaining the principles of geometric optics applicable to the performance of the beads themselves.

Reflection. When light is incident on an interface of two transparent media, it will generally be distributed in three ways: (1) a part of the light will be reflected from the surface of the second medium; (2) part will be transmitted; and (3) the remainder will be absorbed. The proportion of light reflected at the boundary surface is a function of both the angle of incidence and the refractive indices of the two media and is given by

$$R = 1/2\left(\frac{\sin^2(i-r)}{\sin^2(i+r)} + \frac{\tan^2(i-r)}{\tan^2(i+r)},\right) \qquad (1)$$

where R is the fraction of incident light reflected, and i and r are the angles of incidence and refraction respectively. When one medium is air, the reflection at normal incidence is

$$R = \frac{(n-1)^2}{(n+1)^2}, \qquad (2)$$

where n is the ratio of the refractive index of the second medium to that of the first. The equation holds, and the reflection is the same, irrespective of which medium is traversed first.

In Figure 1, the Equation 1 has been plotted for three different glasses having refractive indices of 1.50, 1.75, and 2.00 respectively (in air). These graphs show that external reflection at normal incidence from a glass surface in air is almost tripled for an increase of 0.50 in the index of the glass and that reflection increases very rapidly at angles of incidence beyond about 50 deg., to total external reflection at 90 deg.

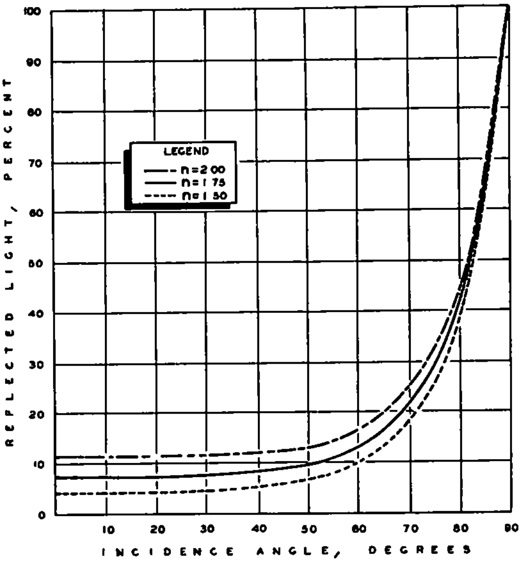

Figure 1. Retention of light from the surface of glass in air.

Refraction. Refraction of light at a spherical boundary between two transparent media is shown in Figure 2. From the principles of geometric optics, we have the relation

$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R} \qquad (3)$$

where p is the distance of the light source from the vertex O, q is the image distance or focal length, n_1 is the refractive index of the first medium, n_2 the index of the second, and R is the radius of curvature of the boundary surface. This equation is an approximation which holds for rays near the axis and is sufficiently accurate for the present purpose. For the conditions under which glass beads are ordinarily viewed, the object distance p is so large in comparison to the radius R that

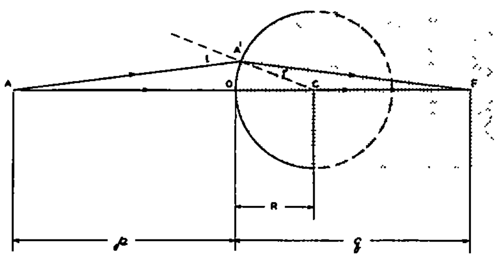

Figure 2. Refraction of light at a spherical boundary.

the incident light rays can be considered parallel and the first term of Equation 3 vanishes. Thus, for a glass of index 1.50 in air (n_{air} = 1.00), the focal surface is at a distance 3R from the vertex O, or a distance R behind an imaginary rear surface of a sphere, shown by the dashed line in the figure. Similarly, to focus parallel light on the rear surface (q = 2R) the glass must have a refractive index of 2.00.

Figure 3 is a sketch of a section through a glass sphere embedded to a depth of half its diameter in a third transparent medium, say an alkyd resin, of index n_3. Any parallel incident beam entering the sphere converges to a point on the axis of the beam at a distance PF behind the sphere. This distance is determined by the refractive indices of air, glass, and resin, n_1, n_2, and n_3 respectively. When n_2 and n_3 are equal, there is no change in direction of the rays at the glass-resin boundary and the distance PF can be determined by a single computation. If a spherically curved reflecting surface, GFH, concentric with the sphere, is now placed at F, the parallel rays of any beams which can enter the sphere will be refracted and reflected symmetrically with respect to the axis of the beam and again rendered parallel on emerging from the sphere to be returned in the direction of the source. It is also apparent from Figure 3 that if the rays of the incident beam are reflected from a point either ahead of or behind the focal surface, they will not emerge parallel. This is shown by tracing the ray along AA', which is refracted to the point D on the rear surface of a bead composed of an average glass of index around 1.5. If this ray were totally reflected at that point, it would emerge along E'E at a considerable angle to the direction of the incident ray. If, however, the index of the glass is increased to 2.0, the refracted ray A'D would be bent down to a focal point P on the rear surface, reflected to B' as shown by the dashed lines, and emerge parallel to its original direction. As a corrollary, it may be stated that spheroids or ellipsoids of the lower index glasses will give better reflex reflection than true spheres in traffic paint, provided their long axis is oriented in the general direction of the oncoming light source.

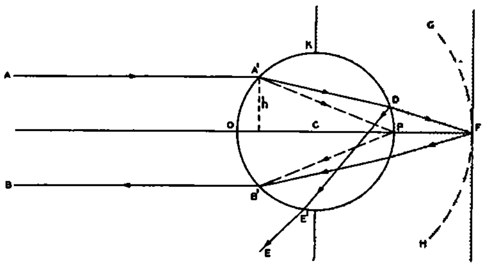

Figure 3. Refraction and reflection by a glass sphere in a third medium.

These principles are made use of in the construction of beaded sheets for reflectorized signs of various kinds. Long-range visibility is achieved by placing beads of a given refractive index on a transparent film of controlled thickness (approximately equal to R + PF in Figure 3), backed by a highly reflecting metallic foil. In this way the amount of light reflected is increased, and this returned light is conserved in a relatively narrow cone of high intensity. Such a reflecting surface is usually plane, however, so that it contains the focal point only at normal incidence and brightness falls off rapidly as the angle of incidence increases. Since the focal length of the bead is a function of its radius, it is obviously advantageous that the beads be as uniform in size as possible for this type of construction. With sufficiently high refractive index of the glass, the focal surface GFH is brought up to the rear surface of the bead, making a spacing coat unnecessary.

If the beads functioned in the ideal manner just described, the resulting perfect reflex reflection would have little practical value, because all of the reflex-reflected light would be returned to the source without reaching the eye of the driver. Actually, however, the inherent aberrations in spherical lenses of this thickness and curvature are more than adequate to produce the necessary dispersion for useful reflex reflection. As mentioned previously, Equation 3 is only an approximation to the formula for refraction at a spherical surface. It holds only for rays near the axis. A more exact relation (6) is

$$\frac{n_1}{p}+\frac{n_2}{q}=\frac{n_2-n_1}{R}+\frac{h^2}{2}\frac{(n_2-n_1)}{n_2^2}\left[\frac{n_1^2}{R}-\frac{n_1(n_2+n_1)}{p}\right]\left(\frac{1}{R}-\frac{1}{p}\right)^2 \quad (4)$$

where the notation is the same as in Equation 3, and h (Fig. 3) is the distance of the parallel ray from the axis. Thus, to bring a ray which is incident at $h = R$ to a focus at the rear surface, n_2 is found from Equation 4 to be 1.75, and for one at $h = \frac{R}{2}$ the value of the refractive index to accomplish the same purpose is 1.96. When $h = 0$, the second term on the right of Equation 4 vanishes, and the relation reduces to Equation 3. From the foregoing it is evident that all parallel rays incident on the sphere cannot be brought to a focus at a single point. By taking the vertical coordinate of the centroid of the circular arc OA'K, which is equal to $\frac{2R}{\pi}$, as an average or resultant value of h, the corresponding average value of refractive index for optimum reflection is found to be about 1.90. Since external reflection increases rapidly as h approaches R, most of the light incident at the extremes of the diameter does not enter the sphere and the optimum index will be somewhat greater than 1.90.

Interrelation of Beads and Paint in Reflex Reflection

As shown earlier, the amount of light reflected from an interface of two transparent media is a function of their refractive indices. Referring again to Figure 3, assume a traffic paint has replaced the transparent resin which holds the bead. Since the finely divided pigment particles are enveloped by the vehicle, they do not come in direct contact with the bead, but are separated from it by a film of vehicle at least one molecule thick. Hence, when a beam of light strikes this interface, the portion reflected is determined by the refractive indices of glass and vehicle in accordance with Equation 1. The remainder is transmitted through the vehicle, with some loss by absorption, to the multitude of tiny pigment particles where some of it is absorbed, some transmitted and the balance diffusely reflected. The amount of light reflected from the pigment particles, again, is a function of their refractive index in relation to that of the vehicle, and the amount transmitted through them depends on their absorption characteristics.

From the above considerations, it is quite evident that beads and paint are intimately related in the reflective process. With a given bead, the amount of reflected light can be influenced considerably by the characteristics of vehicle and pigments in the paint in which it is placed. The converse is also true.

Compatibility of Beads and Paint. Another phase of the bead-paint relationship is mutual compatibility with respect to interfacial tensions, or wetting of the bead by the paint. It is important that the paint wet the bead sufficiently to form a bond that will resist dislodgement of the beads. Too great an attraction will cause the beads to "drown" too easily; too little will result in poor bond. The photographs of Figure 4 illustrate this point. In the first photograph, taken at an age of less than a week, the wetting is almost excessive. The paint has crawled up the sides of the spheres to an extent which limits initial reflex reflection at long range. The second photograph shows a small area of a reflectorized stripe at the age of 7½ months. Although the paint itself is still in good condition, the beads have almost entirely disappeared. The bead sockets and the few beads remaining in the paint seem to indicate a negative capillarity, with consequent poor retention. This is the other extreme.

The two aspects of interrelationship of beads and paint just discussed present a strong argument in favor of treating the reflectorized stripe as an entity rather than as a combination of independent materials. Any evaluation of beads or paint separately which does not take the above

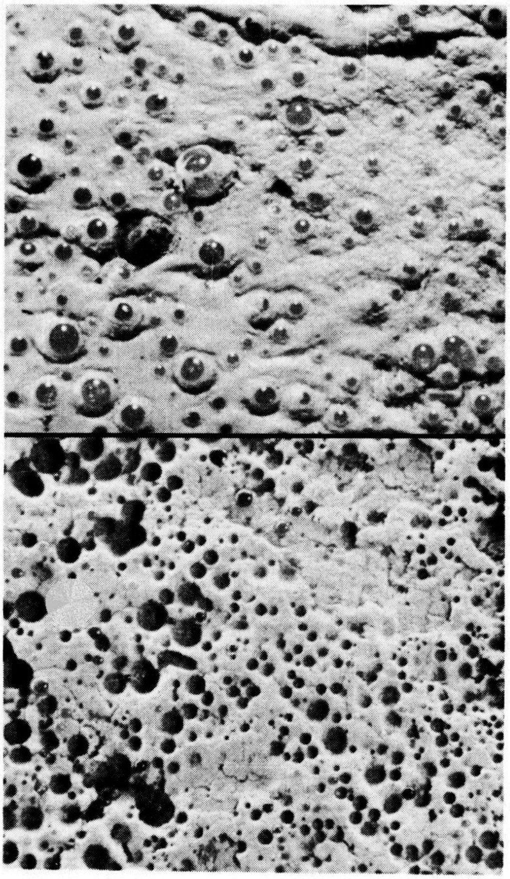

Figure 4. Wetting of beads by paint: Top, good wetting; bottom, poor wetting.

mutual effects into account is necessarily incomplete and may be misleading.

Glass Bead Gradations

Most users have assumed thus far that the glass beads should be uniformly graded from coarse to fine, the theory being that the smaller beads would be successively exposed for effective reflection as the paint wore down. Although the theory is logical and plausible, there are no published data to show exactly the relation between gradation and continuing optimum reflectivity. There are certain well-established facts, however, based on experience and simple geometry, which definitely indicate the desirability of using beads of smaller maximum size.

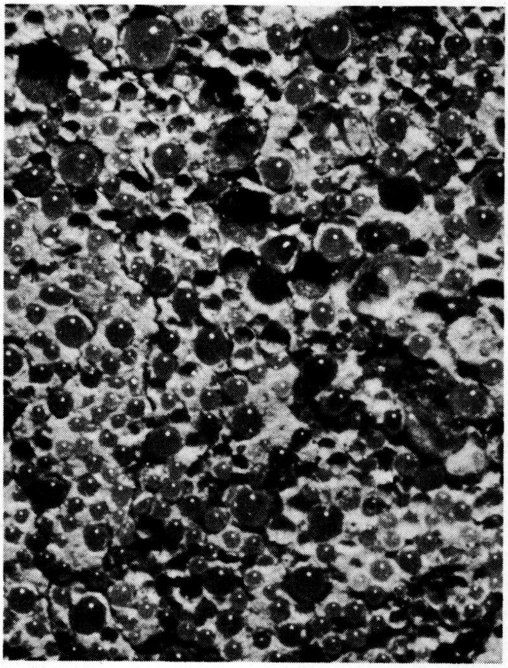

Figure 5. Effect of size on bead retention.

Other things equal, the projected reflecting area per pound of beads is greatly increased as the average diameter of the beads is decreased. This is true because the volume and cross-sectional area are proportional to the cube and square of the radius respectively. If the radius is halved, it takes eight times as many beads for equivalent volume. The total cross-sectional area of these eight beads is twice that of the larger bead. Similarly, if the average radius is reduced to one third, the surface area is tripled for the same weight of beads. Since beads are sold by weight, which is proportional to volume, it is obvious that a dollar will buy more reflection in the smaller beads.

Fortunately, the smaller beads not only are more economical but also have several other distinct advantages over the larger ones. Pound for pound, small beads, because of their greater surface to mass ratio, maintain useful reflection longer, thus adding materially to the life of the stripe. Not only is this true theoretically, but it has also been amply substantiated by experience. Figure 5 is a photograph of a month-old stripe containing premixed beads overlaid with larger ones. For every large bead lost, represented by the empty sockets in the picture, four smaller ones of half the diameter would have to be dislodged to bring about an equivalent loss in reflection. The figure shows that the smaller sizes are not lost in anywhere near that proportion. Furthermore, better distribution, with accompanying uniformity of light return, is possible with the smaller beads. Other advantages of the smaller beads are that they: (1) can be premixed with the paint; (2) reduce drying time; (3) reduce the effect of relative humidity on drying time; and (4) lower the loss by rebound when bead-paint mixtures are sprayed on the pavement. One more significant fact on bead size remains to be mentioned, however. Apparently owing to the method of manufacture, the percentage of irregular and fragmentary particles is noticeably lower in beads of smaller size.

Effect of Imperfections on Reflection

The most common imperfections occurring in glass beads, and the ones generally taken into account in evaluating the beads, are: (1) irregularly shaped particles and (2) gas inclusions. The presence of extraneous material and other imperfections of relatively rare occurrence need not be considered here.

Particle Shape. The test for roundness has received a great deal of attention, and apparatus for measuring this property has reached an advanced stage of development. As far as is known now, however, no one has determined the significance of this property quantitatively. Fragments, of course, are practically useless as far as reflex reflection is concerned, and a large percentage of them cuts down efficiency. Nonspherical shapes, such as spheroids, ellipsoids, etc., are probably not too detrimental. As mentioned previously, when these particles are oriented with their long axis is the direction of light incidence, they give a more efficient light return than round ones for the lower index glasses. If the nonround particles are randomly oriented in the paint, the number of particles with their long axis in line with the direction of light should compensate approximately for those not so oriented in the efficiency of light return. The influence of particle shape can be determined experimentally, and such tests should be performed soon.

Gas Inclusions. Gas inclusions are a serious defect in glass beads because they interfere with reflex reflection and weaken the bead structurally. Experiments in the Michigan State Highway Research Laboratory show that losses in specific intensity of 20 to 40 percent can result from excessive gas inclusions in commercially produced beads. The tests were performed by measuring the brightness of two sets of panels coated respectively with beads which had been separated at a predetermined specific gravity into two fractions by a sink-float method. Work is now under way to find a satisfactory method of measuring gas content. The problem is complicated by the fact that optical characteristics are influenced strongly by the size and number of the bubbles, as well as the total volume of gas present.

Tests such as these, and others currently being developed for clarity of glass beads, are probably helpful mostly from the standpoint of providing a general background of knowledge for development of the product and interpretation of test results. In the final analysis, photometric tests give a practical and realistic picture of prospective performance unobtainable in any other way. In these tests, the effects of refractive index, roundness, gas inclusions, and imperfections of all kinds are lumped into one resultant figure representing optical performance. For specification purposes, measurement of the contributing properties is probably unnecessary.

PRINCIPLES OF APPLICATION

Application of transparent spheres for the purpose of reflectorizing pavement marking stripes can be said to involve two techniques. In the first of these, the beads are dropped directly on the wet paint; in the second, beads are mixed in the paint and the combination sprayed through the gun. In some instances, both methods are employed simultaneously (overlay).

Bead dispensers designed for use in dropping beads on the fresh paint are positioned low on the paint truck as close as possible to the stripe, in order to minimize effects of air movement and mechanical vibration. They are located approximately 1 ft. behind the spray guns,

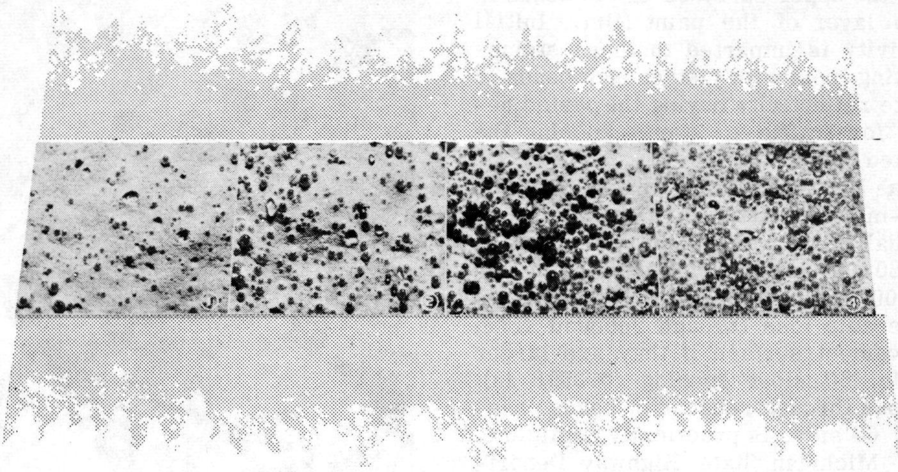

Figure 6. Nonuniform bead distribution across a traffic stripe.

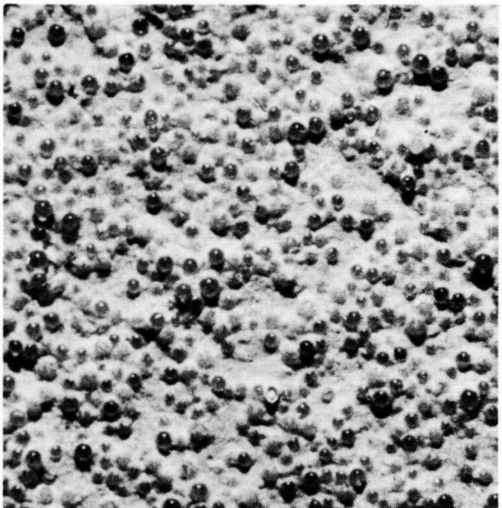

Figure 7. Ideal bead application on laboratory prepared panel.

so that the paint has had contact with the pavement a little more than a tenth of a second before it is covered with beads.

Although beads applied by dropping impart the highest initial reflectivity,

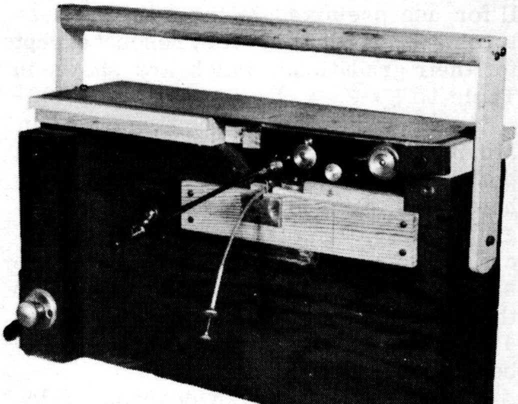

Figure 8. Stereophotomacrographic camera.

the technique is open to several objections. It is very difficult to assure uniform dispersal of beads across the width of the paint stripe (see Fig. 6). A large percentage of beads is lost as a result of winds, inaccurate orientation of the dispenser, or other mechanical variables not necessarily under the control of the operator. Also, the beads may tend to pick up moisture from the air and clump together.

For these and other reasons, interest has developed in spraying paint containing premixed beads, depending on traffic to expose the upper surfaces of the beads in the top layer of the paint film. Initial reflectivity is imparted to these stripes by coating them with just enough beads to promote reflectivity during the period required for traffic to start exposing the premixed beads.

It has been found that beads mixed in traffic-marking paint and subjected to the usual pressures of spray application (40 to 80 psi. or higher on the paint, and 60 to 100 psi. for atomization) will undergo considerable loss through rebound from the pavement surface if they are larger than No. 60 sieve opening (0.0098 in). Bead loss through rebound of beads passing No. 60 sieve is practically negligible.

The Michigan State Highway Department, until recently, has recognized two types of beads for use in reflectorizing pavement marking stripes. These are Type I for application on the wet paint film through a bead dispenser, and Type II for use premixed in the paint. These types are identical in every respect except for their gradations, which are shown in Table 1.

Actually, it has been found expedient in Michigan to use Type II beads exclusively, both in and on the paint, and specifications have been revised accordingly. Photographs have been taken at large magnifications to show that the majority of the small beads do not sink completely into the paint and become covered, provided 4 lb. of beads per gallon have already been mixed in the paint.

Figure 7 illustrates an ideal application of this kind. Figure 8 shows the apparatus used in making these photographs. Further, laboratory studies have shown that beaded panels prepared with white paint containing 4 lb. per gal. of Type II beads and supporting 2 lb. per gal. of the same type will reflect fully as much of the incident light as is reflected by corresponding panels with 4 lb. per gallon of Type II beads in the paint and 2 lb. per gallon of Type I beads on the paint. The latter application is shown in Figure 9. From an economical standpoint, it would therefore appear advantageous to use the Type II beads exclusively.

TABLE 1

GLASS BEAD GRADATIONS

Sieve No.	Sieve Opening *inches*	Amount Passing Type I %	Amount Passing Type II %
30	0.0232	100	
40	0.0165	30 - 70	
50	0.0117	10 - 35	100
60	0.0098		95 - 100
100	0.0059	0 - 5	45 - 75
200	0.0029	0	0 - 2

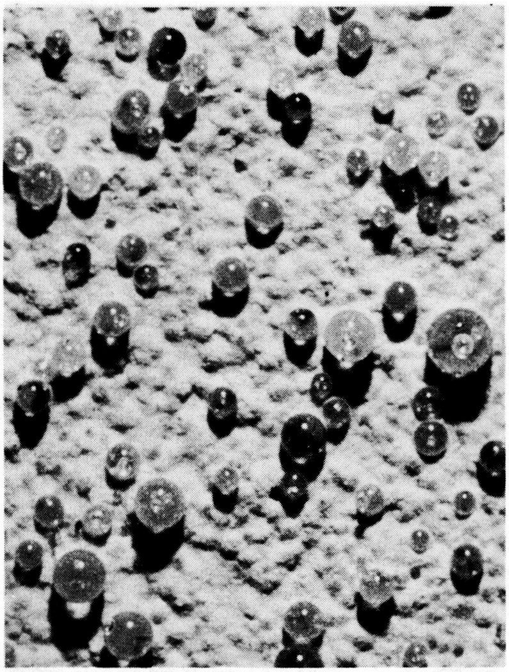

Figure 9. Application of large beads by overlay on laboratory panel.

In addition to the questions of optimum size and other operational factors, the depth of embedment of the glass bead in the paint film and rate of application of the beads are also important in relation to the efficiency of light return.

Effect of Depth of Embedment on Reflex Reflection

Figure 10 (a) shows a perspective sketch of a glass bead in a pavement stripe receiving and reflecting light from the headlamps of a car somewhere to the left, and Figure 10 (b) a vertical section through the center of the same bead in the line of light propagation between source and re-

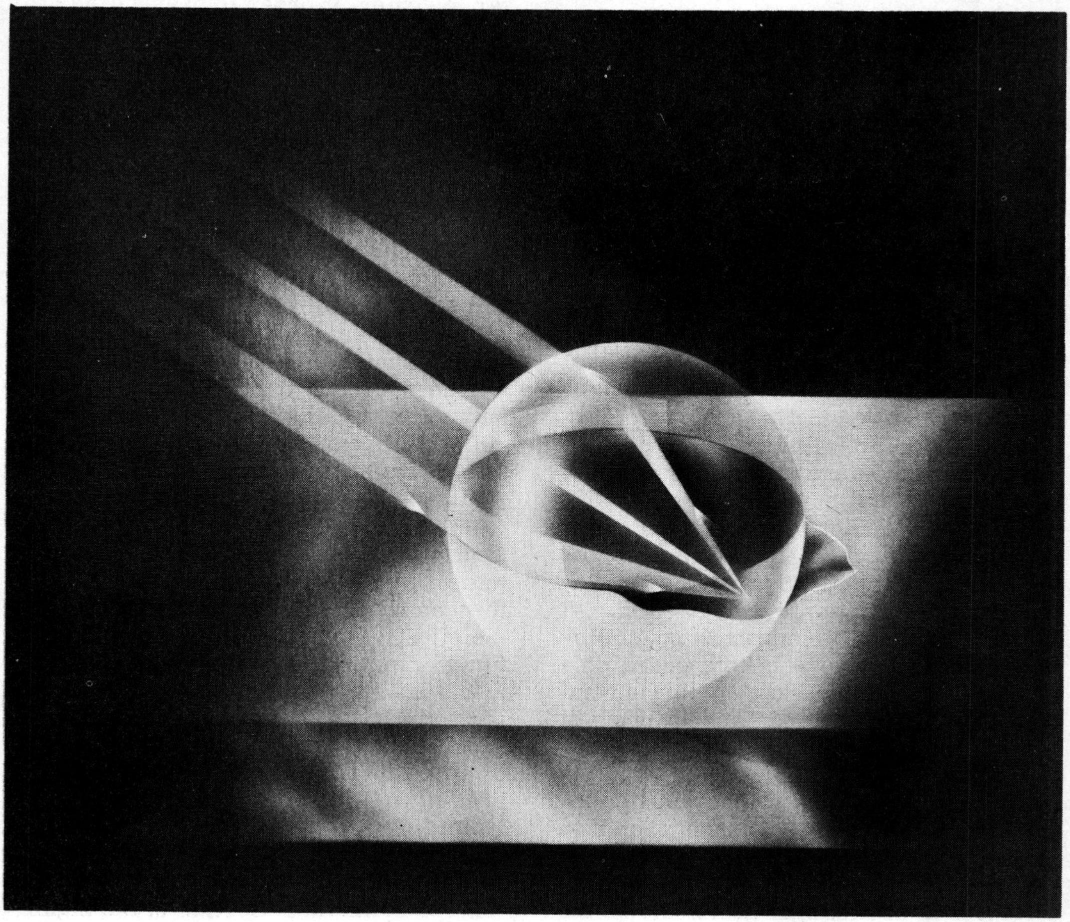

Figure 10 (a). Reflex reflection by a glass bead in traffic paint: Perspective sketch of bead in paint.

flector. The bead is shown embedded to a depth of 50 percent of its diameter and is presumed to have a refractive index of 2.0, which brings paraxial rays to a focus at the rear surface.

An incident ray along <u>AA'</u>, the lowest level at which light may enter, will leave the bead along <u>B'B</u>, approximately parallel to <u>AA'</u>. Refraction occurs at the points <u>A'</u> and <u>B'</u>, and internal reflection at the focal point <u>P</u>. Similarly, a ray incident along <u>BB'</u> will emerge along <u>A'A</u>.

A parallel ray <u>NN'</u>, normal to the front surface of the bead, will enter without change in direction, pass through the center <u>O</u>, and be reflected at point <u>P</u> to retrace its path in the opposite direction. Since the internal path of the rays is symmetrical with respect to the axis of the beam, the chord <u>A'B'</u> at right angles to the axis represents the limits of aperture in a vertical plane, hereinafter referred to as vertical aperture, through which light may be received for reflex reflection. It is evident from the figure that any parallel ray <u>XX'</u> entering the sphere above <u>B'</u> will be doubly reflected within the sphere below the paint line and sent off in an ineffective direction.

The effective vertical aperture <u>A'B'</u> is 2r $\sin\alpha$, where <u>r</u> is the radius of the sphere and α the angle the incident beam makes with the horizontal. The angle α changes continuously with distance between bead and source, becoming larger as the separation distance decreases, so that the aperture widens progressively as the bead is approached. It is obvious, therefore, that the efficiency of light return becomes very small under the

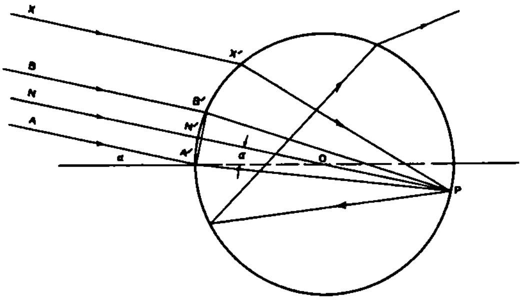

Figure 10 (b) Optical diagram for a median vertical section in the line of light propagation.

conditions of illumination ordinarily encountered in driving, when the beads are embedded to a depth of half their diameters. Where beads are embedded less than 50 percent, the vertical aperture for reflex reflection is correspondingly greater, but this advantage is offset to some extent by the likelihood of poor bead retention. At the small angles of illumination usually involved, beads have to be embedded only slightly over 50 percent (up to the point N' in the figure, an increase in depth of approximately r sin α) to lose the property of reflex reflection altogether. This fact should be of significance when interpreting the efficiency of beads premixed in paint. Stripes of this kind may be expected to show up clearly at short viewing distances at earlier ages than would be the case at greater viewing distances.

Rate of Application

On the basis of an assumed headlamp-to-pavement distance of 32 in., a ray of light from a headlamp will impinge upon a glass bead 500 ft. in front of a vehicle at an angle of 0 deg. 18.5 min. with the horizontal. At 50 ft. this angle is 3 deg. 3.4 min.

Michigan State Highway Department specifications for Type I beads (for application on the paint) require that a maximum of 70 percent pass the No. 40 sieve. This means that at least 30 percent of the beads will be 0.0165 in. in diameter, or larger. When illuminated from a distance of 500 ft., two such beads of the same size embedded one behind the other to half their depth in a traffic stripe would have to be spaced at least 1.55 in. apart, center to center, in order to prevent the near bead from partially obscuring the far bead. This spacing is less for smaller beads and for shorter distances, dropping to 0.06 in. for a Type II bead (premix type) passing the No. 100 sieve and illuminated at 50 ft.

Analysis of Figure 11 discloses that if two beads of the same diameter are lined up at the critical separation distance (x + r), the zone of the incident beam which can be completely reflex-reflected from the second bead will just clear the first bead. When this distance is shortened by an amount equal to the radius of the sphere, only a few thousandths of an inch, reflex reflection from the median vertical aperture of the second bead is entirely cut off. As the beads are placed nearer and nearer together, the zone of possible reflex reflection in the second bead is obscured more and more, first at a rapid rate and then more slowly, so that the eclipse of the effective zone is very nearly complete for all practical purposes when the beads are at about half the original critical distance from each other. Some critical separation distances under various conditions of illumination distance and bead size are given in Table 2. Probably some laboratory research could profitably be done in pursuing this subject a little further to determine actual rates of application for optimum reflection in the significant range of viewing distances. It is quite possible that some bead economy could be achieved as a result of such tests. Long-range visibility is probably the controlling factor, since the wider aperture of reflex reflection and greater intensity of illumination at the shorter distances compensate to some extent for sparser distribution of the beads.

TABLE 2

CRITICAL SEPARATION DISTANCE BETWEEN BEADS ARRANGED IN LINE OF SIGHT

Diameter of Beads *in.*	Corresponding Sieve *No.*	Critical Separation Distance At 500 ft. *in.*	At 50 ft. *in.*
0 0165	40	1.55	0.16
0.0117	50	1.10	0.12
0.0059	100	0.55	0.06

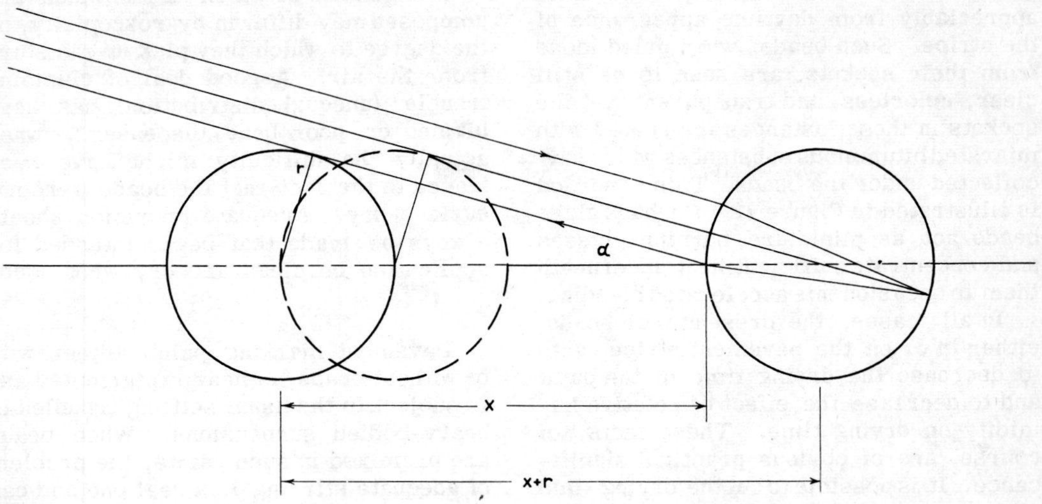

Figure 11. Bead interference in reflex reflection.

Miscellaneous Practical Considerations

It is generally conceded that the use of glass beads for purposes of reflectorization has the further advantage of materially lengthening stripe life. A rational explanation of this would be to consider the beads as bearing the brunt of the traffic loads, thus protecting the paint film which remains between the beads from such abrasion, so long as the beads remain in place. Beads which break loose, however, would have exactly the reverse effect, contributing by grinding or shearing action to the breakdown of the stripe, and the situation would be worse than one in which no beads were present. It becomes a matter of concern, therefore, to provide adequate cementing of beads in place, both from the reflectorization and abrasion standpoints. Cementing of beads in place is a function not only of degree of penetration (anchorage, or tooth), but also of the wetting properties of the paint for the glass surfaces of the beads. As mentioned earlier, paint-bead combinations exhibiting adverse wetting of the beads by the paint cannot be expected to exhibit satisfactory bead retention.

It has been shown rather conclusively that beaded-reflectorized pavement-marking stripes give longer service life when applied on bituminous pavements than when applied on concrete, due, probably to the resilience of the former. The added stripe life is not without its drawbacks, however, one of which is bleeding of the bituminous material through the paint film. Such bleeding appears to be accentuated by the presence of beads. It is as though the beads constitute individual foci for the development of bleeding, for wherever bleeding occurs, it appears to occur first under the beads. In fact, the beads frequently become "discolored", turning

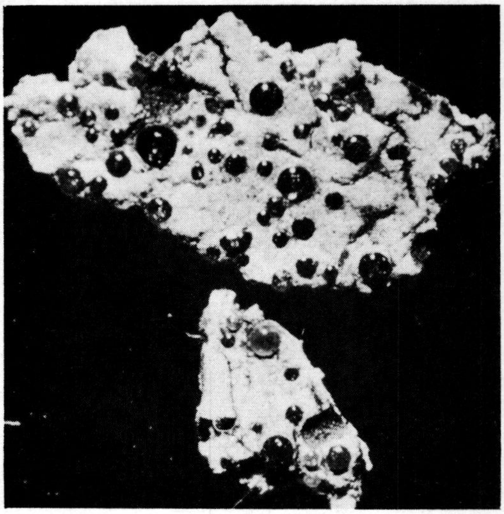

Figure 12. Bleeding of bituminous material under glass beads. Note black color of large beads, and dark-colored film at bottom of empty bead sockets.

quite dark, sometimes black, and detract appreciably from daytime appearance of the stripe. Such beads, when pried loose from their sockets, are seen to be still clear, colorless, and transparent, yet the sockets in these instances are coated with migrated bituminous substances which have collected under the beads. This condition is illustrated in Figure 12. Perhaps glass beads act as miniature burning glasses and concentrate sufficient heat underneath them to occasion this accelerated bleeding.

In all cases, the presence of beads, either in or on the pavement stripe, acts to decrease the drying time of the paint and to decrease the effect of relative humidity on drying time. These facts, of course, are of obvious practical significance. It is possible to cut the drying time of a pavement-marking paint in half by the use of beads alone. Some data on this effect are shown in the graphs of Figure 13.

After a generation of experience with pavement-marking stripes, the critical need still persists for an effective seal to prevent bituminous materials from bleeding through superimposed paint films. The use of glass beads has made this need more acute than ever.

The glasses of which various beads are composed may differ in hygroscopicity, or the degree to which they pick up moisture from the air. A good deal of clumping trouble (unequal distribution) has been blamed on poor bead dispensers, when actually the difficulty might have been traced to the fact that the beads were not surface-dry. Adequate provision should always be made that beads intended for application be clean and dry when used.

Pavement-marking paint, either with or without beads, is heavily pigmented and is subject to the usual settling troubles of heavy-bodied suspensions. When beads are premixed in such paints, the problem of adequate stirring is a real one and can become a source of delays in the striping program. If these paints are allowed to settle undisturbed for weeks at a time, it may become practically impossible to restore them to their original uniform consistency by conventional means. If, however, drums are rolled or up-ended at frequent intervals, such troubles have a way of disappearing, and stirring usually proceeds without complication.

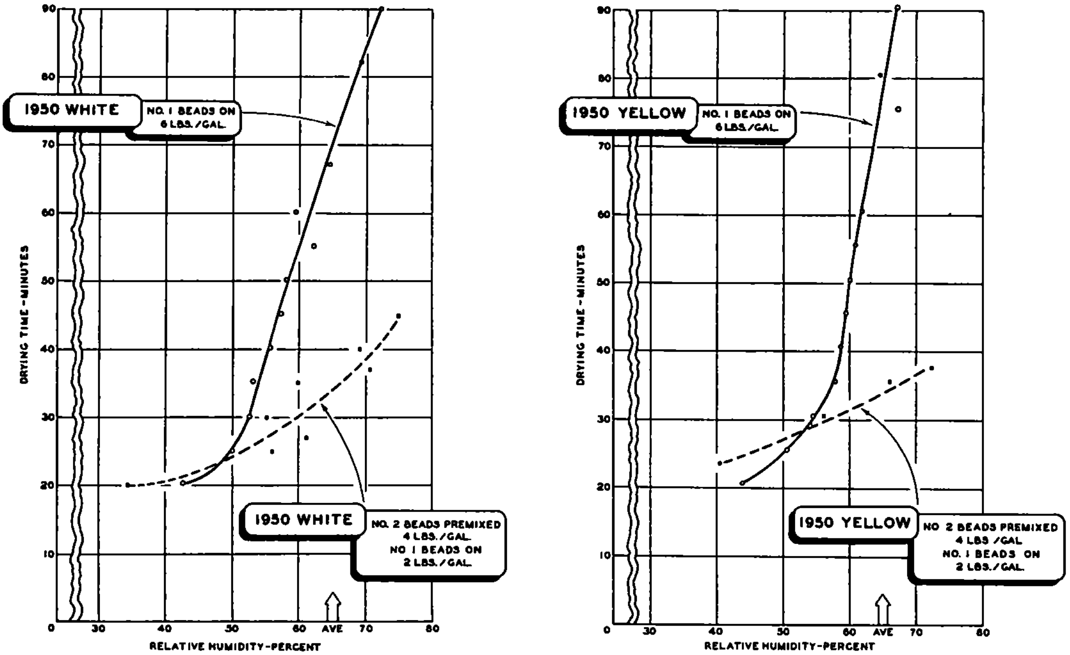

Figure 13. Effect of premixed glass beads on relationship between drying time and relative humidity.

RECAPITULATION

In retrospect, the more significant facts and ideas of the foregoing discussion to be remembered in relation to the use and performance of glass beads in traffic paint are given below. Some of these are stated specifically for the first time in the summary but may be inferred directly from previous statements in the text.

First, all of the properties of glass which significantly affect bead reflectorization are directly related to composition. There is considerable latitude in the selection of desired attributes by proper compounding and processing. The most important factor limiting the range of composition is devitrification, or crystalization, on cooling. The high-silica glasses are, in general, stronger and more durable than the others, but do not have a sufficiently high refractive index for maximum efficiency of reflectorization. It should be possible to produce commercially a glass of satisfactory durability and considerably higher index without undue increase in cost. As a matter of fact, several such products have already appeared on the market.

Second, chemical durability and serviceability are not synonymous terms in defining the qualities of glass beads. Many glasses of relatively poor durability give excellent service. Loss of weight by solution or dulling of surface luster are not infallible criteria of optical performance. Formation of film on some glasses gives noticeable improvement in transmittance and reduction of external reflection, a fact made use of in the present practice of lens coating. Therefore, laboratory results based on loss of luster or weight in extraction or weathering tests may wrongly condemn a perfectly satisfactory glass. Moreover, bead durability should be tied in with the life expectancy of the binder or stripe as a whole. At best, the life of a pavement stripe is relaitvely short. Chemical durability in a bead, then, is not as significant as serviceability, and optical tests are the most reliable method of evaluating serviceability.

Third, color of the beads is important mostly from the standpoint of possible objectionable modification of the color of the painted stripe. However, a noticeable color of the beads in bulk may be totally imperceptible when they are applied to the paint, and a color specification which is unnecessarily restrictive may hamper the development of glasses superior in other respects.

Fourth, the amount and distribution of reflected light is largely determined by the refractive index of the glass composing the beads and its relation to the index of vehicle and pigments in the paint. The pattern of the returned light (divergance-angle characteristis) depends on the index of the glass. Maximum efficiency in the conservation of reflected light is achieved when this index is about 1.90, which brings parallel rays to an approximate focus at the rear surface of the bead. The amount of light specularly reflected from the boundary between paint and bead is a function of the difference in their refractive indices. More particularly, it depends on the difference in index of bead and paint vehicle, since the vehicle completely envelopes the pigment particles and light reaching the latter is diffusely reflected.

Fifth, the depth and firmness of embedment of beads in paint depends on compatibility with respect to the ability of the paint to wet the bead surfaces. Thus, paint and beads, are intimately related in service performance. and the reflectorized stripe should be evaluated as an entity rather than as a combination of independent materials.

Sixth, optimum gradations of beads for maximum usefulness have not been completely determined experimentally. However, experience and the geometry of surface to mass ratios definitely indicate the desirability of using beads of smaller maximum size. The principal advantages of using smaller beads are: (1) pound for pound, they present more reflective surface and are retained better; (2) they can be premixed with the paint; (3) they reduce both drying time of the paint and the effect of relative humidity on drying time; (4) they contain a smaller percentage of imperfect particles; and (5)they suffer smaller rebound losses in spray application.

Seventh, the two kinds of imperfections receiving most attention at present are nonroundness and gas inclusions. A large percentage of fragments is detrimental, but it is doubtful whether other nonrounds, such as spheroids, ellipsoids, etc., significantly affect optical performance. Gas inclusions are definitely harmful, because they interfere with reflex reflection and weaken the bead structurally.

Eighth, depth of embedment is an important factor in reflex reflection of pavement marking beads, because at the very small angles of incidence involved, the effective reflex-reflecting zone of the bead is extremely narrow. When the bead is embedded to a depth of half its diameter, the height of the vertical aperture through which light may be received for reflex reflection is approximately the product of the diameter and the sine of the incidence angle, or only a few thousandths of the bead radius. With only a slight increase in depth of embedment (half of the above vertical aperture), reflex reflection is lost altogether. Decreasing the depth of embedment extends the effective zone vertically, but this advantage is off-set to some extent by the likelihood of poor bead retention.

Ninth, from an analysis of bead interference in relation to critical separation distances, it appears that some bead economy may be achieved by further experimental study of the problem of application rates.

Finally, experience so far indicates that the use of beads lengthens the life of the painted stripe, and that beaded stripes last longer on bituminous pavements than on concrete.

ACKNOWLEDGMENT

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Thermoplastic Striping Compounds

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Texas Engineering Experiment Station

SYNOPSIS

IN 1949, the Texas Engineering Experiment Station inaugurated a research project to develop a compound for striping pavements which would produce stripes with longer service life than those now in general use.

The Road Research Laboratory in England during World War II developed a satisfactory striping compound of a mixture of rosin, mineral oil (a plasticizer for the rosin), pigment, filler, and sand. The mixture is heated to 135 C and placed, while hot, to a thickness of about 1/8 in. Stripes laid in Texas in accordance with the British formulation proved to be too soft, were subject to rather severe discoloration by the adhesion of road dust and tire film to the surface of the stripe, and showed poor adhesion to portland-cement concrete. But the results were sufficiently encouraging to warrant a decision to study modification of the British formulation.

The striping compound produced by adding alkyd resin to the rosin-plasticizer mixture has shown excellent characteristics. The stripe does show discoloration under traffic, and studies are currently under way in an attempt to improve this characteristic.

The rosin striping compound has been rated for service life by laying transverse stripes on asphaltic-concrete and portland-cement-concrete pavements. Glass beads have been incorporated in parts of the stripes.

Four of the rosin-base stripes have been in service for 12 to 14 months. Eight rosin-alkyd resin stripes have been in service for 6 to 8 months; and a large number of others have been in service for lesser periods of time.

Results to date indicate that the rosin-base stripes will have a service life of two to three times that of the comparative paint stripes. Ingredients in the rosin-base stripe are such that the cost of the materials compares favorably with the cost of paint.

● IN FEBRUARY 1949, the Texas Engineering Experiment Station (a part of the Texas A and M College System) initiated a research project to develop a semipermanent center stripe for highway use. Study of the striping problem in Texas and discussion with engineers of the Texas Highway Department indicated that a highway stripe with a service life of 3 to 6 years which could be placed at low cost was the desirable goal. Investigation of the literature and letter contacts established the fact that many individuals and concerns were working with paint stripes in order to improve durability. It was decided that the investigation would be directed primarily toward materials other than paint for striping.

The first possibility considered for producing a semipermanent stripe was the builtup or surface-dressed type, produced by laying a binder layer of asphalt cement and covering it with a layer of uniformly graded aggregate.

When this is constructed with limestone, a rather good white stripe is produced. This type of stripe has been used for a number of years by several highway departments and has proven to have a very long service life. The method of striping has two disadvantages: the night visibility of the stripes is quite poor and no naturally yellow stone is available for producing stripes in the standard yellow color. Therefore, it was decided to attempt to color limestone yellow in order to satisfy the second objection to the use of the builtup stripe. None of the attempts to do this was successful. The method which showed the most promising results was that of forming lead chromate, an insoluble yellow pigment, in the pores of the limestone by a chemical reaction. Good color was produced, but the penetra-

Figure 1. Laying rosin striping compound.

tion into the stone was not sufficient to give practical service life.

The second possibility investigated was the use of hot-melt plastic compounds which would harden upon cooling and thereby produce a permanent line on the pavement surface. The British had developed such a stripe by combining wood rosin, plasticizing oil, pigments, fillers, and sand. This mixture was heated to 135 C, thoroughly stirred, and laid by screeding it on the pavement with a small screed box having an adjustable gate. The thickness of the material as laid was about 1/8 in. The British reports indicated considerable success with this type of stripe. Their experience showed a service life of approximately two years and an initial cost of about twice that for paint stripes.

Since this was the only successful hot-melt plastic stripe which the study of the literature uncovered, the decision was made to begin the investigation by studying the British stripe.

INTERIM RECOMMENDATIONS FOR THE COMPOSITION OF PLASTIC WHITE LINE COMPOUNDS[1]

Gum rosin	15 percent by weight
Mineral oil (viscosity 1/2 to 2 poises at 25 C)	5 percent by weight
Titanium dioxide	10 to 5 percent by weight
Extender (whiting, etc.)	10 to 15 percent by weight
Aggregate (sand)	60 percent by weight

On July 28, 1950, a stripe was laid in accordance with this specification. It was found to be too soft for the hot Texas summer, since the traffic rolled it out, and the adhesion of road dust and tire film to the soft material soon changed the color to very nearly that of the pavement.

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TABLE 1

COMPOSITION OF ROSIN-OIL SERVICE TEST STRIPES INGREDIENTS

(Percent by Weight)

Stripe Number	Rosin	Mineral Oil	Titanium (TiCa)	Whiting	Chrome Yellow (Medium)	Calcium Chromate	Concrete Sand
B-2	23.0	1.0	15	5			56
B-3	22.0	2.0	15	5			56
B-4	23.5	0.5	5	5	10		56
B-5	23.0	1.0	15	5			56
				SILICA			(LIMESTONE)
R-1	22.5	1.5	5	5	5	5	56
R-2	22.0	2.0	5	5	5	5	56
R-3	21.5	2.5	5	5	5	5	56

MODIFICATIONS OF BRITISH COMPOUNDS

In order to produce a harder stripe, the amount of plasticizing oil in the compound was reduced. A number of oil-rosin combinations were tried in the laboratory with the hardness of each compound being measured with the standard penetration apparatus for asphalt and the brittleness being measured by means of a cold-bend test. The proper oil content was selected as 2 to 8 percent of the weight of the rosin-oil mixture, or an oil content of 0.5 to 2 percent of the weight of the total mixture. Laboratory tests in which the pigment, filler, and sand were varied indicated agreement with the British interim specifications with regard to proper proportions of pigment filler and sand. Yellow color was produced quite successfully by the use of chrome yellow alone or with calcium chromate as pigment.

Four test stripes using the composition selected as having desired hardness and brittleness characteristics on the basis of the laboratory work were laid in August and October of 1950. These test stripes were laid transversely across half of the roadway in order to get maximum traffic effect. The stripes were laid at the same

TABLE 2

APPLICATION DATE ON ROSIN-OIL TEST STRIPES

Stripe Number	Color	APPLICATION Date	Temperature F.	Thickness in.	Time Protected From Traffic	Condition When Opened to Traffic
	Asphalt Surface Area 1				min.	
B-2	(W)	8/15/50	98	.125	45	Hard-High Gloss
B-3	(W)	8/15/50	98	.125	45	Hard-Slight Tack
B-4	(Y)	10/13/50	87	.180	10	Hard-High Gloss
P-4	(W)	7/25/50	96	.020- .030	75	Hard-Dry to Touch
P-5		7/25/50	96	.020- .030	45	Dry-Soft-Slight Tack
	Concrete Surface Area 2					
B-5	(W)	10/17/50	90	.125	10	Hard-High Gloss
P-8	(Y)	8/10/50	98	.020- .030	45	Soft-Slight Tack
R-1	(Y)	6/27/51	94	.180	30	Hard-Dry
R-2	(Y)	6/26/51	95	.180	10	Hard-Dry
R-3	(Y)	6/26/51	95	.180	10	Hard-Dry
*						

P-4 Chlorinated rubber traffic paint
P-5 Pliolite traffic paint
P-8 Pliolite traffic paint (Texas Highway Department Specification YP-3)
* Control paint stripes X-1, X-2, X-3, X-4 Table 9.
Concrete surface area 4

(Y) Yellow
(W) White

TABLE 3

MONTHLY RATING OF ROSIN-OIL TEST STRIPES

Location: Area 1 Pavement Surface: Asphalt

		August (1950)	September	October	November	December	January (1951)	February	March	April	May	June	July	August	September	October	October 15th
B-2 (W)	Plain		0 N	0 M	0 M	0 S	0* MS	0 ES	0 MS	0 MS	0 S	0 ES	0 ES	0 ES	0 ES	0 MS	0 ES
	Beaded		0 N	0 M	0 M	0 S	0* MS	0 ES	0 MS	0 MS	0 S	0 ES	0 ES	0 ES	0 ES	0 MS	0 ES
B-3 (W)	Plain		0 M	0 M	0 S	0 S	0 MS	0 ES	0 MS	0 MS	0 MS	0 ES	0 MS	0 S	0 ES	0 M	0 ES
	Beaded		0 M	0 M	0 S	0 S	0 MS	0 ES	0 MS	0 MS	0 MS	0 ES	0 MS	0 S	0 ES	0 M	0 ES
B-4 (Y)	Plain				0 N	0 N	0 M	0 M	0* M	0 M	0 MS	0 ES	0 MS	0 MS	5 S	10 MS	10 S
	Beaded				0 N	0 N	0 M	0 M	0* M	0 M	0 MS	0 ES	0 MS	0 MS	5 S	10 MS	10 S
P-4 (W)C	Plain	0 N	0 N	10 MS	10 MS	15 MS	25 MS	30 MS	35 MS	50 MS	50 MS	50* MS	60 MS	60 S	75 S	85 ES	85 ES
	Beaded	0 N	5 ES	10 ES	10 ES	40 ES	40 S	40 ES	60 ES	100							
P-5 (W)C	Plain	0 S	0 S	0 S	0 S	15 S	25 M	25 M	30 M	30 M	40 MS	40* MS	50 MS	50 S	60 S	65 ES	75 ES
	Beaded	10 S	10 S	10 S	10 S	20 S	20 M	20 ES	30 S	30 MS	30 S	40* ES	60 ES	70 ES	70 S	80 ES	85 ES
Location Area 2 Pavement Surface: Portland Cement Concrete																	
B-5 (W)	Plain				0 N	10 M	30 MS	100									
	Beaded				0 M	10 S	20 S	100									
P-8 (Y)C	Plain		0 S	10 MS	25 MS	25 S	60 MS	60 S	100								
	Beaded		0 ES	25 ES	50 ES	95 ES	95 ES	95 ES	100								
Location: Area 4 Pavement Surface. Concrete																	
R-1 (Y)	Plain												0 N	0 S	0 ES	0 MS	5 M
R-2 (Y)	Plain												0 N	0 S	0 ES	0 MS	10 M
R-3 (Y)	Plain												0 N	0 ES	0 ES	0 MS	0 M

* Noticeable cracking of film.

RATINGS: Film loss in percent.
Discoloration: (N) none; (M) moderate; (MS) moderately severe, (S) severe, (ES) extremely severe

(C) Control paint stripes
(Y) Yellow
(W) White

locations as two paint stripes which had been laid the latter part of July 1950. Glass reflectorizing beads were applied to a portion of each stripe. The stripes were rated the first of each month by visual examination on the basis of film loss and discoloration. The percentage of exposed pavement within the area originally covered by the stripe was estimated and recorded as film loss. The discoloration of

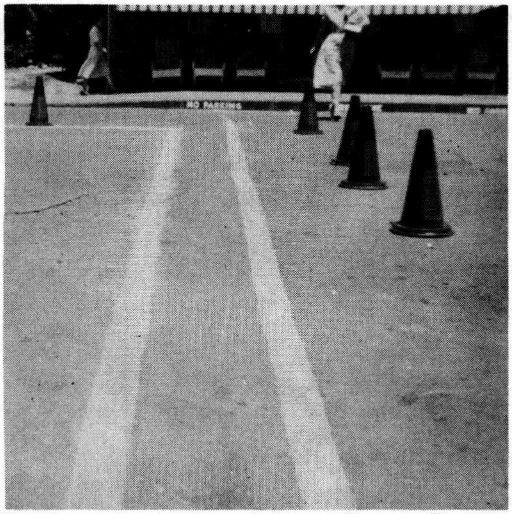

Figure 2. Stripes as laid in Bryan, Texas. Rosin stripe is at right and (Texas) standard YP-7 paint stripe is at left.

Figure 3. Stripes shown in Figure 2 after 5 months' service. Paint stripe was repainted twice.

TABLE 4

COMPOSITION OF ROSIN-ALKYD RESIN SERVICE TEST STRIPES

Ingredients (Percent by Weight)

Designation	Rosin	Alkyd Resin	Plasticizing Oil	Lead Drier (24%)*	Cobalt Drier (6%)*	Titanium (TiCa)	Whiting	Silica Filler	Chrome Yellow (Medium)	Calcium Chromate	Concrete Sand	Limestone Sand	Ottawa Sand	Crushed Limestone (-8 + 16)
BA-1	18.0	6.0				5		5	5	5	56			
BA-2	18.0	6.0				7	7	7			55			
BA-3	19.2	4.8				7	7	7			55			
BA-4	18.7	5.3				5		5	5	5	56			
BA-5	20.4	3.6				5		5	5	5		56		
BA-7	19.9	3.6	0.5			5		5	5	5			56	
BA-8	19.4	3.6	1.0			5		5	5	5		56		
BA-10	19.7	4.3				5		5	5	5		56		
BA-11	19.4	3.6	1.0			10		5				61		
BA-13	19.4	3.6	1.0			5		5	5	5				56
BA-14	19.4	3.6	1.0			10		10						56
BA-15	15	2.25				5		5	5	5			62.75	
BA-17	15.5	2.0	0.5		.34	5		5	2	8			62	
BA-18	19.4	3.6	1.0		1.0	5		5	5	5			56	
BA-19	15.5	2.0	1.0		0.1	5		5	5	5	56			

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*Percent metal based on alkyd resin.

TABLE 5

APPLICATION DATA ON ROSIN-ALKYD RESIN TEST STRIPES

Location: Area 4 Pavement Surface Portland cement concrete

Stripe No.	Color	Date	Temp. F.	Thickness in.	Time Protected from Traffic min.	Condition When Opened to Traffic
BA-5	(Y)	6/27/51	94	0.18	15	Hard-Dry
BA-7	(Y)	6/27/51	94	0.18	10	Hard-Dry
BA-10	(Y)	6/18/51	95	0.08	10	Hard-Dry
BA-13	(Y)	7/10/51	98	0.20	15	Hard-Dry
BA-14	(W)	7/10/51	98	0.15	10	Hard-Dry
X-1(C)	(Y)	6/19/51	96	0.035	255	Dry
X-2(C)	(Y)	6/19/51	96	0.013	255	Dry
X-3(C)	(Y)	6/19/51	96	0.021	240	Dry
X-4(C)	(Y)	6/19/51	96	0.014	240	Dry
BA-15	(Y)	7/17/51	101	0.10	10	
BA-17	(Y)	7/26/51	98	0.18	10	Slight Tack
BA-18	(Y)	7/24/51	100	0.18	10	No Tack
BA-19	(Y)	7/24/51	100	0.18	10	Hard No Tack

X-1 Texas Highway Department YP-7 (Alkyd) Beaded
X-2 Texas Highway Department YP-7 (Alkyd) Plain
X-3 Texas Highway Department YP-3 (Pliolite) Beaded
X-4 Texas Highway Department YP-3 (Pliolite) Plain

TABLE 6

APPLICATION DATA ON ROSIN-ALKYD RESIN TEST STRIPES

Location Area 1 and 3 Pavement Surface Area 1 Asphaltic Concrete
Area 3 Portland Cement Concrete

Stripe No.	Color	Date	Temp. F.	Thickness in.	Time Protected from Traffic min.	Condition When Opened to Traffic
P-16	(W)	3/22/51	82	0.020	60	Dry to Touch
P-17	(Y)	3/22/51	82	0.020	45	Dry to Touch
BA-1	(Y)	4/27/51	85	0.100	2	Hard Surface
BA-2	(W)	5/5/51	86	0.125	5	Soft
BA-3	(W)	5/5/51	86	0.125	5	Soft
BA-4	(Y)	5/10/51	83	0.125	5	Hard Surface
BA-8	(Y)	6/28/51	97	0.180	2	Hard Surface
BA-11	(W)	7/6/51	98	0.150	None	Slightly Soft

P-16 Commercial traffic paint, beaded
P-17 Commercial traffic paint, beaded

the paint stripe was rated by comparing the color of the test stripe with that of a sample of the striping material placed on a block of similar pavement material. Discoloration was rated from "none" to "extremely severe" (indicating a color very nearly that of the pavement surface). Colored photographic prints, which were taken at the time of each rating, clearly record the extent of film loss and discoloration. Black and white prints record film loss but do not indicate discoloration.

Tables 1, 2, and 3, show the composition, application data, and monthly rating of the rosin stripes and paint stripes used for comparison.

In several instances, the stripes show an improvement in the discoloration rating. This improvement is due to the washing action of rainfall and the chalking action of the pigments.

ROSIN-OIL STRIPES AND CONTROL PAINT STRIPES

Asphalt Surface - Area 1

B-2 (Rosin-Oil Stripe). This stripe gave an excellent appearance for a few months. The discoloration by the adhesion of road dust and tire film was at times so severe that the stripe had a color very nearly that of the pavement surface.

Cracks appeared in January and became severe during the ice storms in February, during which a low temperature of 5 F was recorded. Even though these cracks extended completely through the stripe to the pavement, no film loss has been observed, and after 14 months of service, the stripe is still effective.

B-3 (Rosin-Oil Stripe). This softer stripe has shown intensive discoloration from the beginning but washes clean during rains to a color very nearly that of the original color. After 14 months of service, it shows no signs of cracking or noticeable wear.

B-4 (Rosin-Oil Stripe). This yellow stripe contained a harder binder than stripe B-2. Cracking was more severe, and these cracks widened to the extent that a film loss of 10 percent had occurred after approximately 12 months. Discoloration has not been as severe as for stripe B-2.

TABLE 7

MONTHLY RATING OF ROSIN-ALKYD RESIN TEST STRIPES

Area 1 Asphaltic Concrete Pavement

		April (1951)	May	June	July	August	September	October	October 15
P-16C (W)	Beaded	0 MS	0* S	10 ES	10 ES	10 ES	10 ES	10 ES	10 ES
P-17C (Y)	Beaded	5 MS	10* S	10 ES	20 ES	20 ES	20 ES	30 ES	30 ES
BA-1 (Y)	Plain		0 M	0 MS	0 S	0 MS	0 S	0 MS	0 S
	Beaded		0 M	0 MS	0* MS	0 S	0 S	0 MS	0 S
BA-2 (W)	Plain			0 MS	0 S	0 S	0 S	0 S	0 S
	Beaded			0* S	0 ES	0 ES	0 ES	0 ES	0 ES
BA-3 (W)	Plain			0 M	0 S	0 MS	0 ES	0 ES	0 ES
	Beaded			0* MS	0 ES	0 S	0 ES	0 ES	0 ES
BA-4 (Y)	Plain			0 M	0 M	0 MS	0 MS	0 MS	0 MS
	Beaded			0 MS	0 MS	0* S	0 S	0 S	0 MS
BA-8 (Y)	Beaded				0 N	0 M	0 MS	0 MS	0 S
BA-11 (W)	Beaded					0 MS	0 S	0 MS	0 ES

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*40 percent loss of beads

Ratings: Film loss (percent)

Discoloration (N) none, (M) moderate, (MS) moderately severe, (S) severe, (ES) extremely severe.

(C) control paint stripes.

(Y) yellow.

(W) white.

TABLE 8

MONTHLY RATING OF ROSIN-ALKYD RESIN TEST STRIPES

Area 3 Portland-Cement-Concrete Pavement

		April (1951)	May	June	July	August	September	October	October 15
P-16C (W)	Beaded	0 MS	0 S	0 ES	0 ES	10 ES	10 ES	15 MS	15 S
P-17C (Y)	Beaded	0 MS	0 S	0 ES	0 ES	10 ES	10 ES	10 ES	10 ES
BA-1 (Y)	Plain		0 N	0 M	0 M	0 MS	0 S	0 M	0 M
	Beaded		0 M	0 M	0* M	0 MS	0 S	0 M	0 M
BA-2 (W)	Plain			0 M	0 ES	0 ES	0 S	0 MS	0 S
	Beaded			0 M	0* ES	0 ES	0 S	0 MS	0 S
BA-3 (W)	Plain			0 MS	0 ES	0 ES	0 S	0 MS	0 ES
	Beaded			0 MS	0* ES	0 ES	0 S	0 MS	0 ES
BA-4 (Y)	Plain			0 M	0 M	0 S	0 S	0 M	5 MS
	Beaded			0 M	0* MS	0 S	0 S	0 M	5 MS
BA-8 (Y)					0 N	0 MS	0 S	0 M	0 MS
BA-11 (W)	Beaded					0 MS	0 S	0 M	0 S

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*Indicates approximately 40 percent of beads absorbed into stripe.
Ratings: Film loss (percent)
Discoloration: (N) none, (M) moderate; (MS) moderately severe, (S) severe, (ES)Extremely severe.
(C) Control paint stripes.
(Y) Yellow.
(W) White.

P-4 (Paint Stripe). Film loss became noticeable over smooth surfaces of protruding aggregate after only one month of service. The color of the stripe was good except in the areas where reflectorizing beads were applied. Film cracks were observed in the spring of 1951. The effective life of the stripe was considered to be 7 months.

P-5 (Paint Stripe). Discoloration was severe and film loss over protruding aggregate was noticeable at the time of the first rating. Film cracks were observed in the spring of 1951. The effective life of the stripe was considered to be 10 months.

Concrete Surface - Area 2

B-5 (Rosin-Oil Stripe). Loss of adhesion and resulting film loss was rapid. Failure of the stripe began during the first freezing weather in December and was complete in January. The stripe did not discolor as severely as the same composition on the asphalt surface.

P-8 (Paint Stripe). Discoloration was severe from the beginning, especially in the beaded portion of the stripe. Film loss in small evenly distributed spots was noticeable at the time of the first rating. The effective life of the stripe was considered to be 4 months.

R-1 (Rosin-Oil Stripe). After only a slight amount of rainfall, air bubbles or blisters appeared over the surface of the stripe. These bubbles were initially ironed out by traffic with only small surface deformations. During the cooler weather of September and October, these blisters were broken by traffic. This resulted in a pitted surface on the stripe. Small areas of the stripe have lost adhesion to the pavement and have flaked off.

R-2 (Rosin-Oil Stripe). The same general pattern of blistering has been observed as for R-1 above. Small areas of the stripe have flaked.

R-3 (Rosin-Oil Stripe). This softer stripe has shown some blistering and resulting blister holes, but blistering has not been as severe as for stripes R-1 and R-2.

The initial work with the rosin stripe indicated the following three major difficulties in its use: (1) The Rosin-oil stripe had poor adhesion to concrete. (2) The proper balance between hardness and brittleness in the striping compound was difficult to achieve; soft stripes were deformed and discolored by traffic, whereas hard stripes were too brittle and cracked severely in cold weather. (3) The stripes showed excessive discoloration due to the adhesion of road dust and tire film.

The experimental work performed in the period from September 1950 to the present time has been primarily directed toward producing a rosin stripe which would overcome the difficulties indicated. Tests were first conducted with twelve chemical and oil plasticizers to replace the mineral oil. The results, based on the performance of the stripes under traffic, indicate that chlorinated paraffin and chlorinated diphenyl oils are better plasticizers than mineral oil.

Attempts were made to incorporate both natural and synthetic rubber in the rosin-oil compound. Natural rubber was incorporated in the form of finely ground rubber crumbs. Examination of laboratory samples containing these crumbs showed the small rubber particles to be evenly divided throughout the mix, indicating that the rubber did not soften sufficiently to blend with the binder material. A uniform blend was obtained with synthetic rubber, but the resulting compounds were sticky and hard to spread. The surface of the spread material did not harden properly after the material had cooled.

The incorporation of alkyd resin in the rosin striping compound was found to materially improve adhesion, hardness, and flexibility of the stripe. This modification of the British composition has shown the most promise, and an extensive study of the rosin-alkyd resin compound was started in February of 1951.

ROSIN-ALKYD RESIN STRIPING COMPOUND

Laboratory tests on binder compounds containing alkyd resin indicated that satisfactory hardness and brittleness was obtained by the incorporation of from 10 to 16 percent alkyd resin and no plasticizer with rosin, or with 10 percent alkyd resin and from 1 to 4 percent of oil plasticizer.

Seven rosin-alkyd resin compounds containing no plasticizing oils have been laid as test stripes on various streets of the A and M College of Texas campus. These stripes are designated BA-1 through BA-5, 10, and BA-15. A number of stripes have also been laid which contain rosin-alkyd resin-oil plasticizer binders. Of these, five have been in service long enough to be reported at this time. These stripes are numbered BA-7, 8, 11, 13, and 14.

A cobalt-metal drier was added to the rosin-alkyd resin striping compound in order to harden the surface of the stripe and thus prevent discoloration due to the adhesion of foreign matter. Three of these stripes have been in service almost three months. They are stripes BA-17, 18, and 19.

The composition of the rosin-alkyd resin, rosin-alkyd resin-oil, and rosin-alkyd resin-oil-drier stripes is shown in Table 4.

Rosin-alkyd resin service test stripes were applied to the pavements in three locations. The application data and monthly ratings of these stripes and the paint control stripes used with them are shown in Tables 5, 6, 7, 8, and 9.

TABLE 9

MONTHLY RATING OF ROSIN-ALKYD RESIN TEST STRIPES

Area 4 Portland-Cement-Concrete Pavement

		July 1951	August	September	October	October 15	Remarks on final ratings
BA-5	Plain	0 N	0 S	0 ES	0 MS	5 MS	Blister holes
BA-7	Plain	0 S	0 S	0 MS	5 MS	5 S	
BA-10	Beaded	0 MS	0 ES	0 ES	5 MS	5 S	
BA-13	Plain		0 S	0 ES	0 MS	0 MS	No blisters
BA-14	Plain		0 S	0 ES	0 ES	0 S	
X-1	Beaded	0 MS	0 ES	0 ES	0 ES	0 ES	Black
X-2	Plain	0 MS	0 MS	0 M	0 M	2 MS	
X-3	Beaded	0 MS	0 ES	0 ES	0 ES	10 ES	
X-4	Plain	0 MS	0 S	0 MS	0 MS	0 M	
BA-15	Plain	0 M	0 M	0 MS	5 MS	5 MS	
BA-17	Plain		0 M	0 ES	0 M	0 S	Some Blisters
BA-18	Plain		0 MS	0 ES	0 MS	0 MS	
BA-19			0 M	0 ES	0 MS	15 S	Blister Holes Some Flaking Greenish color

RATINGS Film Loss (Percent)

Discoloration (N) none, (M) moderate, (MS) moderately severe, (S) severe, (ES) extremely severe.

(Y) Yellow

(W) White

ROSIN-ALKYD RESIN STRIPES AND CONTROL PAINT STRIPES

At the time of this report, the oldest of the rosin-alkyd resin stripes have been in service for only 5 ½ months. The weather during this period of time has been generally hot, and there has been only a small amount of rainfall.

All of the rosin-alkyd resin and rosin-alkyd resin-plasticizing oil stripes have shown good adhesion to both portland-cement-concrete and asphaltic-concrete pavements. These stripes have all been subject to discoloration by the adhesion of road dust and tire film.

Discoloration of these stripes has been about the same as for the rosin-oil stripes discussed earlier. The incorporation of metallic driers has only slightly reduced discoloration.

In the use of paint stripes for comparison with rosin striping compounds, the following points have been observed: (1) Failure of paint stripe films has occurred because of loss of bond or adhesion to the pavement. (2) Discoloration of paint stripes in some cases has been very nearly as severe as for the rosin compound stripes. (3) Discoloration of the portion of each paint stripe beaded with glass reflectorizing beads has been more severe than for unbeaded sections; this discoloration has materially reduced day visibility of the stripe.

Several paint stripes, not reported in this paper, have been beaded in alternate 6-in. sections. This method of bead application greatly improves day visibility without materially reducing night visibility.

CONCLUSIONS

Although some of the striping compounds reported in this paper have been service tested for a relatively brief period of time, the following general conclusions appear to be justified:

1. Yellow and white stripes compounded according to the specifications for the British "Plastic White Line," modified by the reduction of oil content, have shown good service life on asphalt pavement. Comparison with standard paint stripes indicates a relative service life of more than 3 times that of the paint stripes. The undesirable characteristics of this material are (1) poor adhesion to concrete pavement and (2) discoloration by the adhesion of foreign matter.
2. The incorporation of alkyd resin in the rosin compound materially improved adhesion of the striping material to portland-cement concrete but did not materially reduce discoloration. The rosin striping compound modified by the addition of alkyd resin has very definite possibilities as a striping material. The short drying time of from 5 to 10 min. is a definite advantage in its use.

ACKNOWLEDGMENT

Contents of this paper are based on Project No. 192 (Development of Semi-permanent Center Stripe for Highway Use) of the Texas Engineering Experiment Station. Under this project, adhesive materials and dyes were investigated with respect to their luminosity, resistance to abrasion, and weather resistant qualities. By permission, some data of the Road Research Laboratory, Harmondsworth, Middlesex, England are used and discussed in this paper.

Appreciation is expressed to the many companies and individuals who generously gave information and materials for the experiments.

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Traffic Paint Tests

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SYNOPSIS

TRAFFIC-paint-testing procedures are reviewed in an attempt to determine which tests might be considered as standard. Although there is no official set of standard tests for traffic paints, those in use by a large percentage of consumers and those established by ASTM are considered as standard.

Certain laboratory control tests together with small scale road tests are given as the most effective means available at the present time for evaluating candidate traffic paints.

Laboratory tests as used to predict traffic paint durability are considered unreliable without further testing details and clarification.

Current ASTM efforts to establish accelerated laboratory traffic-paint tests for durability and suspension are reviewed. The need for such accelerated tests is emphasized in order to permit performance rather than compositional specifications.

● SUITABLE tests for traffic paint compositions are problems of major importance. These problems are faced by every state highway department in writing reliable traffic paint specifications. Further, the manufacturers, as well as the consumers, are faced with these same problems because various compositions must be evaluated and the more promising candidates selected. For the most part, laboratory and road tests are used in order to determine the compositions which offer most promise. Although actual road tests are believed to be the safest testing procedure to follow, such procedures, of course, require considerable time and do not give the consumer adequate protection against faulty compositions. Obviously it is important that reliable, accelerated laboratory testing procedures be developed. Many accelerated testing procedures have been tried and are being tried. At present, however, there is little agreement regarding a preferred accelerated testing procedure for traffic paint.

STANDARD TESTS

In the evaluation of candidate traffic paints, laboratory control tests and small scale road tests are commonly used (1). Although there is no official set of standard tests for traffic paint, the tests in use by a large percentage of consumers might be considered as standard. Further, certain standards and standard methods of test have been established by the American Society for Testing Materials and insofar as possible such generally accepted and established testing procedures should be used.

Laboratory Control Tests

Laboratory control tests which are widely used include composition, consistency and drying time. Other tests which are reasonably well established and which might be included for control purposes are bleeding and suspension. Since these tests are described in considerable detail in the literature already published, pertinent references are supplied and such details omitted from this paper.

Compositional determinations should cover such possible variables as gallon weight, percent pigment, percent vehicle and total solids (2). Under some conditions it may be desirable to carry the analysis further to determine the type and amount of pigment present also the type and amount of resin or oils or both used in the binder. Obviously the amount of such analytical work will depend to a considerable extent on the degree of control desired.

Consistency (2) measurements are important because such information serves as an effective control and is helpful in judging application characteristics. Consistency limits should be set for the particular paint and application procedure which is to be used. Consistency changes on aging are an indication of poor can stability which in turn may result in poor durability.

Drying Time[1] is a very important characteristic of traffic paint because the traffic line when applied must be protected during the dry to no-pick-up period. The emphasis on shorter drying times is increasing. This becomes doubly important where spray applications are made at the rate of some 15 mph. (3). Obviously under such conditions a slow dry to no-pick-up time would require a very considerable number of flags in order to insure adequate protection from traffic throughout the drying period. In some instances a sacrifice in durability is accepted in order to obtain improved drying characteristics.

Bleeding[2] is defined as the relative condition of discoloration manifested in traffic paint when applied to tar or asphaltic roads. Accordingly, paints designed for tar or asphaltic roads should be examined carefully by means of control bleeding tests. Further, the laboratory bleeding test as developed by ASTM is an easy test to run and is sometimes helpful in detecting unsuspected compositional changes.

Suspension[3] tests on traffic paints are desirable and helpful. The tendency to include coarse particles in the pigmentation of traffic paint compositions in order to obtain improved night visibility serves to increase the possibility of poor suspension. Obviously, suitable suspension limits should be set and control tests used in order to insure that these suspension limits are met.

The above-mentioned laboratory control tests listed as standard because of common usage should not be considered as a completed list. It is certain that additional standard tests, many of which are in use by various consumers, are desirable. In most instances, however, additional information is needed either on reliability or testing procedure in order to encourage general adoption.

Small-Scale Road Tests

Small-scale road tests are used widely to obtain practical drying time, durability and visibility comparisons. The method of making such small scale road tests is well established.[4] In this connection, however, the location and type of road is an important consideration (4) as wide differences in performance can result from such variables. In general, paints show better durability on a bituminous surface (rock asphalt) than on cement concrete (2c).

Drying time as determined from small scale road tests may vary considerably from the rating obtained in the laboratory under more constant conditions. Obviously, the weather, especially temperature and humidity, the manner of application and the amount, as well as type, of paint applied are factors in the drying times obtained from actual road tests. Drying times under adverse conditions can be an important consideration. Accordingly, an opportunity to obtain such information should not be overlooked.

Durability is one of the prime considerations in traffic-paint evaluations (5). The type of failure most frequently encountered is chipping.[5] Sometimes, however, erosion failure[6] is observed. The relative durability of traffic paints can be rated satisfactorily by the use of transverse lines. This is particularly

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[1] Method of Test for Dry to No-Pick-Up Time of Traffic Paint (D 711-48), 1949 Book of ASTM Standards, Part 4, p 388.

[2] Tentative Method of Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding (D 969-48T), 1949 Book of ASTM Standards, Part 4, p. 382

[3] Method of Test for Evaluating Degree of Settling of Traffic Paint (D 869-48), 1949 Book of ASTM Standards, Part 4, p 397.

[4] Method of Conducting Road Service Tests on Traffic Paint (D 713-46), 1949 Book of ASTM Standards, Part 4, p 395

[5] Tentative Method of Evaluating Degree of Resistance of Traffic Paint to Chipping (D 913-47T), 1949 Book of ASTM Standards, Part 4, p 384.

[6] Method of Evaluating Degree of Resistance of Traffic Paint to Abrasion Erosion, or a Combination of Both, in Road Service Tests (D 821-47), 1949 Book of ASTM Standards, Part 4, p. 376

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 (2c).

Visibility is without question a pertinent requirement for traffic paints. The most common practice is to judge day and night visibility by eye (1). In some instances. photographic methods are used. Within the last few years portable night-visibility instruments have been made available which are very helpful in making such ratings (6) and a tentative method of test has been established.[7]

Tests in Use by Various Consumers

Several traffic-paint tests other than those given as standard are used by various consumers (1, 2). As listed in the approximate order of popularity these tests cover:

1. Flexibility
2. Water resistance, hot and cold
3. Hiding power
4. Color stability
5. Spreading rate
6. Abrasion, dry and wet
7. Accelerated weathering
8. Skin resistance
9. Adhesion
10. Hardness
11. Alkali resistance
12. Light sensitivity
13. Daylight reflectance
14. Dilution test
15. Stability

No attempt will be made to discuss these various tests in detail. Certain conclusions are available from published data, however, which may be of interest in connection with further consideration of some of these tests.

According to Goetz (2c) the degree of flexibility as measured by 32 test variations shows no correlation whatever with road durability on concrete pavements. It is stated, however, that the modified wet-abrasion test and the water-resistance test show a direct correlation with field durability. The dry-abrasion test gave no positive correlation between test constants and road performance. Hardness is stated to have an important bearing on the test results obtained with the abrasion machine. Also, the correlation between alkali resistance and road durability is rated as negative.

It is stated by Skett and Herbert (7) that actual road tests gave check results regardless of the type of road, traffic count, method of application, and spreading rate. In general, abrasion tests are stated to give more reliable information on durability than flexibility tests. No one laboratory test or combination of tests used was sufficient to evaluate correctly the durability of traffic paints.

Allen (8), in an ASTM progress report, states that the adhesion, flexibility, and hardness tests examined show no general correlation with field service behavior. However, very close correlation is reported with field service behavior of the samples of traffic paint examined by the abrasion test developed by Leavitt (Maine State Highway Commission) and the combined accelerated weathering and abrasion tests developed by Hickson (National Bureau of Standards) and Werthan (New Jersey Zinc Co.).

Shuger (2d) stated that paints which pass a severe bend test do not necessarily give better road performance. Further, it is stated that 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. Accelerated-weathering tests are mentioned as useful in rating comparative chalking and color failure. However, no great progress has been made on accelerated weathering to secure checking, cracking and adhesion failures which are the types most often encountered in traffic paints.

Light sensitivity[8] of traffic paint is a property which can have a definite bearing on visibility. Accordingly, a test of this type can serve as a helpful control. Likewise, hiding power, daylight reflectance, dilution, and stability tests (2a) can be useful control tests. Under certain limited conditions a skid-resistance test may be of value. Spreading rate generally can be varied widely by adjustments in consistency and application technique.

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[7] Tentative Method of Test for Night Visibility of Traffic Paints (D 1011-49T), 1949 Book of ASTM Standards, Part 4, p 392.

[8] Method of Test for Light Sensitivity of Traffic Paint (D 712-47), 1949 Book of ASTM Standards, Part 4, p. 390.

CURRENT INFORMATION ON ASTM

Subcommittee IV, ASTM Committee D-1 currently is working on accelerated laboratory traffic-paint tests for durability and suspension. Further, consideration is being given to specifications on glass beads as used to improve the night visibility of traffic paints.

The work on accelerated traffic-paint tests for durability is being centered around combined accelerated weathering and abrasion tests also, combination laboratory tests involving hardness, hot water resistance and accelerated weathering. Cooperative tests are in progress but as yet no official reports, beyond the references already given, have been released.

Accelerated suspension tests on traffic paints are in progress. Hot and cold cycles are being used to accelerate settling and an attempt is being made to correlate the accelerated paint settling with normal shelf aging. Consideration is being given as well to a possible correlation of 2-week and 6-month suspension ratings.

In connection with the development of suitable accelerated tests on traffic paints for durability and suspension a maximum testing period of two weeks is believed by many to be highly desirable. Accordingly, a 2-week time limit is included as a part of the goal in the work under way on accelerated tests.

POSSIBLE VALUE ON TESTS IN USE

All of the tests listed here and considered as standard are beneficial and helpful control tests for traffic paint compositions. This would include the laboratory control tests and the small-scale road tests. Further, such tests are used widely and considered important by many consumers.

The tests listed as in use by various consumers might be considered as optional. In certain instances, tests on hiding power, color stability, or light sensitivity, daylight reflectance, dilution, and stability can be helpful controls. The possibility of using such tests as flexibility, water resistance, abrasion, accelerated weathering, adhesion, and hardness to predict ultimate durability is questionable. Certainly, further testing details and a clarification of the meaning of the results obtained are needed before such tests can be used with confidence.

The fact that composition specifications are extensively used is adequate evidence that suitable accelerated testing procedures are not available. In this connection reliable accelerated laboratory tests on traffic paints for durability and for suspension are needed urgently. If accelerated tests could be made available which would be adequate in predicting performance characteristics insofar as durability and suspension are concerned then performance specifications could be used. Such a change in traffic-paint-specification practice would be highly desirable from the standpoint of both the manufacturer and the consumer.

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Road Tests of Traffic Paints

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SYNOPSIS

THROUGH the cooperation of the Pennsylvania Department of Highways, the Titanium Pigment Corporation has made road tests of new traffic paints. Some of the results of these tests are presented in this paper.

Road testing of traffic paints is important as there are no laboratory techniques or tests which will give quick, accurate durability evaluations of the paints.

Early tests indicated that it was possible to use the calcium sulfate extended rutile titanium pigment in a traffic paint without sacrificing durability. Tests were continued with this pigment as it was one of the most economical methods of introducing hiding into the paint.

Results are given showing that the alkyd-type vehicle is preferable for traffic paints of better than average durability. Formulation changes produce distinct variations in durability even in an alkyd vehicle.

The road tests have shown the versatility of the alkyd type traffic paint. There are indications that this type of paint might be used as an all-purpose paint on all highways, either with or without reflectorizing beads.

● ABOUT 5 years ago, the Pennsylvania Department of Highways and the Technical Service Department of the Titanium Pigment Corporation started a cooperative study of traffic paints. When the test program started, the objective was to improve the durability of traffic paints. As the work progressed, a more definite aim was established. The test work was directed toward formulating a traffic-marking paint which would serve as a bead binder as well as an unbeaded paint for use on all types of surfaces. It was realized that such a multipurpose paint would require compromises, particularly with respect to drying time and, perhaps, bleeding over bituminous surfaces. However, it was resolved to try to keep these compromises to a minimum.

In the early work, along with the problem of improving the durability of traffic paints, it was hoped that some laboratory method could be found to predict durability. It was recognized that the road application of traffic paints for test purposes has been, by necessity, a time-consuming and cumbersome operation. The length of time before results become known is often too long. Yet, in spite of this, road testing appears to be necessary. Many tests have been devised by various highway departments throughout the country to give a rapid evaluation of a traffic paint. In certain cases, it appears that these tests might be adequate within certain limitations. For example, a flexibility test might properly evaluate a sample of traffic paint, providing all the samples had relatively the same vehicle and similar pigmentation. Likewise, some type of wheel designed to exert wear upon samples of traffic paint might give a fair evaluation of durability. But once again, the limitations appeared to be that the paints must be very similar in nature to make the evaluation valid. These conclusions were borne out by the comparisons of road tests with various laboratory evaluations. The conclusion has been reached that so far no laboratory method has been devised to properly evaluate the durability of traffic paints of varied composition. Until such a time that an adequate test procedure is devised, road testing will continue to be important.

It is quite apparent that road testing cannot be classed as an exact procedure. The variety of surfaces to which the paints are applied, the differences in weather conditions during application, and the amount of traffic over the surfaces on which the paints are applied prevent exact

TABLE 1

Pigmentation 50% Titanium Pigment-20% ZnO-15% Mg Sil-15% Pumice
50% Pigment Volume

Vehicle: Oleoresinous varnish - 15 gal. oil length

	DURABILITY[a]						
	TRANSVERSE LINE			LONGITUDINAL LINE			
Length of exposure (Mos.)	2	4	6	4	6	8	10
Titanium Pigment							
Titanium-Barium Pigment	8	7	4	9	7	5	4
Rutile Titanium-Calcium Pigment	8	6+	4	9	7	5+	4

[a] Durability is expressed in numbers 0 to 10 indicating the percentage of line remaining on the road. 10 equals 100%, 8 equals 80%, etc.

results from being obtained from any one set of road tests. The Pennsylvania Department of Highways has made a big contribution in devising a procedure for applying test paints to the road. The procedure has been described previously in a paper by Custer and Zimmermann (1). Essentially, with this procedure, the film thickness of the paints is closely controlled. This method helps to eliminate any differences in results which might develop due to variations in paint consistencies. Thus, results obtained may be attributed to changes in pigmentation or vehicle composition. Nevertheless, the results presented should be viewed as being as reliable as possible within the limitations of road testing.

In the early traffic paints, titanium-barium pigment and lithopone were used to produce the necessary hiding. Perhaps in a few instances pure titanium dioxide was used. However, the titanium-barium pigment was by far the most popular pigment in use. Eventually, for economic reasons, the manufacture of titanium-barium pigment was discontinued. A newer pigment, rutile titanium-calcium pigment was produced and suggested as a replacement for the titanium-barium pigment. There was a reluctance on the part of many paint manufacturers, as well as state highway departments, to use or specify this rutile titanium-calcium pigment in traffic paints. The fact that this pigment is extended with calcium sulfate which has some water solubility, has been a deterring factor in its acceptance for use in traffic paints. Yet, an examination of published tables shows that the water solubility of pure calcium sulfate is relatively small. This low water-solubility factor, coupled with the fact that this pigment would be used in a water-resistant binder, indicates that there should be little fear that the calcium-sulfate-extended pigment would degrade materially the durability of traffic paints. Repeated road tests have demonstrated quite clearly that the rutile titanium-calcium pigment may be used to produce high-hiding, white traffic paints having excellent durability.

In 1947 there were a number of test comparisons made of the rutile titanium-calcium pigment with the anatase titanium-barium pigment. All the comparisons indicated that a replacement of titanium-barium pigment by rutile titanium-calcium pigment would be satisfactory from a durability standpoint.

The results expressed in Table 1 illustrate that, in this particular formula, rutile titanium-calcium pigment may be used in place of titanium-barium pigment without effecting adversely the durability. This substitution is just one example of the comparisons made. Results of comparisons of the rutile titanium-calcium pigment with other hiding pigments have been reported previously (1). The results indicated that this rutile titanium-calcium pigment may be used to produce a durable, white traffic paint.

It was quickly apparent, from early road tests, that while the pigmentation of a traffic paint was important, the vehicle was of even greater importance. The vehicle of a traffic paint should bind the pigments together properly, adhere to a variety of surfaces, be resistant to alkali and moisture, and have the ability to dry quickly under various atmospheric conditions. Of all the qualifications of a good traffic paint, probably the greatest stress was laid on the drying time. The demand for fast-drying traffic paints brought about the use of paint with very limited durability. The quick-drying types of paints usually fail rather early by scaling and flaking. In addition to this, their brittleness made them inefficient as bead binders. The beading of these fast-drying types of traffic paint caused even larger areas of the film to lose adhesion. Fortunately, as shown in a recent survey (2), the importance of service life has taken preference over the requirement for drying time. With less emphasis placed on quick drying by the various state highway departments, it is considerably easier to formulate a good durable traffic paint.

As the test program progressed, the search for a more-durable traffic paint continued. The emphasis was not on the pigmentation but on the type of vehicle. The results of one group of tests, for example, gave every indication that the alkyd-type vehicle was superior in durability to the oleoresinous type.

These three types of paints were also used as bead binders. In our test work, the usual procedure is to put down the longitudinal traffic line (parallel to the flow of traffic) about 70 to 80 ft. in length. The first half of this line is applied without beads either in the paint or applied on top. The second half is applied with beads added to the top of the paint in the normal manner. In this manner, there are two tests for each paint.

In testing the paints in Table 2 as bead binders, the alkyd-type traffic paints once again proved to have superior durability. In this case, as in almost all other cases, the reflectorized paints had approximately twice the life of the same paints unbeaded.

Using different rutile titanium-calcium and titanium-dioxide pigmentations in each of the three vehicles mentioned in Table 2, the alkyd vehicle again produced the most-durable traffic line. It did not matter whether it was beaded or used without beads, it was still the most durable traffic paint.

The alkyd vehicle has many points in its favor for use in a traffic paint. It has good adhesion to nearly all surfaces used in road construction. It has good water and alkali resistance and good flexibility. Its abrasion resistance, once it has dried thoroughly, is good. However, it appears to have one major fault: It does not dry with the speed that is generally specified by the various state highway departments. In addition to this,

TABLE 2

Pigmentation: 50% Rutile titanium calcium pigment-20% ZnO-15% Mg Sil-15 % Pumice 50% Pigment Volume

	DURABILITY						
	TRANSVERSE LINE			LONGITUDINAL LINE			
Length of exposure (Mos.)	2	4	6	4	6	8	10
Vehicles							
15 gal. oil length oleoresinous var.	7	5	4	8	7	6	4
20 gal. oil length oleoresinous var.	8	6	4	8	7	6	5
Medium oil length alkyd	9	8	6	9	8	8	7

Pigmentation: 16.5% Titanium Dioxide-20% ZnO-48% Mg Sil-15% Pumice 50% Pigment Volume

	DURABILITY						
	TRANSVERSE LINE			LONGITUDINAL LINE			
Length of exposure (Mos.)	2	4	6	4	6	8	10
Vehicles							
15 gal. oil length oleoresinous var.	6	4	3	7	6	4	2
20 gal. oil length oleoresinous var.	8	6	4	8	7	5	4
Medium oil length alkyd	9	7	5	9	9	8	7

due to its slow setup (or tack-free time) it discolors considerably when applied over asphalt or tar surfaces. This slow setup allows the thinners remaining in the paint to act on the bituminous surface, dissolving the bitumens and causing discoloration.

In order to overcome this deficiency in alkyd traffic paint, other paints which had good records for no bleeding on bituminous surfaces were re-examined. It was found that such paints took advantage of fast-evaporating, low-solvency thinners to prevent or to minimize bleeding. Several combinations of such thinners in various concentrations were tried with the alkyd vehicle. Finally, it was found that a medium oil length alkyd, based on either soya or linseed oil, might be used satisfactorily in a traffic paint for use on bituminous roads if that alkyd were cut to 50 percent solids in V. M. and P. naphtha (initial boiling point 190 to 225 F.) instead of the usual mineral spirits, (initial boiling point 300 F.). A paint such as this still showed some discoloration, particularly when the rest of the thinner used in the paint was mineral spirits. The use of common-type mineral spirits for the thinner in an alkyd type traffic paint makes the setup time much too slow. However, it was found that if the paint was made with an alkyd cut in V. M. and P. naphtha and thinned to the proper consistency with a fast-evaporating, low-solvency thinner, such as textile spirits or rubber solvent (Initial Boiling Point 110 to 150 F.), discoloration was held to a minimum. This alkyd traffic paint, using the lower solvency thinner, has been tested on tar, bituminous-concrete, and cement-concrete roads. The durability has been excellent. The resistance to bleeding, when it was applied on bituminous concrete roads, has been good. Some bleeding was observed when the paint was used on a tar road. Nevertheless, there is still good contrast during the daytime between the line and the tar road. Under no circumstances did the discoloration of the line from any source effect the night visibility of this paint.

It has been found that the alkyd traffic paint, using the proper thinners, is satisfactory for use on bituminous-concrete and cement-concrete roads without the use of beads. The same paint may be used on any type surface as a reflectorized paint, giving excellent durability and excellent night visibility.

Once it had been found that the alkyd vehicle would produce a durable traffic paint, the pigmentation was again examined to determine a suitable combination of pigments. Since it had been determined in the early test work that no harm would result from the use of rutile titanium-calcium pigment as the hiding pigment, its use was adopted in the alkyd paint. A titanium-dioxide pigmentation was not selected for economical reasons. Traffic paints are generally formulated as flat paints or as paints having a high pigment volume concentration. In this range of pigment-volume concentration, the rutile titanium-calcium pigment produces more hiding per pound of pigment at less cost than other hiding pigment combinations. It will produce a paint with a raw material cost of 15 to 20 cents per gal. lower than a paint with equal hiding made with rutile titanium dioxide as the hiding pigment. There has been no evidence that a combination of rutile titanium dioxide and extender would not be as durable as the rutile titanium-calcium pigment combination. But from an economical standpoint, it was logical to select the least-costly pigment combination.

With the adoption of rutile titanium-calcium pigment as the hiding portion, the remainder of the pigmentation had to be selected. Several combinations of pigments were tried with the rutile titanium-calcium pigment to determine durability. There were a number of pigmentations that gave satisfactory durability, with no one in particular showing outstanding characteristics. From this work it appeared that the rutile titanium-calcium pigment with extender would provide as lowcost durable pigmentation as any of the others tested.

Since magnesium silicate had been used in most of the earlier work, it was assumed that this extender would give good results. However, the testing of other extender pigments in combination with rutile titanium-calcium pigment indicated that equal or better results might be obtained. One of the extenders which

TABLE 3

TRAFFIC PAINT

Pigmentation	Pounds Non-Vol.	Total Pounds	Gallons
Rutile titanium calcium pigment		650	24.1
Natural Whiting[a]		350	15.4
Aluminum Stearate[b]		5	0.6
Vehicle			
Alkyd Solution (50% Solids)[c]	334.0	668.0	87.3
Lead Naphthenate (24%)		13.9	1.4
Cobalt Naphthenate (6%)		3.4	0.43
Anti-Skinning Agent[d]		0.8	0.1
Thinner[e]		112.5	19.0

Pigment - 55.7 %
Pig.Vol. Conc. - 52.5 %
Weight per Gallon - 12.2 lb.

Vehicle - 44.3 %
Non-Volatile - 41.8 %

Pigment per Gallon of Paint - 6.8 lb.
Viscosity - 70-75 (Stormer)

[a] A low oil absorption, natural calcium carbonate such as Oolitic F, York Whiting, etc., may be used.

[b] The Aluminum Stearate should be equivalent to Metasap Chem. Co.'s V Grade.

[c] General Electric's Glyptal 2464, Jones Dabney's Syntex 32, U.S.I.'s Aroplaz 1085, etc. cut in V.M.&P. Naphtha may be used.

[d] The anti-skinning agent should be Nat'l Analine Co.'s ASA or equivalent.

[e] Any petroleum thinner with an Initial Boiling Point of 110-150 deg. F. may be used.

gave outstanding results was natural whiting. This whiting should be a natural, low-oil-absorption calcium carbonate. It did not give good results when it was used as a straight weight replacement for the magnesium silicate. Yet, with a pigment volume adjustment, this extender helped to improve the durability of the alkyd traffic paint. Repeated road tests showed that a combination of rutile titanium-calcium pigment and natural whiting at a pigment-volume concentration between 50 and 55 percent in an alkyd vehicle would give excellent results either with or without beads.

At various times during the cooperative testing work with the Pennsylvania Department of Highways, many ways were tried to improve the durability of traffic paints. Various vehicle combinations were used, pigment changes were tried, and methods of application were varied in attempt to find a paint which would give the greatest length of service. Two interesting facts came to light. It was found that a traffic paint is not a great deal different from any other type of surface coating subject to wear. Its service life is proportional to the film thickness. This, of course, is based on the assumption that the paint will fail by a combination of erosion and abrasion and not by flaking and scaling. The road tests indicated that a practical dry-film thickness for all alkyd traffic paint should be approximately 0. 01 in. (or that a gallon of paint should produce a 4-in. line 340 to 375 ft. long). This film thickness appears to give maximum durability whether as an unbeaded or a reflectorized line.

The other interesting fact developed in connection with an investigation of the dispersion of traffic paints:

In actual manufacture, as well as in the laboratory, it has been the practice to do very little grinding of the paint. Practically all the paints tested until recently had a 0 grind on the North Standard of

Fineness Gauge. A road test was made of two paints identical in all respects with the exception that one had a 0 fineness of grind while the other paint was ground to a fineness of 3 to 4. The better-ground paint failed mainly by erosion. The paint with the poor dispersion showed early flaking and scaling. As a result, the durability appeared to be increased by 15 to 20 percent by improving the dispersion of the pigment in the paint. Later comparisons seemed to indicate that small differences in durability formally attributed to minor changes in pigmentation or to vehicles of different manufacturers were minimized.

Summing up all these results, it is believed that it is now possible to formulate one paint that will do a complete job as a traffic marking paint. This traffic paint may be used as a bead binder on any type of highway construction, or it may be used as an unbeaded line on practically all kinds of roads. To some highway departments the use of this paint would necessitate compromises of drying time, for it does not dry quite as rapidly as a lacquer or oleoresinous type of traffic paint. It will dry tack free in 20 to 30 min. and may be opened to traffic within 45 to 60 min. By accepting a slightly slower drying paint, the service life has been increased appreciably. It should give 9 to 12 months service as an unbeaded line and well over 12 months as a reflectorized line. This estimated service would mean that for all roads, with the exception of intersections and sharp curves, repainting would be only necessary once a year. Naturally, those spots subjected to heavy wear would require repainting at shorter intervals.

In Table 3 is given the formulation of a paint which has been developed. It is an illustration of a type of paint that has given good results. Pigments, resins, and thinners from various sources might cause changes in drying time and package stability. Laboratory examination of samples of paints made according to this formulation would check variations in the physical characteristics of the paint.

It is believed that this paint meets the specification for a multipurpose traffic-marking paint fairly closely. However, not all the problems of highway marking will be answered by this paint. But it is expected, through continued road tests and laboratory investigations, improvement will be made in traffic-marking paints. This will be undoubtedly true as more information is obtained of latex-emulsion paints and of new synthetic resins and vehicles. These new materials will perhaps add greater durability and visibility to the traffic paints now in use.

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Application of Plain and Beaded Traffic Paints

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SYNOPSIS

TRAFFIC paint in Washington is applied by spraying. Glass beads, which improve the effective life as well as the visibility of traffic stripes, are mixed with the paint prior to spraying. The paint, in addition to being a good bead binder, must have the following properties for proper spray application: (1) viscosity between 75 and 85 Krebs units, (2) good nonsettling properties, (3) ability to wet moist surfaces, and (4) drying time not longer than 15 min.

Two types of spray machines are used. The first type is an independently steered push-cart machine which carries the spray guns and is pushed by a truck carrying the paint supply. The second type is a self-contained unit in which the paint is carried on the truck and the guns are suspended from a rear platform on the truck.

An average crew consists of three vehicles, including the spray machine, and a personnel complement of six men; 20 to 25 mi. of stripe per day can be applied if the paint dries in 15 min. or less.

Since 1949, field application has been supervised and coordinated by laboratory personnel. Equipment has been modified to enable spray machines to apply beaded mixtures efficiently at a spread rate of 21 to 22 gal. per mi. of 4-in. stripe. A rapid and reliable method of checking field application rate is described.

● A SUCCESSFUL striping program depends not only on the quality of the paint, but also on the satisfactory and economical application of the material in the field. The overall appearance of the stripe (including clean and sharp edges, accurate retracing over old lines, freedom from swirls and sharp angles, and to a certain extent, freedom from unsightly smearing by traffic before the paint is dry) is entirely dependent upon the men and machines that apply it. The general performance of the paint itself, on the other hand, is the responsibility of the formulator. In Washington, traffic paint is formulated in the laboratory and is applied by state forces using state-owned equipment.

Since 1949, field striping operations have been coordinated by laboratory personnel thoroughly familiar with all characteristics of the paint. Field and laboratory forces have cooperated in solving mutual problems. Equipment modifications or new painting procedures developed by any one crew have been acknowledged and the information passed on to other crews. In addition to more-efficient, and consequently more-economical, striping operations, this program has resulted in a stripe of uniformly high quality throughout the state.

REQUIREMENTS OF TRAFFIC PAINT

This discussion will deal mainly with the field application of traffic paint. A successful striping program cannot be accomplished, however, with a basically sound striping material to use. Experience in Washington has indicated that traffic paint must meet the following general requirements if it is to be applied uniformly at an adequate rate of spread:

1. The viscosity of the material must be high enough to afford good handling characteristics in the equipment used. The rate of application of a low-viscosity material is difficult to adjust. The operation of the machine on the road when attempting to apply a low-viscosity material is quite inflexible. A viscosity at 70 F in the range of 75 to 85 Krebs units for paint and 90 to 105 Krebs units for beaded mixture has proved most satisfactory for our equipment.

2. The paint, when used as a premixed binder, must hold the beads in

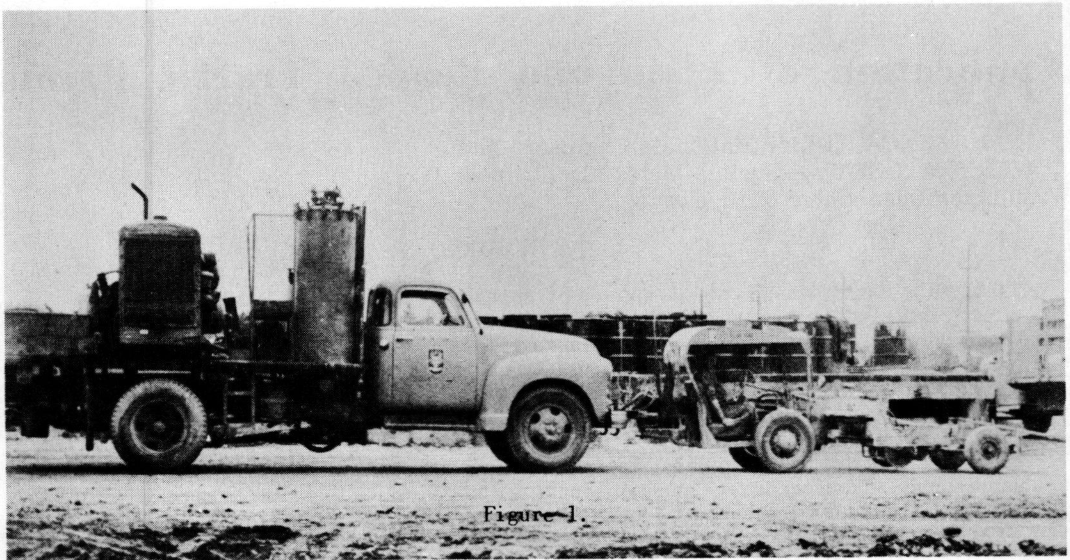

Figure 1.

suspension in the paint tanks and in the stripe after application. Each bead should retain its original position in the film and not settle through to form a layer next to the road surface during the drying period. Not only must the paint hold the beads in suspension in the containers and in the applied film during the drying period, but it must have sufficient suspending power to prevent the beads from being forced to the bottom of the paint film as they are ejected from the spray gun.

3. The paint must be able to wet moist surfaces. Many times, even during summer months, night fogs and heavy dews leave a film of moisture on roadways. The paint must wet through this moist and dirty surface and bond to the roadway itself. Glass beads often carry a residual moisture film which requires proper wetting action by the paint if the beads are to be completely dispersed in the tanks and uniformly applied to the roadway. A water-miscible solvent, such as acetone, alcohol, or methyl ethyl ketone, in the paint appears to be helpful in attaining thorough wetting of moist surfaces.

4. The paint must have rapid through-dry as well as rapid solvent release. A paint having quick surface-dry and slow through-dry will usually break under early traffic resulting in a smeared line, which is not only unsightly but also very hard on the morale of the paint crew. Our present specifications require a maximum dry-to-no-pick-up of 15 min. The paint we are using actually dries somewhat faster than that in the field under good drying conditions.

5. The problem of cleaning tanks and equipment is of major importance to the field crew. The cold-cut formulation we use is very helpful in that respect in that the hardened film can be redissolved in the solvents used in thinning the paint. This property may not be present in cooked-type vehicles which require catalytic driers.

BEADED TRAFFIC STRIPES

The State of Washington uses beaded traffic stripe exclusively at the present time. The cost of glass beads has decreased sharply in the past few years. This reduction in bead cost has been accompanied by a rapid increase in the cost of most paint raw materials. The end result is that beads, on the basis of cost per solid gallon, are only slightly more expensive, or in some cases actually cheaper, than good-quality traffic paint. As was stated in an earlier publication (1), the use of glass beads results not only in vastly improved visibility, but also in appreciably longer effective service of traffic stripe.

We use premixed beads in all of our traffic stripe. On heavily traveled primary highways, in addition to premixing 4 lb. of small beads in each gallon of paint, we drop 3 lb. of larger beads on each gallon of the applied beaded mixture. On all other roadways we omit the overlay beads and use 6 lb. of premixed beads in each gallon of paint.

The affinity of the glass beads for moisture often presents a problem in the application of overlay beads. In many cases the moisture film on the beads causes them to cling together and clog the hoppers and feed lines of the gravity dispensers. In normal summer weather dry, ventilated bead storage prevents this difficulty. In high-humidity areas, storage for 48 hr. in heated storerooms prior to using will assure free flow of the beads through the dispenser.

Since the premix beads are applied by spraying, there is a tendency, of course, for some of the beads to rebound and escape from the film. Experience has indicated that the application rate, rather than the line pressure, is the controlling factor in rebound loss. If the mixture is applied at a minimum rate of 18 gal. per mile of 4-in. stripe, the loss of beads through rebound will not exceed 10 percent. This maximum loss of 10 percent appears to be quite constant at line pressures of from 40 to 80 psi. and atomizing pressures of from 30 to 40 psi. These values represent the range of pressures normally used on our machines. Extensive field tests have indicated that rebound loss, even at low line pressures, may amount to as much as 50 percent if the application rate is reduced to 10 gal. per mi. of 4-in. stripe.

EQUIPMENT USED FOR PAINT APPLICATION

The first traffic-striping machine used in Washington consisted of a motorcycle and side-car combination with a small compressor and tank. Next came a simple paint cart pushed by a truck, then more elaborate push carts, and finally a large self-contained unit. Two push-cart machines and four self-contained units are in use today. Both types of machines apply the paint through large spray guns.

Push-Cart Machine

The push-cart machine (Fig. 1 and 2) is pushed by a $1^1/_2$-ton cargo truck. It is attached to the truck by a double-roll system, which permits free movement horizontally and vertically in a plane perpendicular to the line of travel. The truck carries the air compressor, paint tanks, and main feed controls. A pacing wheel mounted on the truck drives a "bitumeter" which records stripe footage and gives ground travel in feet per minute. A motor tachometer and hand throttle on the truck enable the driver to maintain a constant motor speed. If the truck is

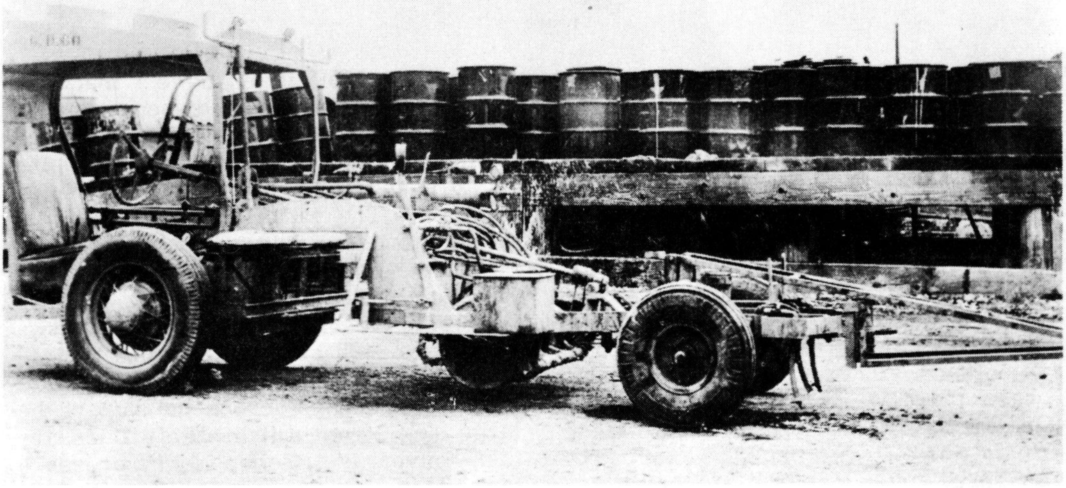

Figure 2.

properly powered and geared, the pacing wheel, hand throttle, and motor tachometer enable the driver to maintain a constant ground speed regardless of terrain. Feed lines from the paint tanks, which have capacities of 200 gal. and 60 gal., respectively, of main and barrier paint, are $1^1/_4$-in. galvanized pipe sloping from the tanks to the front bumper. The air and paint lines on the truck are connected to the lines on the cart by 1-in. neoprene pressure tubing. Feed lines on the cart are $^3/_4$-in. galvanized pipe. The cart, which is independently steered, carries three spray guns, bead dispensers for overlay bead application, and operating controls for the guns. Sharp stripe edges are secured by means of steel discs set 4 in. apart with the guns operating between them. The boom shown on the front of the cart carries a sight through which the cart driver looks to maintain a straight line of travel.

A gear-type pump is used for transferring the paint into the tanks on the truck. The beads for premixing are added after the paint is in the tanks. Paddles operated by an air motor are used to keep the paint and bead mixture stirred.

Self-Contained Machine

The self-contained unit (Fig. 3), which was built in 1950, is our newest machine. It has the guns and bead dispensers suspended from the rear platform It has a tank capacity of 400 gal. of main striping mixture and 100 gal. of barrier striping mixture. The tanks are provided with stirring paddles driven by a power take-off on the truck. All tank openings are gasketed to withstand pressures of more than 100 psi. The compressor has a capacity of 125 cu. ft. per min. It provides compressed air to the air manifold, visible in Figure 3 across the bank of the large tank, from which all air lines are fed. Solvent is provided from a pressure tank and is piped into the system so that all guns and lines may be flushed while on the

Figure 3.

road. The three spray guns on this machine, as on all our other machines, are DeVilbiss WV-598 high-speed spray guns with Z-27 air cap. Air curtains provide sharp edge cuts on the stripe. A pacing wheel, motor tachometer, and hand throttle are also used on this machine to give positive speed control. The double-mirror system shown on the front of the truck places the driver's apparent point of vision about 6 in. above the ground, enabling him to maintain a straight line of travel. The mirrors are hydraulically operated and are controlled from the cab.

VEHICLE AND PERSONNEL REQUIREMENTS OF STRIPING CREWS

The vehicle complement of an average striping crew consists of (1) a panel-type lead vehicle carrying small equipment and personal effects, and showing warning signs and blinker lights, (2) the striping machine, and (3) a light cargo-type follow-up truck carrying reserve paint, beads, and heavier items required for the day's operation. This truck carries rear warning signs and blinker lights and picks up the wet paint markers dropped from the striper.

An average personnel complement consists of six men, including a foreman, one man in the lead vehicle, a driver on the striping truck, a paint man, and two men in the rear truck. The foreman lays out the day's work, keeps the daily record of operation, and fills in where necessary. The entire crew works wherever required on loading, cleanup, and maintenance.

AVERAGE GROUND SPEED OF STRIPING MACHINES

In order to meet adequate standards of stripe appearance, a ground speed of 4 to 5 mph. has been found most efficient for our present equipment. Experience has shown that about 1 mi. of wet paint behind the machine is all that can be protected against smears and traffic crossover. Difficulty is often encountered in congested traffic areas in keeping traffic under control with only 1 mi. of wet paint behind the machine. State police help is utilized as much as possible in those areas.

An average striping crew, particularly one using the large self-contained unit, can stripe 20 to 25 mi. per day if the paint dries in 15 min. or less. Some proprietary formulations we have used took as long as 45 min. to dry. In order to protect such material from smearing by traffic, the ground speed of the machine is cut to about 1½ mph. Since the vehicle and personnel requirements are the same as for the faster-drying paint, it is apparent that the cost of application per mile of stripe is more than doubled when the slower-drying material is used.

FIELD SUPERVISION OF PAINT APPLICATION

In the post-war years, the heavy increase in traffic throughout the state made it apparent that closer coordination of state-wide striping operations was imparative in order to achieve uniformity in operations. Since the striping material being supplied appeared to meet nearly all of the theoretical requirements set up by laboratory test methods and good formulating practices, the next step was to attempt to have it applied uniformly in the field. The first step was to eliminate mechanical defects in the equipment. These improvements included: (1) providing spray guns large enough to give adequate flow rates at an economical rate of travel, (2) reducing feed-line friction losses by increasing tubing sizes to the point where reasonable feed pressures would supply sufficient materials to the guns, and (3) increasing the size of the air compressor to the point where not only sufficient air was supplied for normal operation, but an emergency reserve was readily available. These three items have been attended to on all of our machines and the equipment is now capable of satisfactory operation.

Considerable time was lost by some of the crews in transferring the paint into the tanks on the spray machines, especially from 5-gal. cans. By substituting power stirrers for manual stirring, and by furnishing gear pumps to transfer the paint to the tanks, it was possible to supply the paint in 50-gal drums rather than 5-gal. cans. This not only speeded up the loading operations but also saved from 5 to 10 cents per gal. on the purchase price of the paint.

The paint lines and guns often clog after short stops in the field. The time lost in cleaning the equipment on the road was reduced materially by providing a solvent line in the feed system such that the paint feed can be shut off and the lines and guns cleaned by blowing with solvent.

Coating the underside of the spray platform on the self-contained units with heavy grease prevented paint spatters from hardening. The coated platforms are now cleaned quickly and efficiently by merely spraying with solvent.

The external-mix spray guns require proper balance of line pressure and atomizing pressure for efficient operation. It was found that stripe appearance and uniformity were materially improved by instructing each crew on the proper adjustment and maintenance of the spray guns.

Laboratory tests and observations of carefully controlled, experimental field stripes indicated the premixed paint should be applied at a rate of not less than 21 gal. of mixture per mile of 4-in. stripe. The following method of checking field application rates has been developed and has proved rapid and reliable. It can be performed with a minimum of apparatus by nontechnical personnel and is actually used by the field crews to check their own applications:

An ordinary piece of glazed butcher paper, 24 in. long, previously weighed, is placed ahead of the machine and is coated as the machine passes over it. The paper is immediately rolled up and weighed on a 200-gram capacity triple-beam balance. The loss of solvent through evaporation is negligible. By knowing the unit weight of the mixture and referring to charts which have previously been prepared, the application rate in gallons per mile is determined. Pressures and ground speed, which were recorded previous to taking the test panel, are then adjusted until further test panels show that the proper application rate is obtained. The method, while admittedly subject to some error, is accurate enough for practical purposes and has been very helpful in maintaining uniform and adequate paint application.

We have been considering placing some type of metering device in the paint line ahead of the guns so that the gun operator, by reading his pacing disc and flow meter, may have a running check on the application rate. We have not as yet, however, actually installed such a device.

CONCLUSIONS

The quality of a traffic stripe is judged primarily by the satisfaction that it gives the motoring public. Satisfactory service from any striping material is dependent to a great degree on the technical skill of the striping crew. The men must be able to operate the equipment properly, to register closely when retracing old stripes, and to apply new stripes neatly with a minimum of swirls and sharp angles. Cooperation between field crews and laboratory personnel has resulted in a more efficient striping program and a higher quality traffic stripe than was normally obtained before the field-supervision program was instituted.

Field Studies of Traffic Paints

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SYNOPSIS

THIS PAPER reports a field-performance study of traffic-marking paints. In August 1949 eight experimental sections of paints were installed on various types of pavement surfaces. Eleven paints purchased from leading manufacturers were included in the study. Eight of these were installed as plain paints and also as binders for beads-on-paints, while the other three were of the beads-in paint type. All paints were applied with a self-propelled traffic-line striper (Kelly-Creswell, BP-3) which, except for size, was identical in many respects to those used by the department in actual field operations. Extreme care was used to insure a wet-film thickness of 0.015 in.

The paints were installed in duplicate as transverse lines in accordance with ASTM standard method of conducting road-service tests. For comparative purposes, short sections of longitudinal lines of the reflectorized paints were incorporated in the study. One test section was installed on an abandoned road and subjected to weathering only. A further test section was devoted to a study of various bead types and particle-size gradation.

Performance was evaluated at intervals over an 18-month period. Durability and reflectivity were determined by means of visual inspection, a photographic record and night visibility as measured by the Hunter meter. The paints were rated in order of their performance and on the basis of these studies purchasing specifications were prepared. Approximately 80,000 gal. were purchased and applied in 1950. Despite the severe winter, field forces reported this past spring that the pavement lines on primary roads were in generally good condition and that in many cases only spot work would be necessary until late summer or early fall.

● ACCORDING to provisions in Virginia law, materials purchased with state funds must be secured through competitive bidding from specifications written for those materials. This, of course, is intended to secure the best of available materials at the least cost to the state. Similar provisions are found in the laws of most other states. In the parade of ever improving manufactured products the question arises, however, as to just what constitutes the best of available materials. Costly advertising campaigns by competing manufacturers give conflicting viewpoints as to product superiority. The answer often lies in experimental field studies in which competing products are subjected to conditions similar to those they would be expected to encounter in actual practice. In such a manner it is possible to demonstrate and establish product superiority for particular conditions and to do so independently from manufacturers' claims.

This paper reports a field-performance study of traffic-marking paints conducted in Virginia. In recent years the annual expenditure on traffic paints by the state has amounted to well over $300,000. In considering the magnitude of this item, together with other factors such as an ever-increasing traffic volume and new developments in marking paints, it was found desirable to make a study of currently available paints in order to evaluate them as to their suitability for use on Virginia's highways. Prior to the study, the Virginia Department of Highways had used reflectorized paints only for experimental purposes. A change in policy adopting the use of reflectorized paints on all primary highways necessitated the evaluation of available materials and the development of specifications. The specific purpose of the study was to develop specifications that could be used for purchasing reflectorized traffic marking paints.

DESCRIPTION OF FIELD EXPERIMENTS

For this experiment, 11 paints were purchased from leading manufacturers. Eight of these were installed as plain paints and also as binders for beads-on-paint. The remaining three paints were of the beads-in-paint type. Physical and chemical tests were made on these paints by the Division of Tests of the Virginia Department of Highways and the results are reported in Tables 1 and 2. Drying times determined during field test applications are found in Table 3.

In selecting field test sites, due consideration was given to the location of the test sections so as to include such factors as the type of pavement surface, width and number of traffic lanes, volume of traffic, and climatic conditions. In all, eight experimental locations were selected throughout Virginia. These locations are shown on the map in Figure 1. The locations included highways with pavements of portland-cement concrete, various bituminous plant mixes, and mixed-in-place bituminous surfaces. Average daily traffic volumes ranged from about 2,800 to about 11,000 vehicles with the exception of one section for weathering only, over which no traffic passed.

The eight experimental sections were installed in August 1949 under careful supervision and with ideal weather conditions prevailing. All paints were applied with a self-propelled traffic-line striper (Kelly-Creswell, BP-3) which, except for size, was identical in many respects to those used by the Virginia Department of Highways in regular field operations. The laying of a test stripe is shown in Figure 2. Care was exercised to insure that the paints were handled in accordance with the recommendations of the manufacturers. Extreme care was used to secure a wet-film thickness of 0.015 inches. A film-thickness gauge (Fig. 3) was used in all cases except for beads-in-paint.

The paints were installed at each test section in duplicate as transverse lines in

TABLE 1

PHYSICAL TESTS ON TRAFFIC ZONE PAINTS

	Paint Numbers										
Test	1	2	3	4	5	6	7	8	9	10	11
Viscosity - No.3 Ford Cup (Sec.)	119	39	54	121	71	53	51	40			
Viscosity - Stormer (K.U.)	93	75	76	89	86	75	77	71	90	124	91
Weight per gal.	12.25	13.85	12.15	12.65	14.00	13.45	13.20	11.70	14.80	14.9	14.5
Drying Time, Min. (Laboratory)	10	15	12	90	45	35	80	25	30	20	120
Elasticity - 1/4 in. Rod	Very Poor	Good	Poor	Good	Good	Good	Poor	Slight Failure			
Elasticity - 1/8 in. Rod	Very Poor	Good	Very Poor	Slight Failure	Good	Slight Failure	Poor	Poor			

TABLE 2

CHEMICAL TESTS ON TRAFFIC ZONE PAINTS

	Paint Numbers										
Test	1	2	3	4	5	6	7	8	9	10	11
Pigment	59.37	62.05	57.39	60.11	61.34	64.57	60.32	51.75	67.28	69.12	67.41
Vehicle	40.63	37.95	42.61	39.89	38.66	35.43	39.68	48.25	32.72	30.88	32.59
Nonvolatile in Vehicle	35.10	35.73	42.20	46.40	45.78	35.51	38.84	39.83	41.05	34.75	46.76
TiO_2	16.64	5.31	15.13	22.61	6.25	15.58	9.38	28.20	32.17	17.63	58.81
ZnO	5.18	40.83	None		38.76	9.20	1.94	20.09	22.68	5.44	None
ZnS	None	9.47	None		9.77		11.65	None	None	None	None
$BaSO_4$	None	21.98	None	None	22.06	None	38.70	None	None	None	None
Insoluble	68.54	19.43	49.89	9.29	19.93	22.80	15.16	33.84	29.27	64.51	35.13
CaO	0.60									0.50	
MgO	3.64									4.56	
$CaCO_3$			26.80	63.01		47.14	19.40	14.24	11.42		1.98
$MgCO_3$			4.76	2.90		3.73	0.86	3.70	3.46		2.68
Loss on Ignition	6.36									6.90	
Impurities and Undetermined		2.98	3.42	2.19	3.23	1.55	2.91		1.00	0.46	1.40

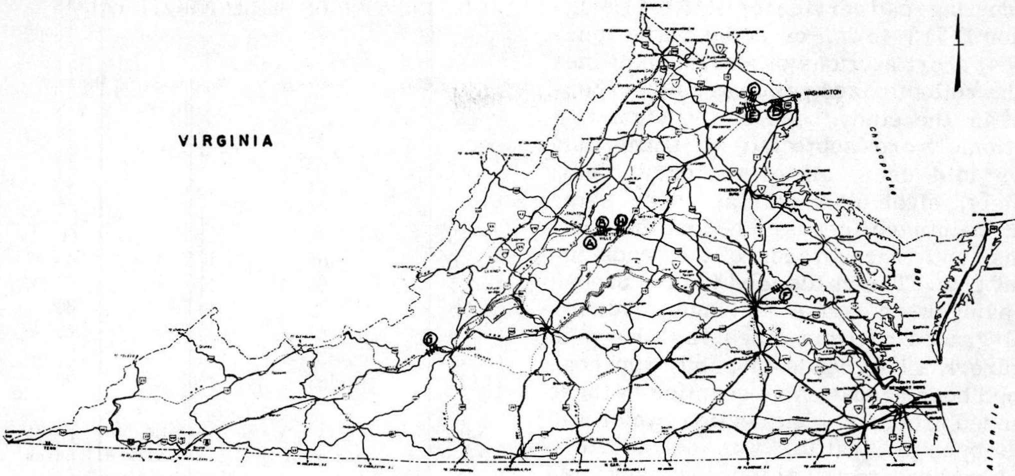

Figure 1. Location of experimental paint sections.

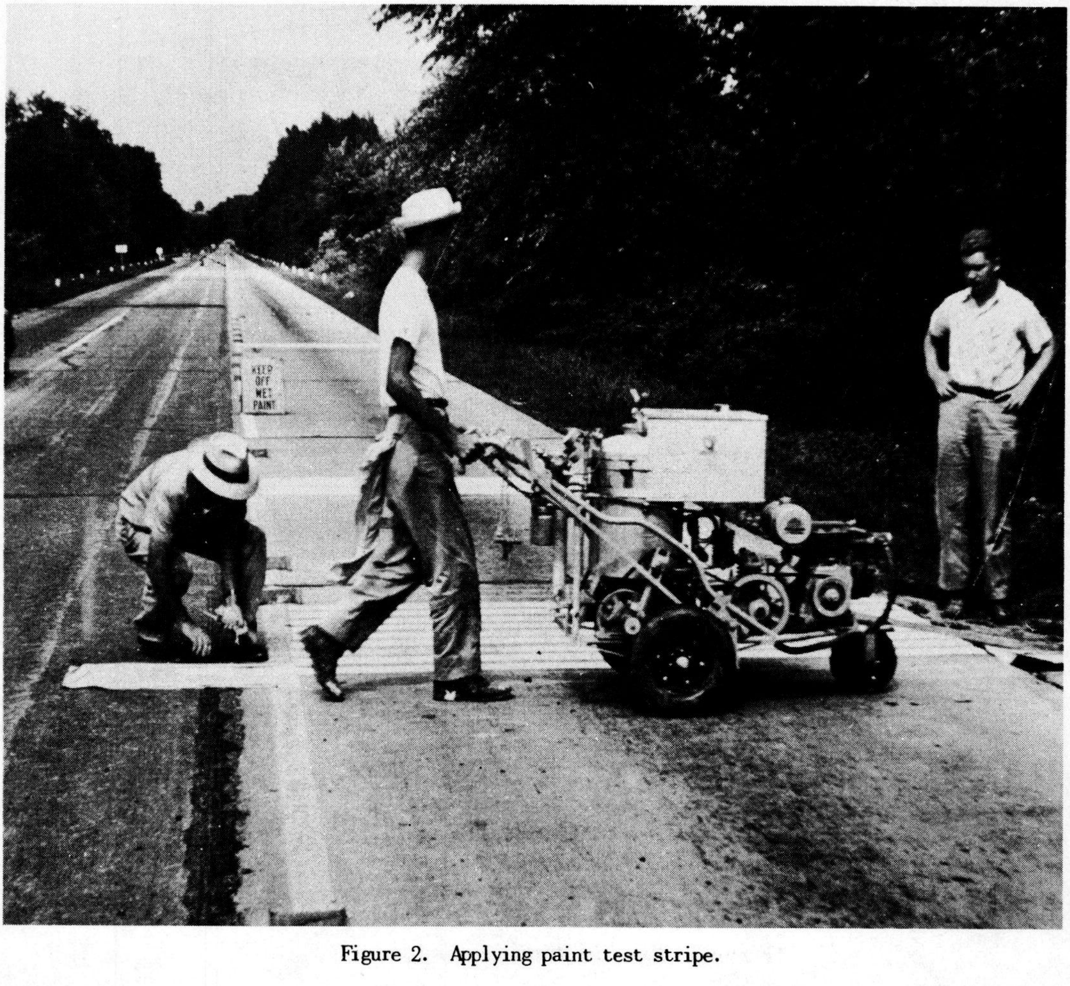

Figure 2. Applying paint test stripe.

accordance with ASTM standard method of conducting road service tests(ASTM Designation D 713-46). For comparative purposes, short sections of longitudinal lines of the reflectorized paints were incorporated in the study. Six of the eight test sections were subjected to traffic and were laid using all of the paint types; namely, eight plain paints, these same eight paints with beads placed on their wet films, and three brands of the beads-in-paint type. The beads used for the beads-on-paint were glass and had medium, well-graded particle sizes, as shown in Figure 4. The beads-in-paint type contained bead gradation as supplied in these branded products. One section, which was also open to traffic, was devoted to a study of bead-material types and particle-size gradation. Plastic beads of one gradation and glass beads of fine, medium well-graded, and coarse particle sizes

TABLE 3

DRYING TIME OF REFLECTORIZED PAINTS

Paint No.	Average *min.*	Maximum *min.*	Minimum *min.*
1	45	75	25
2	43	75	30
3	74	165	45
4	91	120	60
5	99	150	60
6	65	105	45
7	96	170	50
8	79	140	30
9	65	105	40
10	31	55	25
11	163	250	90

Note: Drying time shown is time for paint lines to become thoroughly dry. In all cases this time is longer than that required to prevent picking up by traffic. Values were determined after application of paint at each test section.

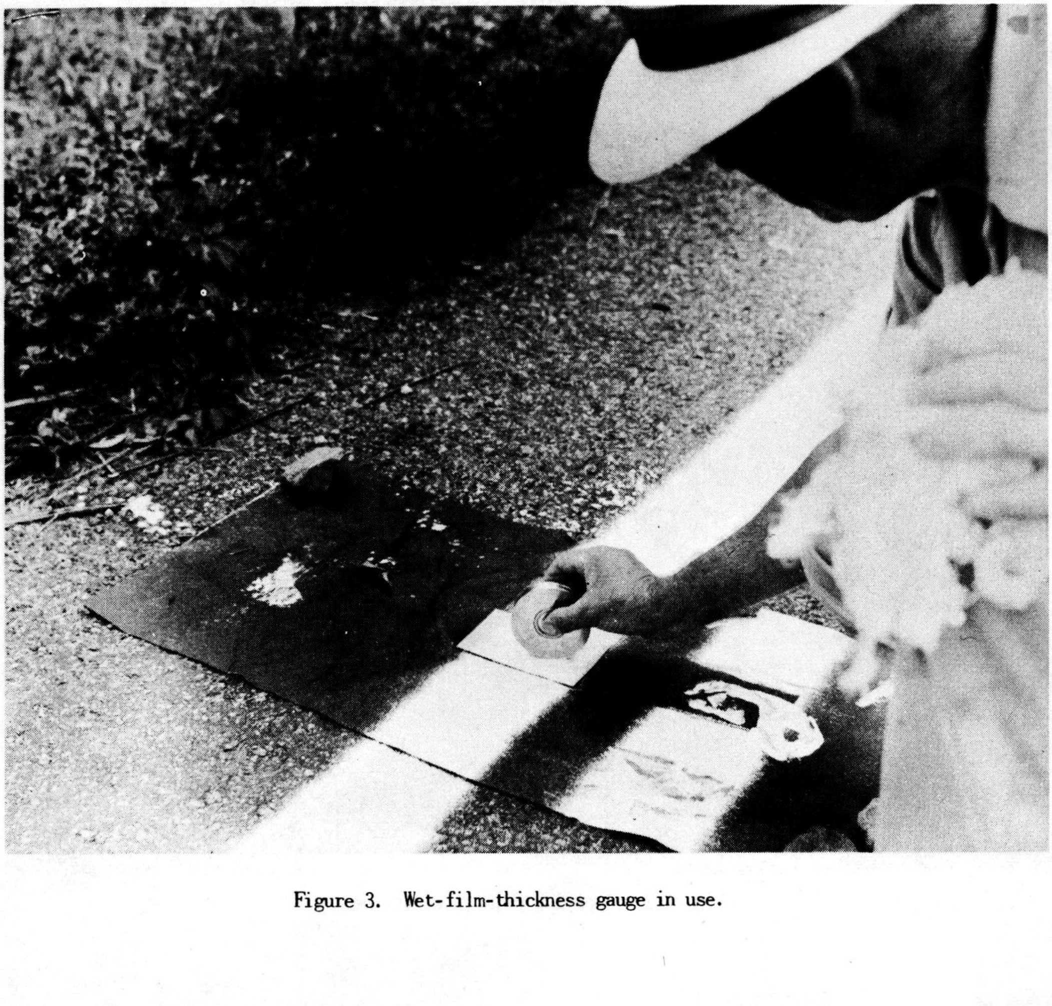

Figure 3. Wet-film-thickness gauge in use.

TABLE 4

PHYSICAL TESTS ON BEADS

Sample	Rounds %	Index Refraction	Average Breaking Load (on 20 - 30 Mesh Spheres) *lb.*	Beads *type*
3	24.0	1.46	Mash Flat at 10 lb.	Plastic
4	78.8	1.54 to 1.56	Too small to test	Glass
5	74.6	1.54 to 1.56	46.7	Glass
6	82.4	1.54 to 1.56	39.6	Glass

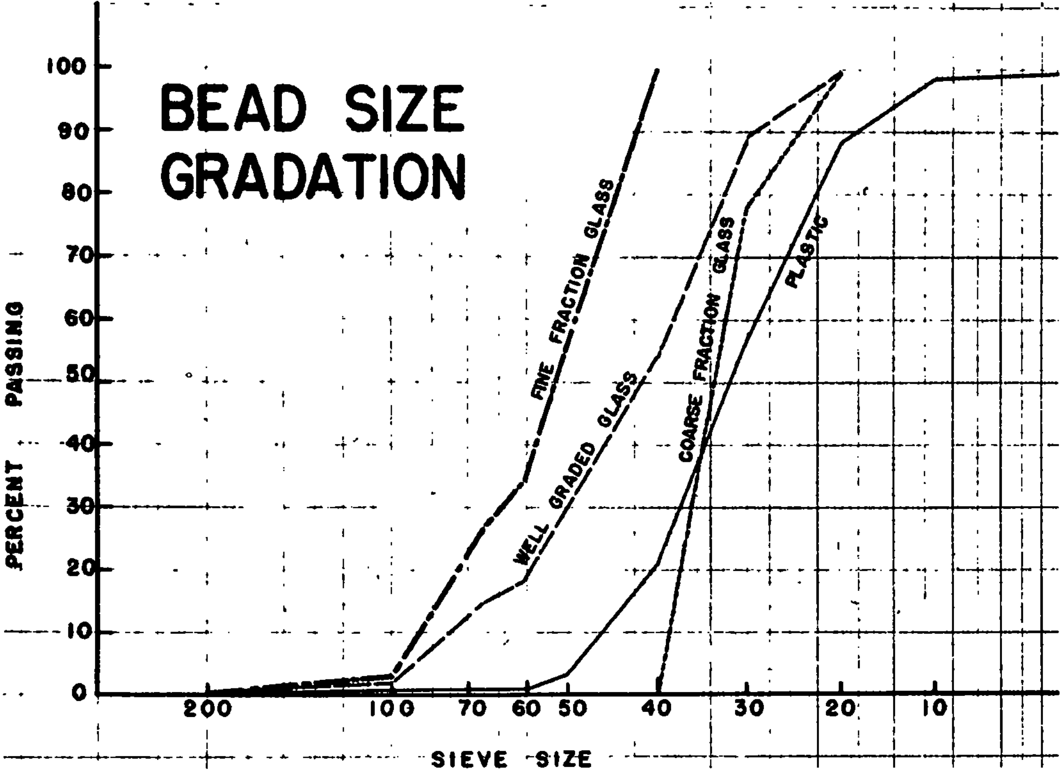

Figure 4. Gradation of beads used for beads-on-paint.

were installed here. Physical tests were made on the beads and typical results are given in Table 4. The particle-size gradations of various typical brands of beads are shown in Figure 4. In addition, one section was placed on an abandoned bituminous pavement and was subjected to weathering only. A general view of a test section open to traffic is illustrated by Figure 5.

TEST DATA

The performance of all test sections was evaluated at intervals over an 18-month period. Two performance properties, durability and reflectivity, were given primary consideration. Durability was determined by visual inspection and was also recorded photographically. To reduce bias in ratings, all observations and photographs were made by the same men throughout the period of study.' Values were recorded as percent failure of the lines.

Reflectivity was measured by means of a Hunter night-visibility meter (Fig. 6), which operates in a manner that makes it possible to simulate reflectance under conditions of night driving. Approximately

Figure 5. General view of a paint test section.

20,000 reflectance readings were taken during the study.

As the data were collected and analyzed, it became evident that the performance of the various paints was dependent upon such variables as pavement type and texture, lane width, number of lanes, volume and type of traffic, and climatic conditions. However, the order of paint ratings was nearly the same for all sections. For this reason, the durability and reflectivity performances as reported here represent the averages of all the test sections.

Durability

The data for failure of the lines in the six regular test sections is summarized in Table 5. From these values, the average failure of the transverse reflectorized lines is illustrated in Figure 7. It is at once evident that some paints withstood traffic wear much better than others. While the order of the paints as plotted on the graph was determined by ranking at age 545 days, it is noted that relative positions would be approximately the same

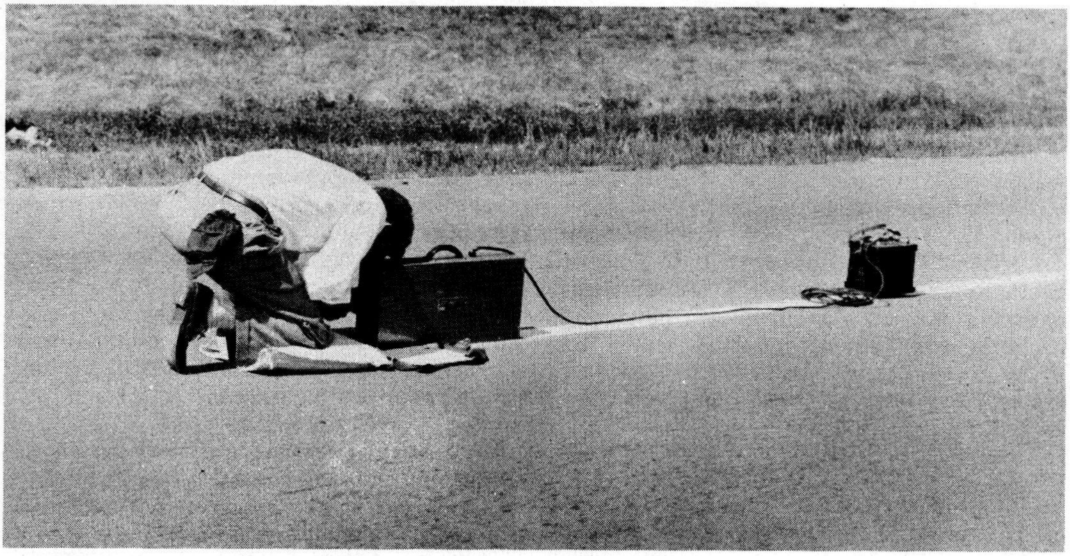

Figure 6. Hunter night-visibility meter in use.

TABLE 5

FAILURE OF TRAFFIC LINES ON SECTIONS B, C, D, E, F AND G AS DETERMINED BY VISUAL INSPECTION

Type Paint	Reflectorized																				Nonreflectorized									
Type Lines	Transverse										Longitudinal										Transverse									
Age Days	138		297		381		476		545		138		297		381		476		545		138		297		381		476		545	
Point No	%	Range	%	Range	%	Range	%	Range	%	Range	%	Rng	%	Range	%	Range	%	Range	%	Range	%	Rng	%	Range	%	Range	%	Range	%	Range
1	13	3-20	42	22-75	55	35-80	69	45-95	79	60-98	6	1-12	31	8-60	43	25-75	59	35-85	79	45-98	14	1-50	59	25-90	63	30-95	75	35-100	84	50-100
2	13	2-25	35	25-45	54	40-75	71	45-90	84	60-98	6	0-15	32	8-45	44	25-60	73	40-98	86	50-100	11	1-25	40	30-75	60	30-85	73	35-95	84	60-100
3	16	10-25	48	30-65	71	40-92	79	45-98	88	60-100	9	1-20	46	18-60	64	35-100	81	40-98	89	50-100	17	8-30	50	5-85	68	30-90	77	35-98	84	50-100
4	6	1-15	15	5-35	25	15-40	35	20-55	50	30-90	2	0-5	10	2-20	14	5-25	25	10-60	39	20-98	10	1-25	23	5-50	35	15-70	45	25-80	57	40-95
5	5	0-15	14	5-27	26	15-35	38	25-55	52	35-80'	2	0-6	11	1-22	21	5-30	32	10-55	48	25-98	9	1-28	25	5-50	38	20-75	48	30-80	61	45-95
6	9	3-15	29	20-40	39	25-45	52	40-70	66	50-95	7	0-15	20	3-40	29	15-30	42	20-80	60	25-100	11	2-20	36	20-50	46	30-75	58	35-90	68	50-98
7	7	3-15	24	10-40	35	20-55	46	30-65	63	35-90	7	1-20	28	12-40	38	25-55	54	35-90	71	50-100	11	3-22	34	15-60	46	30-80	57	35-90	71	50-98
8	4	1-10	16	2-40	28	10-55	40	20-65	54	30-90	2	0-5	15	2-35	25	10-50	37	15-65	59	25-100	6	1-10	26	7-60	36	15-80	46	25-90	56	30-98
9	4	1-10	24	6-50	37	15-75	51	25-90	61	30-95	3	0-10	17	6-40	33	15-65	46	25-100	58	30-100										
10	18	5-35	50	30-85	57	40-95	74	45-100	86	60-100	10	0-20	48	20-95	61	40-96	73	50-100	90	70-100										
11	8	1-25	24	5-45	36	15-75	49	25-90	59	30-98	6	1-15	23	5-45	31	15-65	43	20-98	48	25-100										
Avg (1-8)	9		28		42		54		67		5		24		35		50		66		11		37		49		60		71	
Avg (1-11)	9		29		42		55		67		5		25		37		51		66											

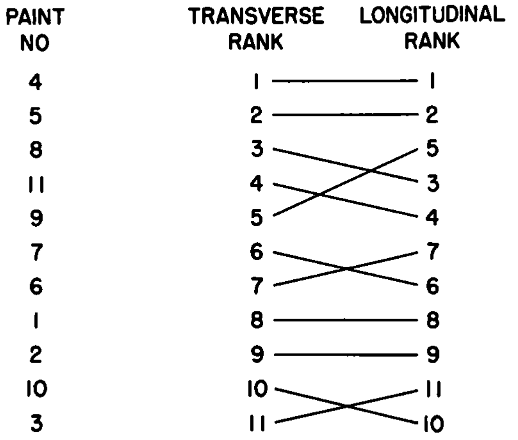

Figure 6(a). Rank correlation of transverse and longitudinal lines rated for durability.

at earlier ages. The several paints on the left would be judged to have superior durability properties, with Paint 4 ranking best. Further examination of the data for reflectorized longitudinal lines and non-reflectorized transverse lines pointed out that in addition to No. 4, Paints 5, 8, 9, and 11 gave a good account of themselves with respect to durability. It is interesting to examine the correlation of relative performance of the transverse and longitudinal test lines. Previous to the experiment, some doubt had been expressed by persons not familiar with testing techniques as to the validity of accelerated tests (such as carried out in the ASTM transverse line method) to determine performance of longitudinal lines as used in actual practice. In Figure 6(a) the paints have been listed in order of durability for the transverse lines at age 545 days. The corresponding rank for the durability of the longitudinal lines are listed in the column at the right in the figure.

The rank-correlation coefficient computed from this data (Spearman's method) is equal to 0.95. Rank-correlation coefficients for transverse and longitudinal performance for durability and reflectance under various other conditions ranged from 0.88 to 0.98. This indicates that good correlation exists between accelerated transverse-line paint tests and longitudinal-line performance under ordinary traffic exposure.

Figures 8, 9, 10, 11, 12, and 13 show the progressive failure of transverse stripes at one of the test sections.

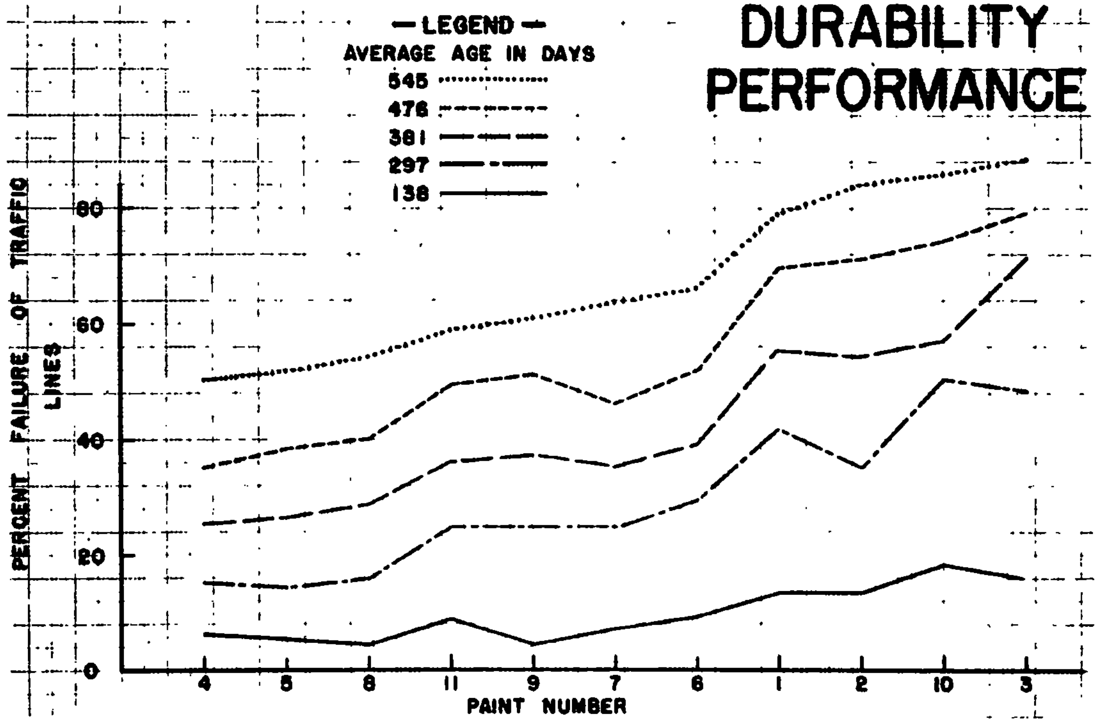

Figure 7. Average failure of transverse reflectorized traffic lines.

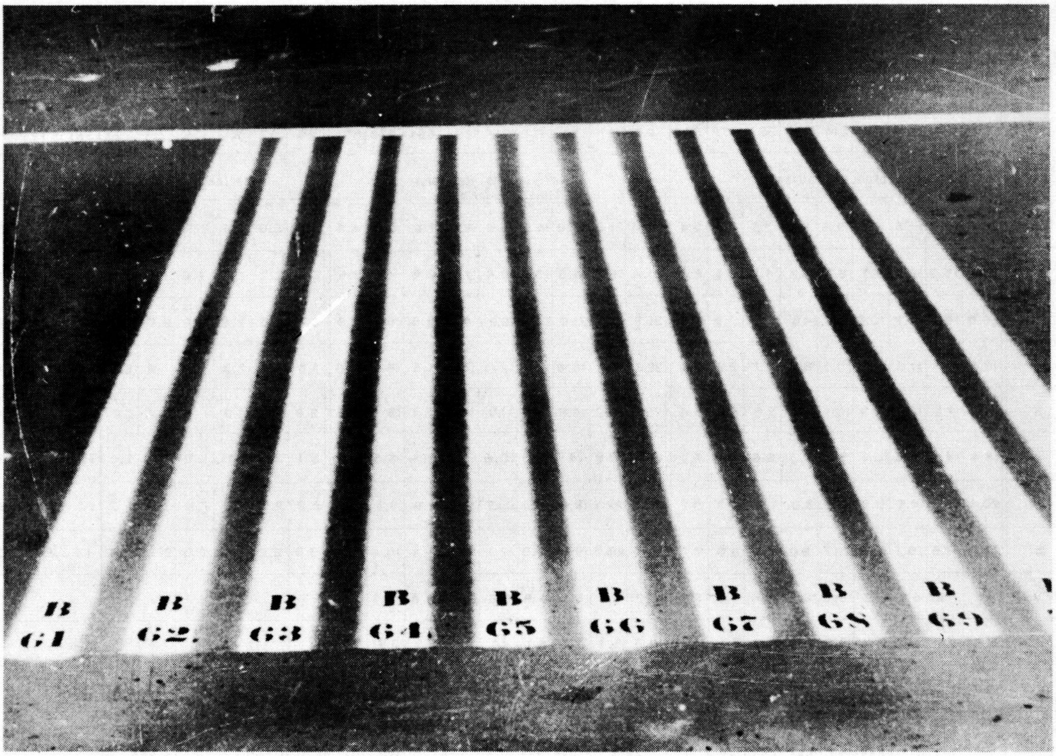

Figure 8. Test Section B at age one day. Note: Section B is on Route 250 in Albemarle County. It is a Type F-1 Paint Mix and carried an average daily traffic of 2,800 vehicles during the test.

Reflectivity

Reflectance measurement of the paints comprised an important phase of the study. The summary values for reflectance measurements are found in Table 7. Certain typical paints with respect to their reflectivity are represented graphically in Figure 14. It was the opinion of some observers that in order for a paint line to give a satisfactory night reflectance, a minimum Hunter meter reading of 10 is required. The problem of establishing minimum reflectance requirements is worthy of further study. All of the plain paints gave uniformly low reflectance readings and decreased gradually with time. The beads-in-paint type decreased in reflectivity for a few months and then increased somewhat as the beads became exposed. One of the three paints tested of the beads-in-paint type gave reflectance values 25 percent higher than the curve shown in Figure 14.

A typical beads-on-paint type, as shown in Figure 14, began with a high reflectance which decreased with age, but which maintained a Hunter reading of 10 at the end of one year. The fourth curve shown in Figure 14 is representative of two of the beads-on-paint type which initially had very-high reflectance properties but which rapidly decreased until reflectivity approached that of plain paint. It was noted that these two paints had poor elastic properties and that apparently the beads were removed from the surface with usage.

Bead Test Section

Some typical reflectance curves for the test section devoted to a study of beads are shown in Figure 15. Reference is made to Figure 4 and to Table 4. It is seen that particle-size gradation of the glass beads appears to have definite influence on their reflectance. The coarse fraction of glass beads (100 percent passing the No. 20 sieve and zero percent passing the No. 40 sieve) produced relatively high reflectance initially, while the fine fraction (100 percent passing the

TABLE 7

SUMMARY OF NIGHT REFLECTANCE READINGS SECTIONS-B, C, D, E, F, AND G

Type Line	Reflectorized Transverse									Reflectorized Longitudinal									Nonreflectorized								
Age Days	24	57	81	114	214	297	381	472	*554	24	57	81	114	214	297	381	*472	*554	24	57	81	114	214	297	381	*472	*554
Paint No	Reflectance Readings									Reflectance Readings									Reflectance Readings								
1	26 5	19 9	14 6	11 9	9 2	6 6	3.5	3 8	3 4	25 3	21 5	16 0	14 0	10 6	8 9	7 5	5 0	4 3	3 3	3 0	2 4	1 9	2 1	2 4	1 2	1 6	2 5
2	19 6	15 7	12.8	9.7	8.3	6.2	4 1	3 4	2 5	21 4	18.3	14 5	13 2	10 4	7 6	2 8	4 9	2 6	2 6	2 2	1 6	1 6	1 8	2 0	1 0	1 4	2 3
3	26 5	19 1	14.7	10.6	6.6	4.8	2.5	2 9	2 4	31 9	24.9	21 0	15.0	6 2	4.8	2.5	6.8	3.4	3 1	2 5	2 2	1 9	2 0	2.0	1 0	1 5	2 4
4	18.4	13.1	11 6	11 7	10 3	8.9	7 1	8.8	8 6	22 5	18.1	15 6	14 7	12 3	13 0	11 5	14 0	10.5	3.5	2 9	2 3	1 9	1 8	2 2	1 1	2 2	2 4
5	18.6	17 2	13.0	10.9	10 1	10.2	9.8	8 2	6 4	22.0	18 2	14 8	13.6	11 0	11 1	12 1	13 6	8 3	2 8	2.3	1 6	1 6	1 7	2.0	1 1	1 5	2 4
6	18 4	14 8	12 5	10 1	9 2	7 3	6 6	6 5	6.2	21.8	15.9	14 5	13 0	10 6	10.1	6 4	9 5	7 9	3 1	2 3	2 1	1 7	1 7	2 0	1 1	1 5	3 1
7	20.4	17 2	14 9	11 2	11 1	8 5	7 4	6 3	5 2	26 5	22.2	19 4	16 1	11 7	9 4	6 9	9 5	6 2	3 2	2 5	2 0	1 8	1.8	1 9	1 1	1 5	2 8
8	23.5	17 5	15 1	12 3	11 7	9.0	6 8	8.0	7 7	29 4	23.3	19 0	17 0	12 1	11 2	11 4	15.6	12 3	3.5	2 6	2 3	2 0	2 2	2.4	1 1	2 1	2 5
9	5 7	4.8	4 5	4 5	6 2	6.4	6 4	7 8	7 0	6 9	5 5	5 6	4 8	5 6	8.1	8 5	12 4	10 4									
10	8 3	6.4	5 5	4 1	3 9	3 9	2 2	3 1	2 4	10 3	6 4	6 3	6 1	4.4	6 9	5 2	8.8	7 9									
11	13.5	8.3	9 5	8 4	10 2	9 5	9 0	9 6	10.4	12 0	10.4	11 0	9 7	11 5	11 1	10 8	13.7	10 1									

NOTE *No readings taken on Section G

For transverse lines, each value represents an average of 60 measurements at the first eight readings and 50 measurements for last reading

For longitudinal lines, each value represents an average of 30 measurements of the first eight readings and 25 measurements at the last reading

The table values were subject to minor calibration corrections

No. 40 sieve and three percent passing the No. 100 sieve) produced initial reflectance of relatively lower values. At an age of 1½ yr. their reflectances were nearly equal. The plastic beads, while containing a high percentage of the coarser sizes, were the poorest performers in the reflectance readings. For the sake of comparison, beads of well-graded glass were placed on a beads-in-paint type and produced the high reflectance also shown in Figure 15. This high reflectivity lasted about three months before approaching values equal to those of regular beads-on-paint. This combination may have application in certain cases where very high reflectance is required.

Weathering Test Section

The test section devoted only to weathering did not produce especially important results. It was observed that the reflectance of all paints was higher than on any of the sections open to traffic and that durability was also greater. Some bleeding was observed, particularly where excessive asphalt was present on the surface.

RESULTS AND CONCLUSIONS

Based on the 18-month study of field performance of 11 traffic-marking paints placed on 8 experimental sections and various type pavement surfaces in Virginia under different traffic conditions. The following results and conclusions have been summarized:

1. The accelerated test as developed ASTM (Designation D 713-46) is a satisfactory method for evaluating service behavior of traffic paints.

2. A good correlation existed between results of the transverse (accelerated tests) and the longitudinal paint line tests under ordinary traffic exposure. Under various test conditions, rank correlation coefficients (Spearman's method) for durability and reflectance ranged from 0.88 to 0.98.

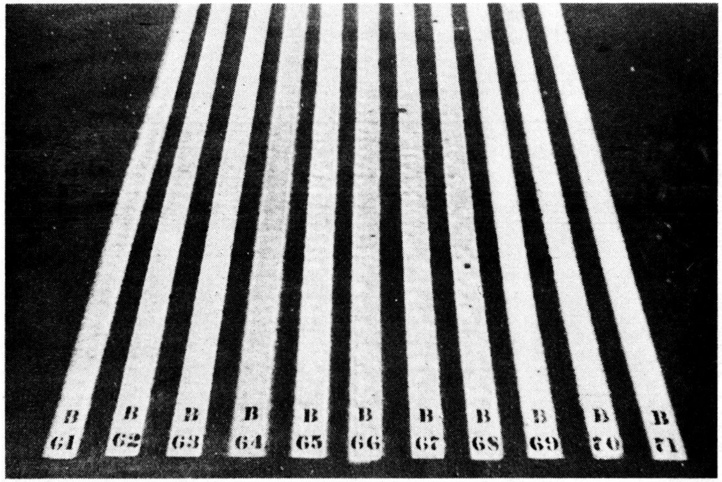

Figure 9. Test Section B at age four months.

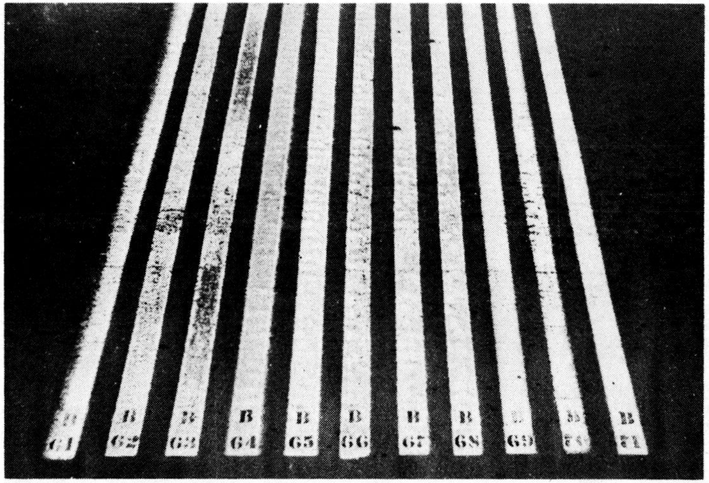

Figure 10. Test Section B at age nine months.

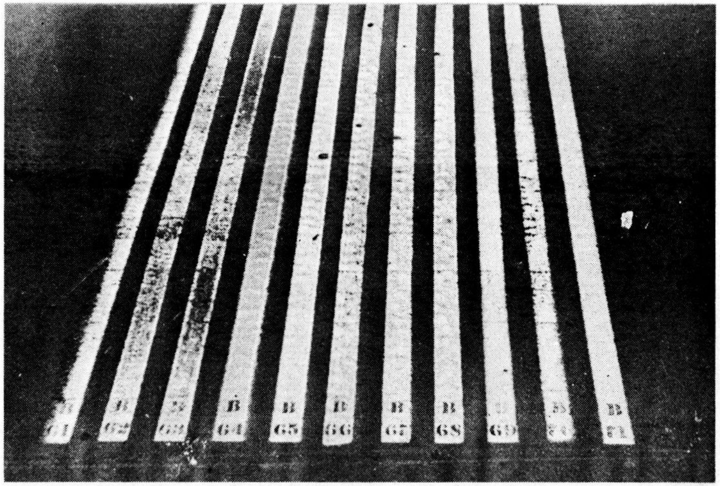

Figure 11. Test Section B at age twelve months.

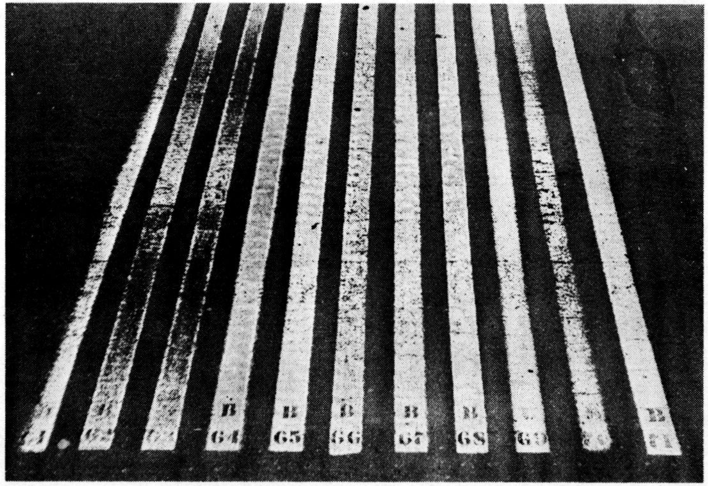

Figure 12. Test Section B at age sixteen months.

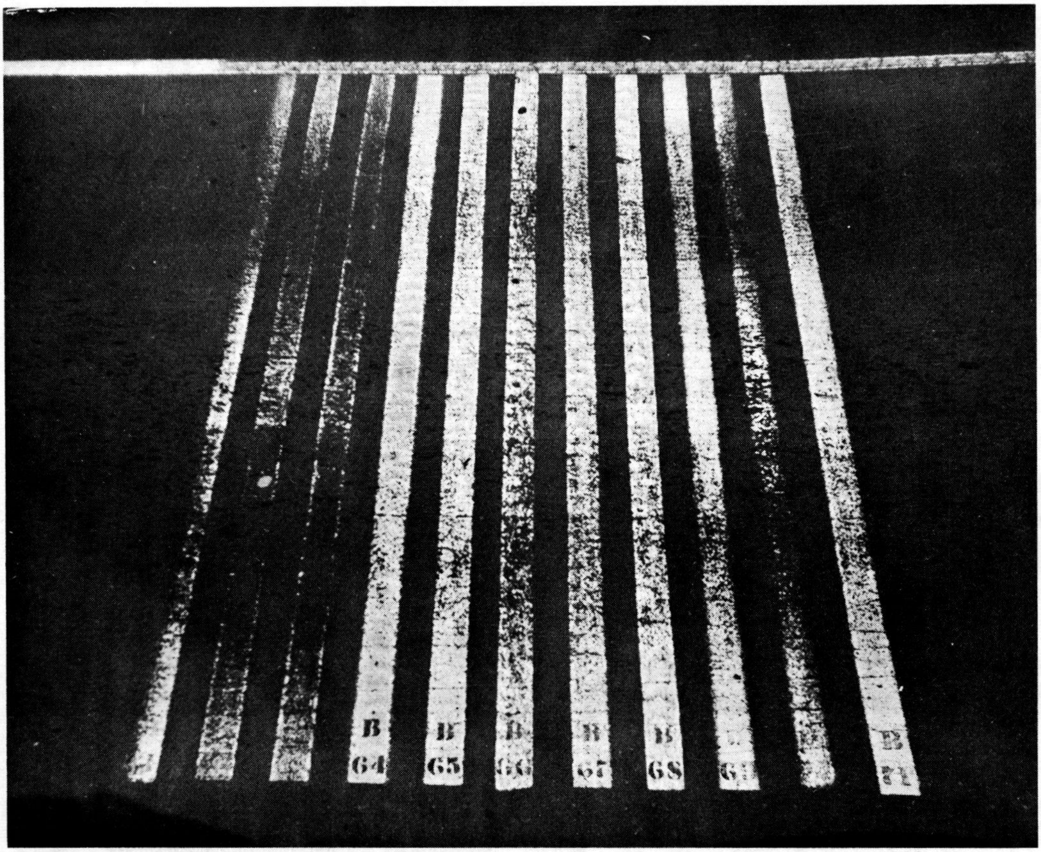

Figure 13. Test Section B at age nineteen months.

3. Except for initial readings, reflectance values on longitudinal lines were consistently higher than those on comparable transverse lines throughout the 18-month period.

4. The composition, type, shape, and size of beads are important factors affecting performance of the beads-on-paint type lines, particularly as determined from reflectance readings. From the experiments it is indicated that the coarse beads (plus 40-mesh) give high reflectance initially, but this is not maintained over a long period. On the other hand, the fine beads (minus 40-mesh) have lower initial reflectance which is more constant with age. The reflectance of graded beads (coarse and fine) is intermediate.

5. In analyzing overall performance, a wide variation was found in the 11 paints tested. The order of ranking the paints at each test section was nearly constant. It was determined that four paints exhibited characteristics which ranked them as being superior in quality. The four top ranking paints in order of performance were Nos. 4, 8, 11 and 5.

6. It is anticipated that the field studies of traffic paints be a continuing one. Periodically, the paints in use by Virginia will be compared under accelerated field exposure with other paints (and perhaps improved types) as they become available.

On the basis of these studies, specifications were developed to secure paints equivalent to Nos. 4 and 5. (It may be pointed out that Paints 8 and 11 were proprietary materials for which specifications were not available.) Specifications for glass beads are given in the appendix.

From competitive bidding on these specified materials some 80,000 gal. of paint and 532,000 lb. of glass beads were purchased and applied during 1950. It is

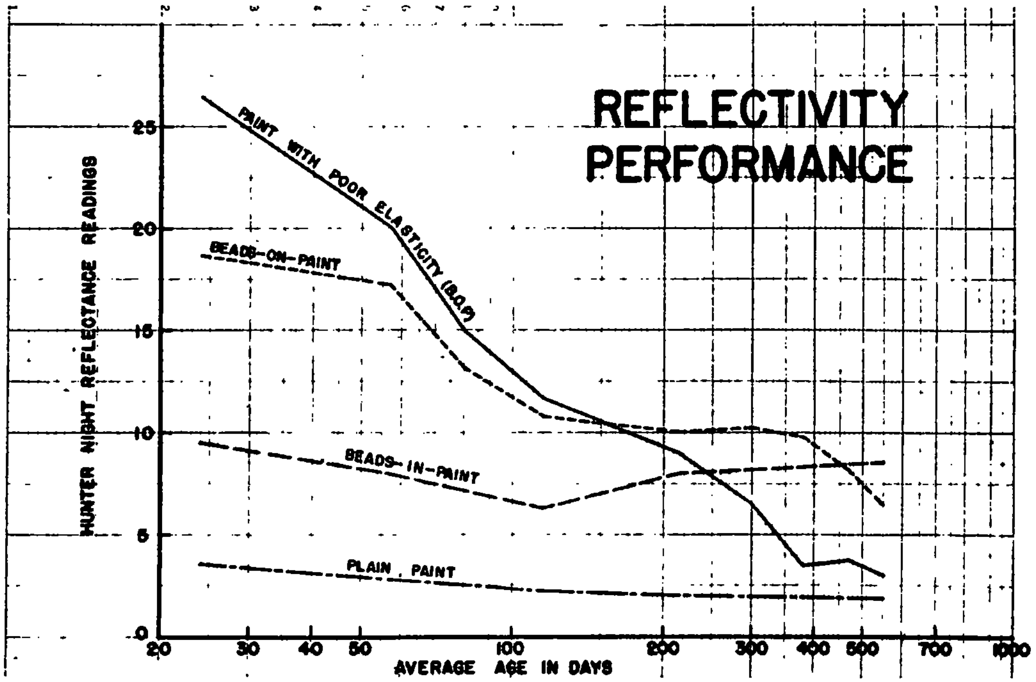

Figure 14. Typical night reflectance readings on transverse lines.

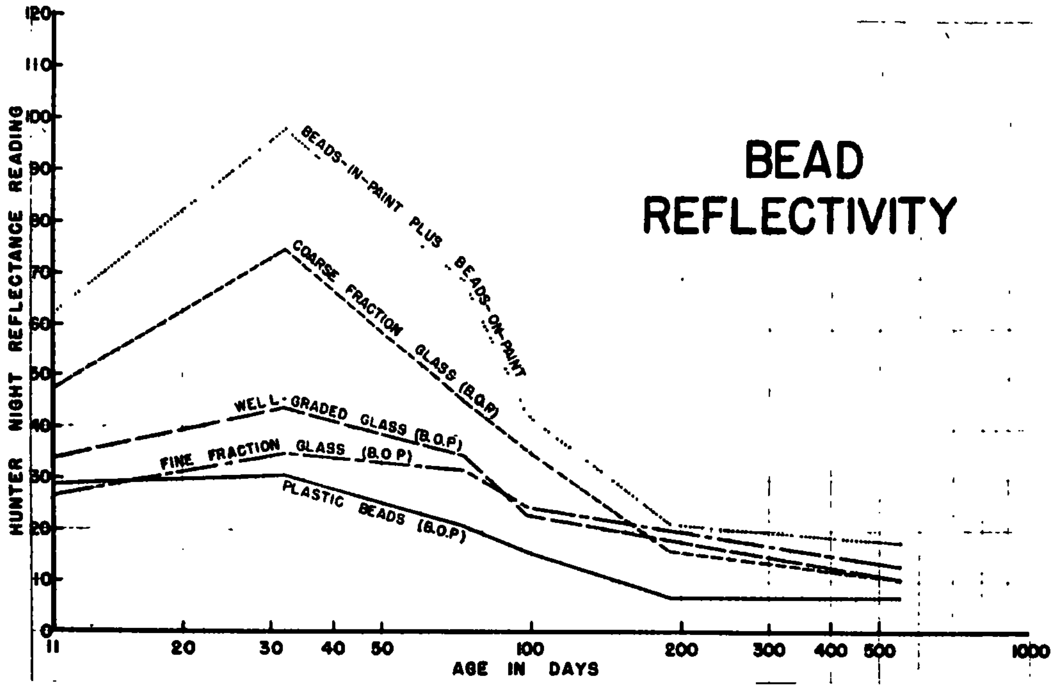

Figure 15. Night reflectance readings for various beads.

important to point out the materials were purchased in 1950 at a saving of approximately $80,000 as compared to the cost of equivalent materials previously used by the highway departments. Performance of the materials purchased under these specifications and applied in 1950 gave very satisfactory performance. Despite the severe winter, field forces reported the following spring (1951) that the pavement lines on primary roads after about one year's service were generally in good condition and that in many cases only spot work would be necessary perhaps until late summer or early fall.

In conclusion, the paint studies have been very beneficial to Virginia's highway department and have demonstrated the savings that may be effected through a small investment in research. It is urged that other states that have not recently made field evaluation of the newer marking paints do so in order to determine which ones are best suited to their particular conditions.

ACKNOWLEDGMENTS

The authors wish to acknowledge the help given in this project. It was initiated and authorized by C. S. Mullen, chief engineer of the Virginia Department of Highways. The work was planned and executed through the Division of Tests, the Maintenance Division and the Virginia Council of Highway Investigation and Research.

Employees of all three cooperating agencies worked together applying and evaluating the paints. However, the laboratory tests were performed by the test division and the night-reflectance readings, as well as the tabulation and analysis of results were made by the research council.

R. L. Sheppe, associate research engineer (now on military leave) supervised the work for the research council. Special acknowledgment is given to C. A. Franklin, a chemist of the test division, and to J. L. Thomas, field engineer in charge of paint crews, for invaluable help and cooperation.

Appendix

VIRGINIA DEPARTMENT OF HIGHWAYS
SPECIFICATIONS FOR
NO. 4 REFLECTORIZED WHITE TRAFFIC-ZONE PAINT
TYPE A
(Test Paint No. 4)

January 31, 1950
Rev. November 15, 1951

General

All traffic zone paint shall be thoroughly ground, shall not settle badly nor cake in the container, shall be readily broken up with a paddle to a smooth uniform paint, capable of easy application with a brush or mechanical distributor in accordance with the rules of good standard practice.

Detailed Requirements

It is intended that this paint shall bind properly graded glass beads in such a manner as to produce maximum adhesion, refraction and reflection. (Beads to be placed on freshly applied line at the rate of 6 lb. of beads to 1 gal. of paint. Wet film thickness of paint to be 0.015 in. The capillary action shall be such as to provide adequate anchorage and refraction without excessive envelopment of the beads.

Composition	Minimum	Maximum
Vehicle	. . .	40%
Pigment	60%	. . .
Titanium Dioxide	24%	26%
Calcium Carbonate	30%	32%
Barium Sulfate	30%	32%
Asbestine	12%	14%

Coarse particles and skins, (total residue on No. 325 sieve based on pigment), maximum 0.5 percent.

Vehicle

The vehicle shall consist of pure alkyd resin, thinners and driers. It shall be free of other synthetic or natural resins. The non-volatile content shall be not less than 45 percent and shall be a glycerol phthalate alkyd containing a minimum of 24 percent phthalic anhydride based on the vehicle solids. The alcohol portion shall be limited to glycerine and the oil portion to refined soya bean oil. The vehicle shall be so processed as to provide a product with an acid number of 5 maximum and color of 7 maximum based on resin solution at 60 percent non-volatile. The volatile portion shall contain not less than 20 percent of a high solvency thinner. (Amsco A type)

Weight Per Gallon

The weight per gallon of the paint shall be not less than 13.2 lb.

Color

It is required under this specification that the color after drying shall be a pure flat white, free from tint, furnishing the maximum amount of opacity and visibility under both daylight and artificial light. The fixed drying oils used shall be of such character as will not darken under service or impair the color and visibility of the paint.

Drying Time

The paint furnished under this specification shall, when applied at the rate of 0.015 in. wet film thickness, dry sufficiently within 1 hr. after application so that it will not be marred under traffic.

Viscosity

Forty-eight hours after this paint has been prepared and put in containers it shall have a consistency of from 80 to 85 K. U. as determined with the Krebs Modification of the Stormer Viscosimeter. An initial viscosity of 80 to 82 K. U. is desired.

Elasticity

A cleaned panel of tin plate (No. 30 U. S. standard plate gauge) measuring 2¾ in. by 6 in. shall be coated with a film of the paint, having a wet film thickness of 0.006 of an in., and baked for 6 hr. in an oven maintained at a temperature of 100C. The panel shall be allowed to cool at room temperature for 1 hr. and shall then be bent rapidly around a ¼ in. rod., The paint film shall withstand this test without checking, cracking, or flaking.

Sample

The color, hiding power, and flatness of the paint furnished under this specification shall be equal to that of a sample mutually agreed upon. When dry it shall show a flat, white, opaque finish, and shall show no graying nor discoloration when exposed to the equivalent of direct summer sunlight for 7 hr. The paint shall show no skinning when a half pint friction top can is half filled, the lid replaced and allowed to set for 18 hr.

A quart sample of paint which the manufacturer proposes to furnish under this specification shall accompany each bid. No bid shall be considered if the sample submitted therewith does not meet fully the requirements of this specification.

TYPE B

(Test Paint No. 5)

January 31, 1950
Rev. November 15, 1951

General

All traffic zone paint shall be thoroughly ground, shall not settle badly nor cake in the container, shall be readily broken up with a paddle to a smooth uniform paint, capable of easy application with a brush or mechanical distributor in accordance with the rules of good standard practice.

Detailed Requirements

It is intended that this paint shall bind properly graded glass beads in such a manner as to produce maximum adhesion, refraction and reflection. (Beads to be placed on freshly applied line at the rate of 6 lb. of beads to 1 gal. of paint. Wet film thickness of paint to be 0.015 in. The capillary action shall be such as to provide adequate anchorage and refraction without excessive envelopment of the beads.

Composition	Minimum Percent	Maximum Percent
Vehicle	36.0	38.0
Pigment	62.0	64.0
Zinc Oxide	40.0	42.0
Lithopone	30.0	32.0
Titanium Dioxide	6.0	8.0
Magnesium Silicate	20.0	22.0

Coarse particles and skins, (total residue retained on No. 325 sieve based on pigment), maximum 0.5 percent.

Vehicle

The vehicle shall be a kettle treated product composed of resins, oils, thinners, and driers so porportioned as to produce a paint of the maximum film elasticity, hardness, durability, and required drying time. The vehicle shall contain not less than 42 percent of non-volatile matter. The non-volatile portion shall contain not less than 55 percent of tung oil. The remainder of the oils shall be linseed oil or dehydrated castor oil. The resin used shall be of the modified phenolic type.

Weight Per Gallon

The weight per gallon shall be not less than 14 lb.

Color

It is required under this specification that the color after drying shall be a pure flat white, free from tint, furnishing the maximum amount of opacity and visibility under both daylight and artificial light. The fixed drying oils used shall be of such character as will not darken under service or impair the color and visibility of the paint.

Drying Time

The paint furnished under this specification shall, when applied at the rate of 0.015 in. wet film thickness, dry sufficiently within 1 hr. after application so that it will not be marred under traffic.

Viscosity

The paint furnished under this specification shall have a viscosity, at 77° F. of from 80 to 83 K. U. as determined with the Krebs Modification of the Stormer Viscosimeter.

Elasticity

A cleaned panel of tin plate (No. 30 U. S. standard plate gauge) measuring 2¾ in.

by 6 in. shall be coated with a film of the paint, having a wet film thickness of 0.006 of an in., and baked for 6 hr. in an oven maintained at a temperature of 100C. The panel shall be allowed to cool at room temperature for 15 min. and shall then be bent rapidly around a ⅛ in. rod. The paint film shall withstand this test without checking, cracking, or flaking.

Sample

The color, hiding power, and flatness of the paint furnished under this specification shall be equal to that of a sample mutually agreed upon. When dry it shall show a flat, white, opague finish, and shall show no graying nor discoloration when exposed to the equivalent of direct summer sunlight for 7 hr.

A quart sample of paint which the manufacturer proposes to furnish under this specification shall accompany each bid. No bid shall be considered if the sample submitted therewith does not meet fully the requirements of this specification.

SPECIFICATION FOR GLASS BEADS FOR REFLECTORIZING TRAFFIC-MARKING PAINT

January 31, 1950
Rev. November 15, 1951

General

1. This specification is intended to cover glass beads for application on traffic paint for the production of a reflective surface to improve the night visibility of the paint film.

2. The beads shall be manufactured from glass of a composition designed to be highly resistant to traffic wear and to the effects of weathering.

Material

The beads shall conform to the following requirements:

1. The beads shall be spherical in shape, and shall not include more than 25 percent of irregularly shaped particles. They shall be essentially free of sharp angular particles, and particles showing milkiness or surface scoring or scratching.

2. Gradation: The beads shall meet the following gradation requirements:

U. S. Standard Sieve	Minimum Percent	-	Maximum Percent
Passing No. 20 Retained No. 30	5	-	20
Passing No. 30 Retained No. 50	30	-	75
Passing No. 50 Retained No. 80	9	-	32
Passing No. 80 Retained No. 100	0	-	10
Passing No. 100	0	-	5

3. Index of Refraction: The beads when tested by the liquid immersion method at 25° C. shall show an index of refraction within the range of 1.50 to 1.65.

4. Crushing Strength: When tested in compression at a loading rate of 70 lb. per min., the average resistance to failure of 10 beads shall be not less than the following:

20-30 mesh size	40 lb.
30-40 mesh size	30 lb.

5. Chemical Stability: Beads which show any tendency toward decomposition, including surface etching, when exposed to atmospheric conditions, moisture, dilute acids or alkalies or paint film constituents, may, prior to acceptance, be required to demonstrate satisfactory reflectance behavior and maintenance under such tests as may be prescribed.

6. Initial Reflectance: When the beads are applied at a rate of 6 lb. per gal. on binder having a wet film thickness of 15 mils, the resulting stripe, at the end of 24 hr. drying, shall show a directional reflectance value of not less than 14 using the Hunter night visibility meter. The binder shall be the Virginia Department of Highways Reflectorized White Traffic Zone Paint or paint of similar pigmentation and non-volatile content.

7. Packing: The beads shall be furnished in units of 100 lb. packed in standard moisture proof bags.

8. Sample: A 5 lb. sample of the material which the bidder proposes to furnish under this specification shall accompany each bid.

Performance Test: Pavement Marking Materials

ROBERT A. BURCH, Traffic Engineer,
North Carolina State Highway Commission

● NOT UNLIKE many other governmental agencies, for many years the North Carolina State Highway Commission purchased pavement marking materials on the basis of formulation specification and lowest cost per gallon.

Most every state-highway department feels it has the best formula, yet there is considerable variation in durability and performance shown by the materials purchased under each of these many specifications. More alarming is the fact that materials purchased under the same specification vary tremendously from year to year.

You have probably heard a state-highway maintenance engineer or a traffic engineer say, "I hope that X Company is not the low bidder this year - their paint didn't last worth a darn last year," or "I hope Y Company is low this year, they delivered a wonderfully durable material the year before last."

This pavement-marking situation is even more serious - it is one of the things that go toward making up the "show case" of the street or highway system. The traffic engineer or the maintenance engineer has been allocated or budgeted certain moneys to be spent for pavement-marking materials. Along comes the purchasing agent who makes an award on lowest price per gallon, spending the traffic or maintenance engineer's money and leaves him with the problem of how it performs.

If it doesn't wear well the traffic engineer or the maintenance engineer must make repeated applications (if weather permits) and be subjected to criticism, official and otherwise, and be unhappy with a line or marking of low average quality.

Therefore, it appears that the problem could be boiled down to a few pertinent factors: (1) Is the material the desired color and does it hold that color? (2) Does the material handle well? Is it easily mixed? Is its shelf life good? Does it apply well? Does it have reasonable drying time? (3) Is it durable? Does it perform?

Now we have said, in effect, we don't care how you make your material - but rather, How does it perform? We are not involved in designing a paint and thus being forced to "sleep in the bed we made." We are putting the burden on the manufacturer to produce a durable, well-performing material for the lowest cost. Thus we leave open the door for research, progress and ingenuity.

So, the question before us now appears to be: What kind of yardstick can we use to determine performance?

PURPOSE

The purpose is to explore the possibility of finding a method to make awards for pavement marking materials on a performance basis.

OBJECTIVE

It is intended to apply pavement marking materials supplied by the vendors to a heavy traffic volume highway. These markings to be applied transversely in order to get accelerated wear and shorten required time of test.

It is anticipated that this test will provide a numerical value of relative performance which can be used as a basis of award with much more accuracy as to the true value of the material than its chemical composition and price per gallon.

MATERIALS

All the material tested was of the premixed reflectorized type. Previous tests repeated over a period of several years rather conclusively revealed that the premixed material gave better over-all performance. Also, the use of premixed material simplified application and eliminated the necessity for additional gadgets on an already complicated machine.

The material was not identified in any way that would disclose composition.

APPLICATION OF MATERIALS

It was decided to apply the test by the same general method of marking currently used by the highway commission, namely, an air-pressure spray-gun arrangement.

All materials were applied on the same day with weather conditions being substantially the same for all.

Realizing that it would be a laborious and tedious job to attempt to apply all materials at exactly the same film thickness, it was decided to load the machine with a 1-gal. sample of a given material, adjust the pressure, etc. to obtain a line as close to the desired uniformity and thickness as visually possible - then to apply the transverse lines across the pavement. The material remaining in the tank was run out longitudinally at the same pressure as was used on the transverse lines. The length of longitudinal line was measured and added to the combined length of the transverse line to give the figure of footage covered per gallon of material.

It is realized that others have used methods approximating laboratory control in the making of "field" tests, and I say "field" advisedly. However, it is open to question whether it is realistic to make field tests with a degree of fineness which can never be achieved in the practical every day use of the material. That is the proving ground where the reckoning of the money spent for it takes place.

RATING OF PERFORMANCE

The method of rating the materials is the nationally known system, as follows:

10	Perfect or absence of failure
9	Good or slight failure
8	
7	
6	Fair or intermediate failure
5	
4	
3	Poor or bad failure
2	
1	
0	Very poor, or poorest degree conceivable, or complete failure.

These ratings were applied to the factors or general appearance, color, and film condition. Numerical photometric readings converted to a scale of 0 to 10 were used for reflection.

The ratings for general appearance, color, and film condition were obtained by periodic visual inspections.

Ratings were made by graduate students and instructors at North Carolina State College who had no knowledge of the identity of the materials.

When a line reached a rating of "3" in any one of the above factors it was considered to have terminated its useful life.

ANALYSIS, EVALUATION AND APPLICATION OF PERFORMANCE RATINGS

It is intended to determine the cost per foot per day of useful life for each material. To do this it is necessary to add to the cost per gallon of each material the application cost per gallon and divide it by the number of days of useful life and the footage per gallon for each material:

$$\begin{array}{l}\text{Cost per foot}\\ \text{per day of}\\ \text{useful life}\end{array} = \frac{\begin{array}{c}\text{cost of}\\ \text{material}\\ \text{per gal.}\end{array} + \begin{array}{c}\text{cost of}\\ \text{application}\\ \text{per gal.}\end{array}}{\begin{array}{c}\text{days of}\\ \text{useful life}\end{array} \text{ x } \begin{array}{c}\text{footage}\\ \text{covered}\end{array}}$$

Up to this point we seem to be getting along fine, that is if we wait for each material to wear out (to reach a rating of "3").

If it had been necessary to wait until each line reached a rating of "3", the test would have lost its usefulness as a tool to aid in the purchasing of materials in the early spring in order to be ready to start marking as soon as weather permits.

Therefore, it was necessary to employ a means of extrapolating to determine the expected remaining life of those lines which had not terminated their useful life.

To do this we have assumed: (1) a perfect line has a rating of 10; (2) a line needs replacement when it has a rating of "3"; and (3) within practical limits the depreciation of a line from a rating of "10" to a rating of "3" is a straight-line proportion.

Therefore, we say,

$$\text{Cost per foot per day of useful life} = \frac{\text{cost of material per gal.} + \text{cost of application per gal.}}{\text{days of test} \times \frac{R_p - R_r}{R_p - R_n} \times \text{footage per gal.}}$$

When

$R_p = 10$, perfect rating

$R_r = 3$, replacement rating

$R_n =$ rating now

Thus we arrive at a numerical value of cost. The material showing the lowest cost in these terms is the material purchased.

CONCLUSION

It is practical to make awards for the purchase of pavement marking materials on the basis of performance. Additional study and research is needed to develop a more convenient practical field method for evaluating the performance and characteristics of material.

RECOMMENDATIONS

1. The development of a reasonably priced, sturdy, direct-reading photometer.
2. The development of a special test striper. Particular consideration should be given to: light weight, more-rapid method of tank cleaning, more-practical and faster handling of small quantities of pavement marking materials generally used in testing.
3. That all tests be applied in early spring to allow for longer evaluation period.

Annotated Bibliography

1924 1. Sawyer, C. L. "White Brick Form Permanent Centerline in Ohio County Road." Engineering News-Record, v. 93, p. 965, 1924.
White bricks were placed in the centerline of a brick road to act as the traffic stripe. Cost of these bricks was $185 per mile.

1925 2. Mattimore, H. S. "Highway Traffic Line Paint." Proc. Highway Research Board, v. 5, pt. 1, pp. 177-184, 1925.
The conditions under which traffic paints are used suggests that the following are the most important factors involved and are those for which laboratory tests of one kind or another are essential in selecting paint for such service: I. Consistency, II. Spreading Rate, III. Hiding Power, IV. Drying time, V. Light Resistance, VI. Visibility, VII, Durability.

3. "Painting Traffic Lines." Automotive Ind., v. 53, p. 1034, Dec. 17, 1925.
Ault traffic line marking machine is manufactured by the Tennessee Tool Works, Knoxville, Tenn. Painting is done by the spray method. An extension spray nozzle is provided for the painting of posts, fences, equipment, etc. It weighs 160 lbs. and is operated by one man.

1926 4. "Brass Cups for Marking Pavements." Roads & Streets, v. 65, no. 3, p. 149, March 3, 1926.
A description of a brass cup used for marking pavements. The cups are 3 in. or 4½ in. in diameter. They are driven in place and are adaptable to asphalt, macadam, wooden block, amiesite, warrenite, and new concrete pavements.

5. "Cost of Traffic Line Marking With Marker Built on the Job." Engineering News-Record, v. 96, p. 780, May 13, 1926.
A traffic line marker capable of marking 8 mi. per day has been put into use in the Santa Ana district of California. The cost of the machine is $35.00 and the cost of marking is $9.00 per mi.

6. Nelson, H. A. & Werthan, S. "Traffic Paint." Ind. & Eng. Chem. v. 18, pp. 965-970, Sept., 1926.
Quantities of paint are being used for marking traffic lines and directions on streets and highways. This paper covers the results of a study of the proper formulating and suitable means for the testing of this type of paint.
The properties of paints designed for this purpose, considered in more or less detail, are consistency, drying, hiding power (opacity), color and color retention, visibility (day and night), and durability.

7. "Permanent Marking of Roads and Streets by Brass Spots." Engineering News-Record, v. 96, p. 260, 1926.
Traffic control information and guide lines may be permanently built into the pavement by use of new brass traffic spots. It is claimed that they are permanent, non corrosive, highly visible, easily inserted, and require no upkeep.

8. "Traffic Lines Easily Marked in Youngstown." Elect. Railway J., v. 68, p. 336, Aug. 28, 1926.
The proposed line is fully marked out and the machine pulled along over this, automatically leaving a clean, white band in its wake.
This road marker is manufactured by the Continental Products Co., Euclid, Ohio.

1928 9. MacDonald, C. "Tar Paint Traffic Lines Increase Road Capacity." Engineering News-Record, v. 100, p. 28, Jan. 5, 1928.

The 3/4-in. radius joints between adjacent strips of concrete are filled with a tar joint filler. Following up the crew which was filling the joints, two men, using the same filler, painted a 4- to 6-in. wide black band on the pavement at these joints.

10. "Marking Streets with Canvas." Engineering News-Record, v. 101, p. 262, 1928.

Strong canvases, paint impregnated, whose backs are coated with an adhesive which makes permanent application easy, have been used for street markings.

11. "Traffic Stripes on California Highways." Concrete, v. 33, p. 36, July, 1928.

In this traffic line marker used by the California Highway Dept., three steel wheels are attached to a light framework of structural steel bars and braced at certain points. Thirteen-inch discs are bolted to two of the wheels to act as a flange or guide along the pavement edge.

1929 12. "Brite Mark Monel Metal Traffic Markers Will Be Shown in Use." Good Roads, v. 72, p. 72, Jan., 1929.

These markers are rust-proof and will not tarnish. They function winter and summer, rain or shine, whereas paint will wash away and is practically useless in winter.

13. "Centerline Painting on Iowa Highways." Concrete, v. 34, p. 30, April, 1929.

Iowa is making use of a specially equipped war surplus truck. It marks a wide black line along the concrete highways at a rate of 2-mi. per hr. Only two men are necessary to operate the equipment.

14. Pope, J. "Rock Asphalt Strip in Concrete Road Makes Permanent Center Line." Engineering News-Record, v. 103, no. 17, Oct. 24, 1929.

A space 1-ft. wide is left in the center of a concrete pavement. This space is then filled to within 1½-in. of the surface with rock asphalt.

15. "Scovill Stop Spot Traffic Markers." Public Works, v. 60, p. 48, Dec., 1929.

A description of a special brass marker which is claimed to remain securely imbedded under heaviest traffic. The marker uses an expanding plug which spreads the lower end as it is driven into place.

1930 16. Beach, A. E. "New Road Marking Equipment." Can. Engineer, v. 59, p. 36, July 8, 1930.

The Littleford trailer attachment is designed to take the place of an operator pushing the Traf-O-Mark along the center of the road following a guide line.

17. Burr, G. D. "Effective Traffic-Line Marker of Cast Aluminum." Engineering News-Record, v. 105, no. 2, pp. 68-69, July 10, 1930.

Discs 4 5/8-in. in diameter and 3/16-in. thick fastened to the pavement with steel pins have proven effective. This article contains a sketch of the marker and method of installation.

18. "Expansion Joints Mark Traffic Lanes, Paving Practice in Los Angeles." Engineering News-Record, v. 105, no. 9, p. 340, Aug. 28, 1930.

The new design consists of spacing the expansion joints and contraction joints so that they are not only adequate for their original purpose but also divide the pavement into traffic lanes of standard width.

19. "Marking Traffic Lanes on California Pavements." Engineering News, v. 104, pp. 408-10, Mar. 6, 1930.

Specifications for paint call for a yellow lacquer that will dry dustproof in 5 minutes and hard in 45 minutes. Analysis of this paint is as follows:

1930 pigment - 30 percent; plasticizer - 2½ percent; nitrocellulose and gum - 27½ percent; solvent and thinner - 40 percent.

20. "Washington Experiments With Street Markers." Elect. Ry. J., v. 74, p. 742, Dec., 1930.

White rubber inserts are the latest of a number of devices to be tried by the Washington Traffic Bureau with the aim of developing a satisfactory traffic lane marker. The inserts are in the shape of a rectangular box with slanting sides 3-in. wide by 2-ft. long by 3-in. deep.

They are expected to be as permanent as the roadbed but the installation is very expensive.

1931 21. Erb, A. K. "Blotting Paint with Sawdust Cuts Costs." Engineering News-Record, v. 107, no. 722, p. 722, Nov. 5, 1931.

An automatic device is described for blotting paint with sawdust immediately following the application of the marking paint. The sawdust blots the paint sufficiently to allow traffic to infringe upon the stripe without causing excessive smearing and has little or no detrimental effect upon the visibility of the line.

22. "Los Angeles Pavement has Built-In Traffic Markers." Eng. and Contr. v. 70, pp. 155-6, June, 1931.

After the concrete had been deposited on the subgrade it was screeded and tamped. A slot was then cut in the fresh concrete to receive the traffic marker. To cut the slot, a guide and wheel were used. The slot was cut to a depth of 3½-in.

23. Stanton, T. E. "State Research Experts Develop Durable Traffic Paint." California Highways & Public Works, pp. 8-9, 11, Dec., 1931.

The material must have certain well-defined characteristics to make it of value for the purpose. It must dry to such an extent in approximately one-half hour or less that it will not be injured by traffic. Other factors to be considered are solution of asphalt by solvents, brittleness of gums, softness of residue, resistance to abrasion action, and retention of color. Extensive investigations have resulted in a specification, which is expected to insure a high grade product with a resultant saving in cost and increase in utility. Further investigations have been conducted to devise equipment for measuring relative visibility.

1932 24. Barker, W. E. "Minnesota's Combined Traffic Line and Expansion Joint." Public Works, v. 63, no. 34, Jan. 1932.

Construction of this joint begins with a heavy wheel pulled by the finishing machine which cuts a groove in the concrete pavement. A built-up T-bar is forced into the groove. After finishing, the T-bars are removed, leaving a joint which, when filled with bitumen, becomes a traffic line.

25. Gardner, H. A. "Paints for Highway Markers." Am. Paint and Varnish Manu. Assoc., no. 410, p. 154, May, 1932.

Many proposals have been received suggesting the use of aluminum paints for highway markers. Results of tests are given showing that panels painted with such a material are hardly visible when viewed by the light of an automobile head light 75 yds. from the panels, with the panels placed at an angle of 30 deg. to the source of the light. This phenomenon is brought about by the numerous shiny scales which act as mirrors reflecting the light only in one direction.

26. "How Shall We Mark Traffic Lanes?" Public Works, v. 63, pp. 28-9, Aug., 1932.

The article discusses different types of markers used in various localities in the United States. These include white rubber markers, metal markers, yellow cotton striping, concrete stripes, asphaltic stripes, and colored paints.

1932 27. "Marking Highways in Indiana." Public Works, v. 63, pp. 36-7, July, 1932.
A centerline marker, material used and season of the year, and cost of marking are discussed briefly. Information is taken from 1931 Report, Indiana Highway Commission.

28. "Necessary Characteristics of Traffic Line Paint." Public Works, v. 63, no. 3, p. 18, March, 1932.
The lacquer vehicle in which the white or colored pigment is ground consists of a nitro-cellulose or a gum dissolved in some highly volatile solvent such as alcohol, benzol, acetone, etc. The residue must be highly resistant to abrasive action.

29. "White Mortar Bands Mark Highway Traffic Lanes." Engineering News-Record, v. 109, no. 19, p. 553, Nov. 10, 1932.
Inlaid strips of white mortar replace painted traffic lines. This account covers the materials and the construction procedures for white concrete inlays and curb surfacing. The materials are white cement, white shiny sand and diatomaceous earth.

1934 30. Bryson, H. C. "Road Marking Paints." Paint, Col., Oil, Varn., Ink, Lacquer, Manu., v. 4, p. 205, 1934.
Good road-marking paints may be made from sodium or calcium caseinate combined with latex in the presence of a stabilizer, with or without a drying oil and containing a fairly high proportion of lithopone, or yellow chrome. Faster drying paints with less hiding power may be produced from spirit solutions of lac, gum copal or the like.

31. "Galvanized Steel Channel Forms Traffic-Lane Marker." Engineering News-Record, v. 112, p. 640, 1934.
A novel, permanent traffic lane marker, forming an integral part of a special light-weight steel and asphalt floor, has been used on the new Dorer Bridge. The marker consists of a heavy weight, 3-in., galvanized-steel channel, laid toes down and arc-welded to the high channels of an interlocking steel channel floor deck.

32. "Raised Center Stripe Used on Mississippi Roads." Public Works, v. 65, p. 14, Nov., 1934.
The raised center stripe is composed of aggregate (crushed stone, gravel, or slag) bound to the surface with a bituminous binder and is applied in one operation. It is 3/8 in. thick and 3-in. to 8-in. wide. A machine is used to do the work.

33. Williams, A. "Rubber Traffic Markers." India Rubber World, v. 90, no. 42, Sept., 1934.
A description is given of molded rubber blocks which are to be used for traffic markers in rubber block pavements. They are also adaptable for use with granite or wood blocks or in asphalt pavements.

1935 34. Martin, G. "Machine Capable of Painting 15 Miles of Stripes Per Day." Engineering News-Record, v. 114, p. 391, March 14, 1935.
This machine, capable of painting 15-mi. of stripes per day, is pushed by a truck. This truck carries the compressor and the paint tanks.

35. Schnell, W. G. "Luminous Highway Paint." Am. Paint Journal, v. 19, no. 23, pp. 52-53, 1935.
The use of luminous paints containing radioactive ingredients for traffic signs on roads is suggested. A new process for obtaining concrete paint preparations from American radioactive minerals will probably render this economically possible.

36. Smith, W. A. "Traffic Striping in California." Roads and Streets, v. 78, pp. 391-3, Dec. 1935.
This is an account of the machines, methods and materials used for striping in California. Specifications are given for a white traffic line marking lacquer that is in use.

1936 37. "Striping Adds Safety to Highways in California. - Review of California Practice Including Equipment, Tests & Paints." Western Constr. News, v. 11, no. 6, p. 198-200, June, 1936.

A review of California practice, including a brief history of traffic striping in California, and a description of the equipment used. A composition specification based on a natural resin vehicle is given, together with test requirements.

38. Sweatt, J. H. "A Machine for Testing the Wearing Qualities of Paints." Maine Tech. Exp. Sta., Univ. of Maine, paper No. 19, June, 1936.

The machine consists essentially of a circular table of concrete to which the traffic paints being tested are applied. This surface is rotated against a tire which functions as an abrading wheel. Power is applied from a ½ H.P. motor by means of a wheel with a tire that serves as one of the supporting bearings for the table.

39. "Traffic Striping in California." Roads and Streets, v. 79, p. 66, March, 1936.

A new type of highway marking in California uses reflector buttons. These are Ross traffic markers and are a non-corrosive metal housing hardened to withstand traffic and so designed that they present no hazard to vehicles passing over them.

1937 40. "Centerstriping Machine Built in Nevada State Highway Department." Contr. & Engr. Monthly, v. 34, no. 2, pp. 1 & 11, February, 1937.

Describes the specification for a special striping machine built by Nevada State Highway Department. Machine is automotive type rear-wheel-drive unit — 94 in. wheelbase and a maximum width of 50 in. Cruising speed of 45 mi. per hr. - paints at 4½ - 5½ mi. per hr. Paint tank holds 65 gal. Spray head assembly is of special design and is non-clogging and self-cleaning.

41. Hickson, E. J. "Some Properties and Tests of Traffic or Zone Paints." U. S. Bur. Standards, Jn. of Research, v. 19, pp. 21-30, 1937: Also, Nat. Paint, Varn. & Lacquer Assoc., circular 532, p. 156, April, 1937.

The article includes the following:

1. Characteristics of the paint are heavy pigmentation, quick-drying, etc.
2. Road exposure tests on eight different types of paints.
3. Machine for accelerated wearing test with photos, description, and method of use.
4. Specification for white traffic paint including the constituents and the results of tests.
5. Specifications for yellow traffic paints.

42. MacGregor, J. "Balto. P.V.P.C. Hears MacGregor on Paints." Oil, Paint & Drug Rep., v. 131, p. 25, May 10, 1937.

In discussing the visibility and durability of highway paints Mr. MacGregor recommended the use of white pigment for the most visible surface and the use of active pigment for the better wearing paint film. The phenomenon of paint failure is caused by the liquid solidifying through gelation and then shrinking.

43. "Modern Equipment for Painting Stripes on Highways." Comp. Air Mag., v. 42, p. 5426, Sept., 1937.

California's highway striping machine paints stripes at the rate of 2 mi. per hr. It is capable of painting a single or a double 4-in. stripe.

44. Nelson, H. A. and Schmutz, F. C. "Accelerated Laboratory Service Tests and Their Possible Use in Specifications for Highway Paints." Repr. Proc. 14th Annual Meeting, Assoc. of New England & N. Y. Res. Engrs., pp. 179-183, 1937.

An evaluation of accelerated weathering tests revealed that these performance tests produce worthwhile results but also have distinct limitations which should be considered before incorporating the tests into highway specifications.

1938 45. Broome, D. C. "Use of Colored or Decorative Asphalt for Roads and Bridges." Journal of the Society of Chem. Industry, v. 57, p. 99-106, 1938.

The mixtures discussed are grouped under headings of mastic, rolled, and rock asphalt; materials in which the principal decorative effect is obtained by the use of colored aggregates, traffic sign mixtures, and paints. Stress is laid on the importance of the bitumen and the pigment employed, and reference is made to the measurement of color, both of the bitumen and of the finished mixture.

46. "General Iron and Steel Corp. Zone Marking Machine." Roads and Streets, v. 81, p. 66, Dec., 1938.

A new zone marker will paint 2-in. to 8-in. width traffic marks. It is a one man machine. Pressure for painting is obtained by pumping the paint with a specially designed pump driven by a 1 H.P. gasoline engine. There are no gages or release valves. The action is simple and positive.

47. Greeves-Carpenter, C. F. "New Reflector Type Curb." Public Works, v. 69, p. 9-10, March, 1938.

Of all the types constructed, it was found that one which had small recesses or reflecting facets was markedly superior. The depth and angle of these reflecting facets naturally determines the degree of visibility created. Two designs were adopted for trial; one, having a wedge-shaped indentation, is particularly effective for use in central dividing strips where traffic parallels the curb; the other is a block type so designed that all faces of the indention are so sloped as to give the maximum reflecting value.

48. "Growing Use of Concrete in Marking Highways." Concrete, v. 47, no. 28, Aug., 1938.

The pigments most suitable for colored concrete are certain metallic oxides, notably those of iron, chromium and manganese, and a few other inorganic materials such as ultramarine and lamp black.

49. Hall, H. W. "Improving Paints, Lacquers and Varnishes by the Use of Diatomaceous Silica." Paint, Oil & Chem. Rev., v. 100, no. 8, pp. 16, 18-20, April 14, 1938.

High quality, carefully-processed diatomaceous silica has a definite place in modern paint, varnish and lacquer production as evidenced by its present day consumption in the industry. Manufacturers recognize the merits of this type of material in formulas for traffic paints and other semi-gloss finishes.

Adoption of traffic paint specifications by a number of states which specify diatomaceous silica in the formulas, also indicate its worth in surface coatings.

50. "Luminous Markings for Highways." Canadian Engr., v. 75, p. 18, Aug. 2, 1938.

Report of a demonstration of "Spectru-Lite" (glass beads applied to paint). Article comments on good visibility obtained and high abrasion resistance of final product.

51. "New Centerline Machine." Roads & Streets, v. 81, p. 64, Dec., 1938.

This machine employs Kelley-Creswell air curtains which maintain straight edges on the traffic line by means of a current of compressed air. This results in the elimination of heavy-edged lines.

52. "Reflecting Traffic Lines." Roads & Streets, v. 81, p. 98, March, 1938.

A coating of glass beads, approximately 0.015-in. in diameter were dropped onto the freshly marked traffic line. It is claimed that the binder compound is not effected by the ultra violet rays because of its chemical components.

53. Reindollar, R. M. "Safety Features Provided Through Pavement Markings." Roads & Streets, v. 81, no. 4, pp. 76-78, April, 1938.

Describes a new type of striping machine that is expected to paint 40 mi.

1938 of road per 8-hr. day. The paint is applied by air pressure, with the unit moving approximately 9 mph.

54. Rogers, E. M. "Inexpensive Traffic Marking Paints." Am. Paint Journal v. 22, pp. 14, 16, 56, 58, May 16, 1938. (Scientific Section, Nat. Paint, Varn. and Lacquer Assoc., Inc., Abs. Rev. N. 57, Jan., Feb. and March 1939).

Formulas given in the state specifications of New Jersey, Illinois, California, Montana, Missouri, Pennsylvania, Vermont and New York are reported. A number of the specifications call for a natural resin e.g. copals.

55. "Saylor-Beall Traffic Line Machine." Roads & Streets, v. 81, p. 74, Oct., 1938.

This machine is capable of laying down 4 mph. A dual spray attachment is available for parallel lines. The complete outfit weighs 150 lb.

56. "Some Efforts to Increase Safety of Night Driving; Luminous Traffic Lines, Reflector Buttons." Roads & Streets, v. 81, p. 48, Aug., 1938.

"Refractolite" binder compound (like paint) is applied to the highway as a traffic line. These glass spheres reflect light to the driver and make the stripe visible for several hundred feet.

57. "White Terra Cotta for Tunnel Road Markers." Brick & Clay Rec., v. 92, p. 12-13, Jan., 1938.

The centerline road markers for a new tunnel are a permanent white, vitreous terra cotta body. Terra Cotta is also used for the side wall below the safety walk.

58. Zinzer, A. L. "Centerline Paint Formulation (for Roads)." Am. Paint Journal, v. 22, no. 17, pp. 26-27, 54-9, Jan. 31, 1938.

Many factors influence traffic paint performance other than paint composition itself. Actual road exposure tests always should be directly comparative with a paint of known composition and performance characteristics, bearing in mind that the road surface is continually changing in character.

It is not economical for a highway department to purchase traffic paint with regard to low gallon price alone. The cost per mile per year must be considered.

1939 59. Barker, W. E. "Rubbed in Traffic Stripes; Pigment Rubbed into Scratched Fresh Concrete." Eng. News, v. 122, no. 107, Jan. 19, 1939.

Pigment rubbed into scratched fresh concrete forms an indelible traffic line. The pigment is rubbed into the top 1/8-in. of finished fresh concrete which is roughened to mix with the color and then is troweled smooth. This practice has been used on recent Texas roads.

60. **Bhattacharya, R.** "Shellac for Road Paints." Oil & Color Trades Journal, v. 96, p. 965, 1939.

A high quality oil-bound distemper produced from shellac (formula given) when tested on bitumen road surfaces lasted for more than two months. This paint dried on a frosty morning in 15-30 minutes.

61. "Colored Concrete for Marking Traffic Lines." Canadian Engr., v. 76, p. 22, May 16, 1939.

Taken from Highway Research Abstracts. A discussion of the general properties of colored concrete, the pigments used and the effect of these pigments on the time of set and the strength.

Pigments used are metallic oxides, especially iron, chromium, and manganese, and a few other inorganic materials such as ultra-marine and lampblack. German investigations in 1936 and 1937 showed variable behavior in time of set, some pigments causing acceleration and other retarding. The strength ratios were not affected beyond experimental error. The surface of the colored concrete may become obscured by efflorescence. This can be reduced by using cement which is thoroughly burnt and well matured and by attention to clearness of the sand and purity of the water.

1939 62. Gardner, H. A. "Physical and Chemical Examination of Paints, Varnishes, Lacquers & Colors." *Institute of Paint & Varnish Research*, Wash., D. C., 9th Ed., p. 44, 1939.

P. H. Hamilton reports the results of tests which indicated that panels painted with aluminum paint were hardly visible when viewed by the light of an automobile headlight 75 yd. from the panels, with the panels placed at angles of 30 deg. to the source of light. White paint because of its chalking characteristics sometimes increases in reflective value, whereas aluminum paints may become soiled by the accumulation of dust and gradually become lower in reflective value.

63. "How Colored Concrete Traffic Lines are Placed into Pavement." *Concrete*, v. 47, p. 30, March, 1939.

Traffic stripes are formed by working mineral oxide in yellow and black into the finished concrete to a depth of $\frac{1}{4}$-in., and hand floating to finish the stripe.

64. Maddox, F. S. "Center Striping; District 15." *Texas Information Exchange*, no. 73, p. 33, July 15, 1939.

Describes use of a split 4-in. paint brush attached to striping machine to prevent the splashing of paint underneath the runners of a small striping machine on open and rough pavements. Several illustrations.

65. "New Type of Road Paint Now Used in Quebec." *Commerce Reports*, p. 1132, Dec. 2, 1939.

One paragraph news note concerning use of a traffic paint containing ground glass. The new paint was reported to be more durable than ordinary paint.

66. "Permanent Lane Markers." *Am. City*, p. 49, Oct., 1939.

The construction of double line markers of white cement and asphalt is discussed. Sketches of the construction are shown.

67. Root, R. "Black Traffic Stripes Made of Asphalt Mastic." *Engineering News-Record*, v. 122, p. 563, April 27, 1939.

A traffic stripe of asphalt mastic about 7/8-in. thick has shown good service in a trial installation at Des Moines, Iowa.

68. Sawyer, J. S. "Specifications for Constructing Colored Asphalt Traffic Lines." *Public Works*, v. 70, no. 10, pp. 20-21, Oct. 1939.

Specifications call for the markers to consist of sand and pigment mixed with "albino" asphalt. In addition the necessary equipment and detailed directions for construction are presented. Development of the Shell Oil Co.

69. Schafer, N. F. "Marking Traffic Lines." *Engineering News-Record*, v. 122, p. 400, March 16, 1939.

A description of the marker used on Indiana highways is given. A heavy cutback asphalt is used on all types of surfaces. Work done when the temperature is below 40 deg. F. and when the pavement is dry is easier because no cover material is required under these conditions.

70. Shuger, L. "Traffic Paint." *Drugs, Oils & Paints*, v. 54, pp. 343-44, 346, 414-416, 418, 420, Oct., Dec., 1939; v. 55, pp.12-15, 126, 128-130, 229-232, 378, 380, 382-84, 385, Jan., April, July, Nov., 1940. In 1940 became *The Paint Industry Magazine*.

Oct. '39: Essential requirements of a traffic paint-methods of test; good package characteristics, proper drying characteristics, short pick-up time, settling, consistency, drying time and visibility are discussed.

Jan. '40: Continuation; hiding power, color retention, and bleeding.

Dec. '39: Continuation; flexibility, abrasion resistance, comparison of road rating to laboratory rating (U.S. Dorry Hardness Abrasion Loss).

April '40: Comparison of present state highway traffic paint specifications.

Composition and requirements for: I. Color, II. Percent pigment in paint;

1939 III. Composition of pigment, IV. Percent non-volatile in vehicle, V. Composition of vehicle non-volatile, VI. Added thinners, VII. Composition of Solvent, and VIII. Oil length.

July and Nov. are continuations.

71. Stalnaker, R. H. "Evolution of the Striping Machine." Calif. Highways and Public Works, Oct., 1939.

A new stripe marking machine has been designed for use in the Division of Highways. Changes in construction include additional capacity, wider range of vision for the driver and an additional tank for yellow paint for use on double line work. Descriptions and photographs of previously used striping machines are included.

72. "Striping for Safety; How It's Done the Country Over." Better Roads, v. 9, no. 4, pp. 33-36, April, 1939.

Description of the equipment used by different highway departments. Odd elongated trucks, hand-pushed carts and 4-wheeled carriages are used in applying traffic lines.

73. "Traffic Paint Formulations." Natural Resins Handbook, p. 91, Am. Gum Importers Assoc., Brooklyn, New York, 1939.

Traffic paint formulations taken from governmental specifications over a wide range of states have been tabulated. All of these formulations have been brought to the same basis.

74. Waters, C. R. "Lane Marking by Broken Lines Placed Automatically by Regular Paint Striping Machine." Roads and Streets, v. 82, pp. 37-38, Dec., 1939.

Describes a mechanism which may be attached to a regular paint striping machine. It provides for the automatic placing of dash lines.

75. Wells, C. D. "Permanent Traffic Stripe on Concrete Pavement." Texas Information Exchange, Texas Highway Department, no. 78, p. 9, 1939.

This article describes procedure for constructing a permanent center stripe in fresh concrete pavement using a dry powder of black magnetic oxide of iron. Illustrations and description of a construction bridge used to cut fresh concrete and from which iron oxide is applied are included. A brief discussion of experimental stripes using orange and red iron oxide with 8 to 10 mesh glass beads is included also.

76. "White Center Line in Ancient Highway in Mexico." Concrete, v. 47, p. 31, May, 1939.

Describes a center line of light colored stones on a section of Mexican highway over 350 years old.

1940 77. "Armor-Flex, New Type Traffic Marker." Roads and Streets, v. 83, p. 89, Sept., 1940.

A plastic marker, 1/8-in. thick, is described that is applied with a special bituminous cement to any type of road surface.

78. "Barford Road Line Marker." Engineer, v. 169, p. 167, Feb. 16, 1940.

Paint carried in the container is gravity fed to the marking roller through rubber tubes connected to the distributor header. When the paint-applying roller is lifted clear of the road, paint control bars fitted across the feed tubes come into operation and the flow of paint is stopped.

79. "B.M.B. Engineering Companies Safety-Line Marking Machine for Roads and Factories." Engineering, v. 150, p. 487, Dec. 20, 1940.

This machine has 3 wheels and is pushed by a man. The paint spray is operated by a pump driven by a four-cycle air-cooled 3/4-horsepower engine.

80. Bryson, H. C. "The Use of Chlorinated Rubber and Diatomaceous Silica in Road Paint." Paint Tech., (London) v. 5, pp. 86-87, 1940.

It is difficult to find a paint capable of withstanding the alkaline salts of the concrete and the aromatic solvents present in coal tar. Casein-based

1940 water paints dry too slowly so the types generally used are cold-cut resin solutions, both natural as well as modified phenolic, coumarone, ester gum and "100 percent phenolic" resins.

Chlorinated rubber is capable of high pigmentation while being resistant to alkaline attack and abrasion.

The use of diatomaceous silica containing a high proportion of spicules gives a high matting effect, decreases drying time and almost doubles the amount of light diffused under night driving conditions.

81. "Experience of Cities with Painted Traffic Lines." Am. Public Works Assoc., Bull. No. 4, Chicago, Ill., Aug., 1940.

The information in this bulletin has been compiled as a result of numerous inquiries which the Association has received concerning painted traffic lines. The bulletin assembles, in convenient form, information on the experience of cities with traffic paint, including durability, frequency of painting, and other pertinent factors.

Specifications in use in six cities are included as well as information on road exposure tests.

82. Hamilton, Russell D. "Traffic Paint Formulation is a Live Subject; Discussion Continued." Paint, Oil and Chem. Rev., v. 102, pp. 24, 26, Sept. 26, 1940.

The failure discussed here is a vehicle deterioration forming a white film which is very unsightly over a dark colored enamel. This whitening is caused by exposure first to sunlight, then to moisture. On white or light color no bad appearance is noticed; however for darker shades appearance is very unsightly. It is concluded that Manila D.B.B. cannot be used satisfactorily for the darker shades of traffic paints.

83. Haufe, K. "The Stability of Concrete Road Marking Sign Paint." Kurt Haufe-Asphalt Teer Strassenbautech, v. 40, pp. 447-54, 1940, Nat'l Paint, Varn. & Lacquer Assoc., Abs. Rev., no. 83, p. 116, 1944.

Tests are described comprising road application, resistance to cold, heat and water; the Reich Auto Bahn paint-testing machine, the Graf test machine, and the Freilager test, with test forms, details, data and illustrations.

84. "'Invicta' Traffic-Line Marking for Roads (Machine by Aveling-Barford, Lt'd.)" Engineering, v. 149, no. 3867, p. 209, Feb. 23, 1940.

This is a hand marking machine, very small and compact, that is pulled along by a handle.

85. "Kelley-Creswell Traffic Striping Machine." Roads and Streets, v. 83, p. 91-92, Sept., 1940.

This machine is designed to mark 1, 2 or 3 stripes at a time using one or two different colors. Intermittent dot-dash striping may be applied.

86. Kesting, B. G. "Permanent Traffic Lines for Concrete Pavements; Use of Black Magnetic Iron Oxide for Coloring." Public Works, v. 71, no. 42, Sept., 1940.

A stripe 6-in. wide and embedded to a depth of 1/8 to ¼-in. is used. Specifications call for the coloring material to be magnetic oxide of iron, or ferrosoferric oxide, made by a process of chemical precipitation so as to form a pigment of uniformly small particle sizes.

87. Kopf, C. W. & Mantell, C. L. "Traffic Paints." Paint, Oil & Chem. Rev., v. 102, pp. 7-8, 28-30, May 23; pp. 44-46, 48-49, June 6; pp. 9-11, 24-27, July 4; pp. 10-11, Oct. 24, 1940.

I. Natural resins in quick drying traffic paints: Natural resins, because of their own low cost and their solubility in cheap solvents, are fitted for traffic paint use and have found wide acceptance. This report includes a discussion on desirable properties, on colors, on California vehicle formula, natural resins in traffic paints and a summary of formulations.

II. The effect of Chinawood and other oils in quick drying vehicles: Different paint formulations were used on test stripes on a bituminous surface along the Brooklyn waterfront and on a concrete highway. The application on asphalt was made to determine the effect of bituminous roads on the color of paints. This discussion on durability is based solely on the results from the concrete road tests while the color was from both applications.

III. Formulations and performance tests of quick drying vehicles, with photographs: The addition of asbestines makes better paint.

88. Meyers, J. E. "Survey of Traffic Paint Testing Procedures." Highway Research Abstracts, pp. 6-8, March, 1940.

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.

Questionnaires were sent out on November 20, 1939, to the representatives of 51 state and city organizations as to the type of work and tests they perform. Fifteen had been returned and the results are given here.

89. "New Multi-Stripe Road Marker Used by Nevada State Highway Dept." Comp. Air Mag., v. 45, p. 6243, Sept., 1940.

This machine is capable of painting three stripes simultaneously. It is a small vehicle pushed in front of a truck, and is capable of painting a white center stripe with a yellow stripe on each side.

90. "Paints for Traffic Line." Highway Research 1920-1940, Highway Research Board and American Association of State Highway Officials, Washington, D. C., pp. 107-9, 1940.

An annotated list of research projects conducted or initiated during the period 1920-1940 on the subject of traffic paints. Studies include abrasion testing, performance tests, paint formulation, etc.

91. Skett, A. and Holzberger, J. H. "Preliminary Study of White Traffic Paints." Am. Paint Journal, v. 24, pp. 18-19, 22, 24-25, April 22; pp. 18, 20-22, 65-69, May 6, 1940. (Scientific Section, Nat. Paint, Varn. and Lacquer Assoc., Inc., Abs. Rev. No. 62, p. 60, April, May, June, 1940.)

Part I. Three series of paints were made up. Each series contained different forms of natural resin. The paints were applied in a transverse manner on a road in a stripe 6 in. wide and 10 ft. long. Six ounces of paint were used on each stripe. All three series were brittle due to insufficient plasticizing.

Part II. Linseed, blown soybean, bodied perilla, oiticica, bodied fish, dehydrated castor and blown castor were used in an attempt to plasticize a paint using Manila resin as a base. Blown castor proved best, dehydrated castor and bodied fish oil next, linseed, soybean and perilla intermediate, and oiticica definitely inferior. Addition of gum elemi had no effects upon the basic formula. The pigment - binder ratio was varied and the optimum pigment volume was 35 - 40 percent. A tung oil to resin ratio 2:8 or a little better is about optimum. Titanium-Calcium pigment gave the best results of the pigments used. Thermally processed Batu scraped is the resin used. Traffic paints of equal performance can be made with spirit type vehicles as with cooked vehicles.

92. Stanton, T. E. "Traffic Paint Article by Kopf and Mantell Stirs Interesting Discussion." Paint, Oil and Chem. Rev., v. 102, pp. 15-16, Aug. 1, 1940.

Stanton defends the California traffic paint formula against criticisms by Mantell and Kopf. Stanton disagrees that castor oil is superior to Chinawood oil as a plasticizer. California tests showed that in addition to inferior durability, castor oil was found to be slower drying and to possess a higher gloss when fresh. The California procedure for manufacture of traffic paints is given.

93. "Traffic Painting in St. Louis." Public Works, v. 71, no. 6, p. 30, June, 1940.

A special paint machine which has resulted in savings in labor costs and in paint used has been put into use in St. Louis. This paint machine instead of marking a single 6-in. stripe, marks 3 stripes, each 1½-in. wide with a 3/4-in. spacing between.

1940 94. Waters, C. R. "High Speed Highway Lane Marking With Automatic Device for Dash Lines." Public Works, v. 71, p. 34-36, May, 1940.

This machine puts down solid or broken lines, two-color if desired, one or more lines, 20 to 40 mi. per day. Description and operation of equipment is given.

1941 95. Bloom, S. A. "The Place of Chemistry in Highway Materials Control." Highway Builder, pp. 4-7, 17, June, 1941.

A discussion of method of tests and testing problems related to various highway materials. The discussion on traffic paint includes a list of desired properties of the paint, also the necessity for a sand-paper texture for visibility is shown. The difficulties in measuring durability because of the many variables are discussed. The proper design of test instruments to correctly evaluate reflector buttons is also covered.

96. Bryson, H. C. "Road Paint." Oil & Color Trades Journal, v. 99, p. 175, 1941.

Spirit-soluble Manila copal gums are widely used in road marking paints. Spirit-soluble ester gum is cheap, possesses a uniformity beyond any natural product and has excellent resistance to water and to discoloration by light and tar products. Solvent-retention characteristics are overcome by the addition of a high viscosity ethyl-cellulose solution. The wear factor is considerably increased. A formula is included.

97. "Colored Lane Speeds Traffic on Mountain Highways." Concrete, v. 49, p. 4, Jan., 1941.

Red oxide was added to portland cement in Tennessee and Kentucky to color an extra truck lane on long grades.

98. Corder, Leon W. "Center-Striping Missouri Highways." Better Roads, v. 11, no. 3, March, 1941.

Missouri practice of traffic striping is a state-wide program. Describes equipment used for striping, method of laying the stripe, types of paint used and the author's ideas on the future development in traffic painting.

Missouri is conducting experiments on the use of ester gums and alkyd resins as substitute for natural gums.

99. Edelstein, Edwin. "Zinc Resinate Traffic Paints." Paint Industry Mag., v. 56, pp. 347-48, Oct., 1941.

Twenty or more paint formulations using cheap zinc resinates were tried in service. Included in each group of paints was one made according to specifications quite commonly used by various State Highway Departments.

Listed are three complete formulations that are now in use with suggested modifications.

100. Glanville, W. H. "Plastic White Lines for Roads." Roads & Bridges, v. 79, no. 12, p. 48, 1941.

A description of the British development of a thermo-plastic material to be used as an alternate to traffic paint. Details of the composition, grading, and manufacture of the plastic material are given. The material is recommended only for open and medium-textured bituminous road surfaces which must be clean and dry. Preliminary tests indicate that a useful life of at least six months may be expected. (This article is essentially the same as that appearing in Commonwealth Engr., v. 29, no. 5, pp. 120-121, Dec. 1, 1941 under the same title).

101. Goetz, W. H. "Field and Laboratory Investigation of Traffic Paints." Proc. Highway Research Board, v. 21, pp. 233-259, 1941.

Only durability of traffic paint is considered. Object of study was to establish a correlation between field performance and laboratory tests and to determine the characteristics of the paint film necessary to good durability on the road. Samples of traffic paints tested represent the specification material of eight different states. Old concrete, new concrete and bituminous surfaces were used. Special attention has been given to abrasion and flexibility tests.

1941 102. Herbert, M. S. "Some Effects of Pigmentation upon the Durability of Traffic Paints." Am. Paint Journal, v. 25, pp. 14, 18, 20, 24, 58, 60, Aug. 11, 1941. (Scientific Section, Nat'l Paint, Varn. and Lacquer Assoc., Abs. Rev. No. 68, p. 228, Sept. and Oct., 1941).

Consumption of traffic paints is constantly increasing. Tests were conducted by painting cross-lines on roads where the traffic was from 1,800 to 5,700 cars per day. The paints were applied by a Line-O-Graph on a smooth stretch of road. The consistencies of all paints were determined before use. The study was divided into four parts; effect of inert extenders, effect of pigment volume, effect of white prime pigments, and effect of colored pigments. Results have shown that with proper pigmentation the modified California lacquer, which contains no China Wood oil, has good durability characteristics. The durability of 12 specification traffic paints which were used as controls was generally inferior to that of the experimental paints.

103. Mantell, C. L. and Kopf, C. W. "Traffic Paint." Paint, Oil & Chem. Rev., v. 102, no. 22, pp. 10-11, Oct. 24, 1940. (Nat'l Paint, Varn. & Lacquer Assoc., Abs. Rev., no. 64, p. 2, 1941).

The writer adds another chapter to the forum on traffic paint formulation by answering an open letter relative to the use of Manila DBB gum in traffic paint.

104. "Marking Highway Lanes with Stone Chips (Stones Sealed with Asphalt)." Engineering News-Record, v. 127, pp. 27-8, July 3, 1941.

Stripes of contrasting stone chips are being used in experiments in lane marking on highways in Texas and South Dakota. These stripes may be applied at low cost and have been found to show up well in all kinds of weather.

105. Mattiello, Joseph J. "Protective and Decorative Coatings." John Wiley & Sons, Inc., New York, v. 1, p. 239, 1941.

The Manila resins are widely employed in traffic paints, of which a typical formulation is given. These traffic paints dry to a semi-gloss finish in half an hour or so to form hard surface films which resist abrasion by the wheels of vehicles, do not pick up in traffic, and withstand a wide range of climate, weather conditions and temperature changes.

106. O'Brien, M. A. "Tiny Glass Beads Used to Make Traffic Lines Brighter at Night." California Highways & Public Works, v. 19, no. 1, p. 16, 1941.

The process of placing glass beads in traffic paint has proved successful in making the striping brighter and more effective at night. Manufacturer's claims are that use of beads approximately doubles the life of the painted lines. A method of application is described and photographs are included.

107. O'Brien, M. A. "Improving Night Time Visibility of Traffic Lines - California." Roads & Road Constr., v. 19, pp. 102-103, 1941.

A report of California experiments with glass beads on traffic paint. Good reflection is obtained and the beads are cleaned by traffic. The higher costs of application and cost of beads limit their use to special cases.

108. "Plastic White Lines for Roads." Commonwealth Engr., v. 29, no. 5, pp. 120-121, Dec. 1, 1941.

A description of the British development of a thermo-plastic material to be used as an alternate to traffic paint. Details of the composition, grading, and manufacture of the plastic material is given. The material is recommended only for open and medium-textured bituminous road surfaces which must be clean and dry. Preliminary tests indicate that a useful life of at least six months may be expected.

(This article is essentially the same as that printed under the same title - by W. J. H. Glanville, in "Roads & Bridges," v. 79, no. 12, p. 48, 1941).

109. "Research on Marker Paint." Roads & Bridges, v. 79, p. 25, Oct., 1941.

Editorial comment on the advantages of glass beads in traffic paints and a description of its wide usage in Canada. The need for additional research to develop more rapid drying time and bead-holding properties is cited.

1941 110. Schafer, N. F. "Centerline Marking on Indiana's Pavements (Stones Sealed with Asphalt)." Public Works, v. 72, no. 2, pp. 17-18, Feb., 1941.

Black and white traffic lines are discussed. Brief specifications are given for applying the lines with cutback asphalt on light colored surfaces and for white marks on black surfaces.

111. Skett, A. and Herbert, M. S. "Accelerated Testing of Traffic Zone Paints." Proc. Highway Research Board, v. 21, pp. 223-232, 1941.

The purpose of this investigation was to determine the practical value of laboratory tests used at the present time to evaluate the actual durability of traffic paint under service conditions. Nine paints were used in the investigation; - 6 white and 3 yellow. Eight laboratories cooperated in laboratory tests. Paints were applied to 12 localities for service tests. General conclusion drawn was that no one laboratory test, or combination of laboratory tests is sufficient to evaluate correctly the relative durability of traffic paints.

112. Skett, A. and Holzberger, J. H. "Progress in Natural Resin Research." Am. Paint Journal, v. 26, pp. 7-9, 60, 62, 64, June 2; pp. 56-59, June 9; pp. 18, 20, 22-23, 26, June 16, 1941; Fed. of Paint and Varnish Production Clubs Official Digest, no. 207, pp. 346-361, 1941.

This work is concentrated on cold cut varnishes. The formulation of the best white Manila spirit paint thus far found is given. It is superior to cooked vehicles in color, color retention, drying, non-bleeding properties, ease of manufacture, and lower in cost.

Among the cooked paints very little difference is shown in durability between Batu, Pale East India, and modified phenolic.

Blown castor oil is superior to china wood, dehydrated castor, fish, soya and linseed oil in the Manila paints, but poorest with Batu and Pale India resin. The most promising oils with these latter resins seem to be dehydrated castor, china wood and fish.

113. "Texas Improves Traffic Stripe (Stones Sealed with Asphalt)." Roads & Streets, v. 84, p. 54, June, 1941.

This stripe is built up to about 1/4-in. thick. Small black stones are spread into the asphalt stripe on concrete surfaces. It is non-skid, non-glaring and its visibility is good.

114. "Traffic Lines." Sci. Am., v. 164, p. 298, May, 1941.

Method used in California to increase the effectiveness of the traffic stripe after dark utilizes glass spheres or beads. These reflect headlight beams and hence make the traffic stripe more visible.

To apply the beads, a bead dispensing machine is placed directly behind and approximately 18 in. away from the spray nozzle.

115. "Traffic Paints." New Jersey Zinc Co., Paint Progress, v. 2, no. 4, p. 8, Oct., 1941.

Highway departments have been considering raw materials such as Batu (natural) resin, zinc resinate, and combinations of ester gum with dehydrated castor oil, oiticica and other oils for use in traffic paints. In order of durability, the best two white formulations of this type at the present time are a 50:30:10:10 titanated lithopone-zinc oxide-mica-magnesium silicate pigment combination in a cooked Batu resin-linseed oil vehicle, and the same pigment combination in a "cold-cut" Batu resin-processed oil vehicle.

116. "Traffic Paint Substitute (Soybean Oil)." Engineering News-Record, v. 127, p. 881, Dec. 18, 1941.

Soybean oil has been substituted for tung oil in traffic paints. Experimenters think it will prove a very satisfactory substitute.

117. "Trends in Traffic Stripes; Advances with Zinc Pigments." New Jersey Zinc Co., Paint Progress, v. 2, no. 3, pp. 6-8, July, 1941.

Traffic paints must be fast drying. To obtain this the paint chemist must pigment his product high and decrease the non-volatile constituent of

1941 the vehicle. The vehicle is most often manipulated to meet varying climatic conditions and "non-bleeding" requirements.

In the final analysis, the object is a paint having satisfactory durability and economy. For this reason, the zinc sulfide pigments - lithopone and titanated lithopone have been widely used.

118. Wells, C. D. "Permanent Traffic Stripe in Fresh Concrete." Concrete, v. 49, p. 6, July, 1941.

In Texas, placement of a permanent stripe by incorporating magnetic black iron oxide in the freshly placed concrete has been practiced. Three pounds of oxide were found necessary per 100-ft. length. The equipment and procedure for applying the stripe are discussed.

1942 119. Cullimore, W. H. "Modern Brick Pavements - A Review of Recent Practice and the Development of Centerline and Traffic Lane Markers." Roads & Streets, v. 85, no. 1, pp. 49, 52-53, Jan., 1942.

The installation of permanent brick lane markers of clearly contrasting color insures the engineer of full utility of the street width between curbs. Brick may be used effectively as permanent lane markers on other type pavement surfaces.

120. "805 Paints in New Jersey Zinc Traffic Paint Testing Program." New Jersey Zinc Co., Paint Progress, v. 3, no. 3, pp. 2-3, Oct., 1942.

Paints have been applied in many localities and on many types of roads. The majority of tests have been on concrete highways in Pennsylvania. The paints fail more rapidly and show greater differences between good and poor paints on concrete surfaces.

The results of these tests have been shared with paint manufacturers and consumers, and have contributed to the development of new and improved paint finishes based on zinc sulfide and zinc oxide pigments.

121. Flocks, K. "Paint for Traffic Control. 1941." U. S. 2, 232, 023 Nat'l Paint, Varn., & Lacquer Assoc., Abs. Rev., no. 71, p. 42, 1942.

A discussion on the use of fine glass rods embedded in painted road lines. There is a great increase in night visibility.

122. Lotz, P. L. "Project No. 1 - Traffic Paints." (Consolidated report) Official Digest, Federation of Paint & Varnish Production Clubs, no. 212, pp. 4-9, Jan., 1942. (Scientific Section, Nat'l Paint, Varn. & Lacquer Assoc., Inc., Abs. Rev. no. 72, p. 90, July, 1942.)

Summaries of work by several Production Clubs on paints to camouflage roads are given. Formulae recommended include cold cut Manila, Batu or East India, cold cut resin, casein in oleoresinous vehicles.

123. Mantell, C. L. & Others. "The Technology of Natural Resins." John Wiley & Sons, Inc., New York, pp. 373-408, 1942.

I. A discussion of the desirable properties of traffic paints.

II. Table containing 39 traffic paint formulae from 26 states of the Union. These formulae use both oil and spirit vehicles.

III. Data on the formulation, and laboratory test results of several traffic paints.

IV. Photos showing different paints after having been on the road for a period of time.

124. Mitchell, R. A. "Glass Beaded Paint for Blackout Traffic Control." Engineering News-Record, v. 129, no. 20, p. 720, Nov. 19, 1942.

White paint surfaced with glass beads has been found superior to any other type of painted pavement marking. 500 miles of this type have been laid in Philadelphia and found to be very satisfactory.

Although glass-beaded paint costs more than twice as much as ordinary traffic paint, experience shows that it wears 4 to 5 times as long.

125. "Night-Time Visibility of Surface-Dressed Traffic Lines." Public Works, v. 73, no. 10, p. 22, Oct., 1942.

1942 Road Research Laboratory in Great Britain has been studying the production of white traffic lines by use of white or light colored stone chips held to the surface by tar or asphalt. The visibility of different size and texture stone chips is discussed.

126. Shisler, J. A. "Permanent Lane Markers at Canton." Engineering News-Record, v. 129, p. 221, Aug. 13, 1942.
The center marker strip is a solid line of marker brick formed by the overlap of two lines of the buff colored brick, while the intermediate marker strips are formed by laying a buff colored brick in every other row of bricks.

127. Shuger, L. and Rodli, G. "Marker (Prismo Holding Corporation)." Nat'l Paint, Varn. & Lacquer Assoc., Abs. Rev., no. 72, p. 93, 1942.
A reflecting pigment binder is described. This marker is said to have great durability and resistance to shock.

128. Shuger, L. and Rodli, G. "Road-Marking Lines." Nat'l Paint, Varn. & Lacquer Assoc., Abs. Rev., no. 74, p. 202, 1942. Leroy Shuger - U. S. 2,268, 537, Dec. 30, 1941; C.A. 38, 2743 (1942).
Lines are formed with the use of a reflecting binder comprising a pigment, a non-volatile oil, and a resin, with a series of autocollimating units such as small glass spheres partially embedded in the binder, the ratio by volume of pigment to non-volatile oil and resin being less than 50 percent. U. S. 2, 268, 538 relates to various details of laying similar markers.

129. Skett, A. and Holzberger, J. H. "Traffic Paint Studies - 1941." Am. Paint Journal, v. 26, pp. 56, 58, 60-61, March 16; pp. 51, 54, 56, 58-59, March 30; pp. 52-53, 56, 58, April 13, 1942. (Scientific Section, Nat'l Paint, Varn., Lacquer Assoc., Inc., Abs. Rev. no. 73, p. 167, August 1942.)
A study of a variety of paints exposed in three locations indicates that Batu resin in cooked varnishes is superior to modified phenolic. Tung oil gives the best durability, but linseed oil is almost as good. Batu spirit varnishes are almost as durable as cooked varnishes. Pigment formulas for Batu, East India and Manila spirit paints are recommended.

130. "Surface-Dressed Traffic Lines." Surveyor, v. 101, no. 2630, pp. 207-9, June 19, 1942; also, Roads & Road Constr., v. 20, no. 235, pp. 147-152, July, 1942.
White or light colored chippings are held to road surface by tar of bitumen.
The most important feature of the surface dressed line is that it shows to a better advantage at night. This is because the surfaced dressed line retains a rough textured surface which reflects light at night. Dimensions of the line, type of stone chippings, size of stone chippings, type and viscosity of binder and rate of spread of binder are discussed.

131. "Testing the Wearing Properties of Traffic Paints; Data of Interest Where Paint is Subject to Abrasion." New Jersey Zinc Co., Paint Progress, v. 3, no. 2, p. 2, July, 1942.
It is recognized that the major factor causing failure is the wearing, chipping, and abrasion action of traffic, rather than normal weathering. New Jersey Zinc Company's instrument for measuring abrasion resistance consists of multiple rubber discs set at an angle of ten degrees with a straight arm holding them. When these wheels are rotated, both a rotating and sliding action are obtained. A layer of sand supplies the abrasion factor.

132. "Traffic Paint, Exterior, White and Yellow." Federal Specification TT-P-115, April 29, 1942.
Paints meeting the specification must show wear properties equal to or better than white and yellow comparison paints that are given.

133. "Traffic Zone Paint." Roads & Bridges, v. 80, p. 118, March, 1942.
A summary of an investigation conducted by the Highway Research Board of Canada. Six white and three yellow paints were selected for study. Ten

1942 cooperators tested each of the samples by his own methods. The conclusions arrived at are given. The chief points brought out are that road-testing is the only reliable method for testing traffic zone paints; a laboratory abrasion test used by some cooperators gave good correlation if the average of a number of tests was used, but the need for modifications was apparent; flexibility tests as conducted showed striking lack of agreement indicating a need for more study on the methods of testing.

134. Waters, C. R. "The Production of Highway Signs and Marking of Highways in Peace and War." Proceedings of 18th Annual Convention, Assoc. of Highway Officials of the North Atlantic States, pp. 31-52, 1942.

A discussion of the methods and materials used for signs in the shops of the New York State Department of Public Works. Electrolytic processes for zinc coating are used since the zinc is not removed with the paint in case of sharp impact such as caused by bullets, stones, etc. Synthetic resin paints of the glycerol phthalate type are used for painting and the silk screen process is used for stenciling. For reconditioning removable signs the same procedure is used as for manufacture, but heavy cast iron signs of a permanent nature are reconditioned by spray painting in place.

For pavement markings a "pushmobile" is described which paints at approximately 15 mph. - for word messages a stencil and hand spray are used.

The three major types of traffic paints are listed i.e., the spirit varnish, the oleoresinous, and the lacquer. The extent of use for each of these is given. A report of tests to compare the service behavior of the California type (spirit varnish) paint with a New York paint which is specified on the basis of performance tests is given. These tests were inconclusive as to the relative durability but the California paint was superior for night visibility during the first two months after application and the California paint dis-colored less on bituminous surfaces.

A discussion of pavement markings and materials to be used under blackout conditions is included.

135. Wethan, Sidney. "Performance Tests as an Aid in Maintenance of Traffic Paint Quality." Fed. of Paint & Varn. Prod. Clubs. Official Digest, no. 213, pp. 75-93, Feb., 1942. Paint Industry Mag., v. 57, pp. 82, March, 1942. (Scientific Section, National Paint, Varnish and Lacquer Assoc., Inc., Abs., Rev. no. 73, p. 166, August, 1942.)

Especially during periods of raw material shortages, adequate performance tests are necessary to evaluate paint products. Many tests are already accepted for traffic paints, but methods of measuring some properties are still to be standardized. Night visibility may be evaluated in a dark room with conditions of illumination and view similar to road conditions, by visual comparison with a standard. Drying time is tested with a loaded wheel. A portable machine driven by hand for determining resistance to wear is described. Results correlate well with road tests. Some suggestions on formulation are given.

136. "White and Yellow Traffic Paints." Nat. Paint, Varn. & Lacquer Assoc. - Circ. no. 632, p. 13 & 17, Jan. 15, 1942.

General requirements are given for paint that shall be ready mixed and suitable for either concrete or bituminous surfaces.

Detail requirements include drying properties, hiding power, color and daylight reflectance, consistency, flexibility, bleeding test, and water resistance.

White and yellow paints are compared and discussed.

1943 137. "Bead Striping for Dimout Areas Now Regular California Practice." Concrete, v. 51, p. 38, Oct., 1943.

The mixing of glass beads with traffic paint for center striping has become standard practice on all principal highway routes in California. There is no sparkle to indicate the presence of beads; the line is simply brighter at night. The operation of a bead dispensing machine is described. The average diameter of the beads is about 1/100 in. Improved methods of handling have reduced the cost to the point where the process may be economically used on main highways.

1943 138. Davis, W. W. "Measuring Optical Properties of Reflectorized Materials." Traffic Engineering, v. 14, no. 2, p. 27-29, Nov., 1943.

A report of the test method developed by the Army Engineers for measuring the optical properties of reflectorized materials such as paint with glass spheres for lane markings or signs. The equipment consists of a goniophotometer in which the test surface may be illuminated at various angles and a photoelectric receptor. Minimum requirements for optical properties of reflectorized materials recommended for military traffic control are given. A discussion on measuring the optical properties of reflectorized materials is included. Mr. R. S. Hunter, Bureau of Standards, Washington, D. C. assisted in preparing the paper.

139. Dawson, D. H. and Skett, A. "Accelerated Testing of Traffic Zone Paints." Proc. Highway Research Board, v. 23, pp. 267-272, 1943.

The effort to correlate laboratory tests on traffic-zone paints with practical road service tests has been continued.

Ten white paints differing widely in durability characteristics were applied on nine roads in New Jersey, New York and Pennsylvania. They were observed throughout their life and graded by several observers. Observations were made over a 15 to 18 month period.

The same paints were submitted to seven cooperators for tests with particular emphasis on the use of abrasion tests and overall ratings, using a variety of laboratory testing methods.

140. Edelstein, Edwin. "The adaptability of Resinates in Present-Day Formulation Problems." Paint, Oil, & Chem. Rev., v. 105, no. 7, pp. 12-14, 16, April 8, 1943.

Due to their greater availability, there is now considerable interest in methods for processing the soft oils so as to convert them into fast drying, high viscosity vehicles of satisfactory stability.

The quick solvent release demonstrated in the Sward Hardness Rocker Tests, together with the properties of fair water resistance, excellent compatibility with zinc oxide and outstanding adhesion to all kinds of surfaces makes the zinc resinates exceptionally well suited for traffic-paint formulation.

141. "More Than 800 Paints Used in Extensive Traffic Paint Testing Programme." Canadian Paint & Varnish Mag., v. 17, pp. 5-6, 42, April 15, 1943.

An announcement of a program of testing by the research division of the New Jersey Zinc Company and a general discussion of the need for such tests. (No information as to the paints used or the results obtained is given.)

142. "Reflector Beads and Safety." Western Constr. News, v. 18, no. 5, p. 217, May, 1943.

Use of these beads increases visibility greatly. They are only about 1/100-in. in diameter and give no impression of roughness or irregularity. They become embedded to about ½ of their diameter and are practically immune to crushing. A striping machine constructed by the California Division of State Highways will paint three stripes simultaneously and drop glass beads into the wet paint.

143. "Road Marking for Blackout Conditions." Public Works, v. 74, no. 9, pp. 47-8, Sept., 1943.

Tests show that embedding glass beads in the paint used for road markings more than doubles the visibility under blackout conditions. It has been found valuable for marking and numbering airports.

A white centerline on concrete is of practically no value. A black line on concrete is observed 30 percent of the time. On bituminous surfaces a white line was 40 percent effective. When glass beads, about 1/10 in. in diameter, were embedded in the paint, the line was 83 percent effective on concrete and 90 percent on bituminous surfaces.

144. "Substitute for White Paint Road Markings." Roads & Bridges, v. 81, pp. 31-32, June, 1943.

The material presented in this article was extracted from the Wartime Road Note No. 6 of the British Road Research Laboratory. The available substitutes for the standard paints are listed as: (1) Alternate traffic paints; (2) plas-

1943 tic white line; (3) surface dressed white lines. Information concerning the durability and other properties such as composition and methods of construction is given for each of these types.

145. "Surface-Dressed Road Markings." Roads & Bridges, v. 81, p. 41, Sept., 1943.
Detailed information concerning the materials, specifications and methods of application for surface-dressed road markings. This information was abstracted from Wartime Road Note No. 6 of the British Road Research Laboratory. The traffic lines consist of a strip of light colored aggregate held to the road by a tar binder. The aggregate must be light in color and must not crush under traffic. The best nominal size is passing 3/8 in. and retained on ¼ in. mesh. The binder used is the hot application type - the amount used and exact grade is varied according to road conditions and type aggregate etc.

146. "Traffic Paints." (British Standards Institution Spec. B.S./A.R.P. 38, 1943) Nat'l Paint, Varn. & Lacquer Assoc., Abs. Rev., no. 86, p. 200, 1943.
Six types of paint are considered; (1) Type A, white line road paint: methanol/resin type; (2) Type B, white line road paint: oil base paint; (3) Types C and D, white line road paint: water paint; (4) Type E, general service traffic paint: water paint. Performance tests and instructions concerning the use of the different types are also given.

147. "What is the Best Time of Year to Apply Traffic Paint?" New Jersey Zinc Co., Paint Progress, v. 4, no. 2, p. 6-7, Oct., 1943. See also: Public Works, v. 75, no. 4, p. 28, April, 1944.
Several paints were applied over a 5-month period on the same section of highway. The results show that: (1) Weather conditions during application, drying time and exposure affects paint durability. (2) Excessive moisture during first month is detrimental. (3) Saturation of the fresh film with water accompanied by freezing promotes film failure. (4) Exposure of fresh dry paint to cold is not detrimental. (5) High grade traffic paint stands up better than a low grade paint.

148. "White - Best Color for Night Visibility." New Jersey Zinc Co., Paint Progress, v. 4, no. 1, p. 11, April, 1943.
White is the best light-reflecting color because the lighter the color, the higher the reflection of light and the darker the color, the higher the absorption of light. White possesses the highest reflectance factor and hence the best visibility.

149. "White Line Road Marking." Gr. Britain, Dept. of Science & Industrial Research, Road Research Laboratory Road Note No. 6, 13 pages, 1943.
A discussion of wartime substitute for the standard traffic paints. These are (1) Alternate traffic paints; (2) plastic white line compositions; (3) surface dressed white lines. Details of the composition and properties of the plastic line are given as well as detailed information on the surface dressed white line. The alternate paints are reported to deteriorate rapidly (about 1 month in winter and 2 in summer). The plastic lines last about a year with good retention of color, but the original color is not as good as paint. Surface dressed lines are never as white as painted lines but night visibility is good.
Note: Excerpts from this paper are published in Roads & Bridges v. 81, p. 31-22 (June) and p. 41 (Sept.), 1943, under the titles, "Substitute for White Paint Road Markings" and "Surface-dressed Road Markings," respectively.

150. Zinzer, A. L. "Good Paint - In Spite of War." Better Roads, v. 13, no. 12, p. 25-26, Dec., 1943.
Note on satisfactory war time substitute paints developed in paint laboratory of Texas Highway Dept. using raw materials & facilities available.

1944 151. Allen, C. W. "Tests for Abrasion, Adhesion, Flexibility and Hardness of Traffic Paints." ASTM Bulletin, no. 130, pp. 29-36, Oct. 1944.
Progress report of group 2 of subcommittee IV on traffic paint, of ASTM committee D-1 on paint, varnish, lacquer and related products.

1944 I. The adhesion, flexibility, and hardness tests examined show no general correlation with field service behavior.

II. The accelerated weathering and abrasion tests show close correlation with field service behavior.

The purpose of this study is to determine, if possible, the value of these tests in estimating the behavior of traffic paints in service and possibly to recommend to the Society methods of tests that are proved to be of value.

152. "Asphalt Center Stripes Stay Put." (stones sealed with asphalt) Roads & Streets, v. 87, p. 80, Aug., 1944.

The stripe is similar to an ordinary seal coat, built 6-in. wide along the centerline. It consists of an application of quick-drying cutback made with high melting point asphalt, over which is immediately placed a chip covering of 3/8 in. maximum size aggregate.

153. "Brick Found Excellent for Traffic Markings." Brick & Clay Rec., v. 104, p. 13, June, 1944.

Recent brick road construction makes for an increased use of bricks for traffic marking. Buff bricks with staggered offsets make a good traffic line.

154. Gidrani, B. S. & Kamath, N. R. "White Line Road Paints." Oil & Color Trades Journal, v. 106, p. 590, 1944. (Nat'l Paint, Varn. & Lacquer Assoc. Abs. Rev., no. 100, p. 35, 1945).

Two traffic paint formulations using water as the volatile matter and bleach lac were tested; the first dispersed in ammonia water is satisfactory in all respects and can be used on all types of roads, the second dispersed in ammonium bisulphite water and fish oil as a vehicle is faster drying and more water resistant, but bleeds on bituminous surfaces and does not have as good color retention.

155. Hassett, R. J. "Glass Beads for Road Stripes." Public Works, v. 75, no. 11, p. 18, Nov., 1944.

The use of glass beads embedded in the centerline paint to minimize accidents is very effective.

156. "How It's Done in Texas: Asphalt Center Stripes Stay Put." Roads & Streets, v. 87, pp. 80-82, Aug., 1944.

For several years the Texas State Highway Dept. has striped an increasing mileage of its pavements with sealing asphalt and chips.

157. Jelinek, O. K. "Simplifying Traffic Lane Delineation." Civil Eng., v. 14, p. 522-523, Dec., 1944.

Method used by the Chicago Park District. A 5-gal. can filled with water is fastened to the side of an automobile. As it travels along the driver turns a valve allowing the water to drip on the road. The lanes are thus defined according to the natural movement of the driver.

158. Lesser, Milton A. "Alkyd Resins in Emulsion Paints." Am. Paint Journal, v. 29, no. 6, pp. 62, 66, 68, 1944.

Paints of this type of water dispersed alkyds on asphalt and tar surfaces will pay a large part in the post war market.

159. Neal, H. E. "Rapid and Economical Traffic Striping." Engineering News-Record, v. 133, pp. 842-845, Dec., 28, 1944.

State of Ohio puts 125,000 gal. of traffic paint on 10,500 mi. of road each year at an application cost of $2.30 per mi. Striping is done with shop-assembled trucks that apply one to three stripes at a time at a speed of 15 mph. The paint is air-agitated, atomized and is blown onto the pavement.

160. "Plastic White Lines." Roads & Road Constr., v. 22, no. 256, pp. 101-102, April, 1944.

Gives results of a questionnaire directed to highway authorities of counties and boroughs, concerning the use of plastic white lines for road marking. The mileage painted, the visibility characteristics, the difficulty of installation, and the general opinion of their merit are covered.

1944 Conclusions drawn are: The plastic line is easy to apply (although not as easy to paint). Over a 2 year period it is generally cheaper than paint. It provides a reasonable visibility throughout the year although the visibility is not as good as that of a newly-painted line. Although satisfactory on bituminous roads it does not give good results on wood-block paving, granite setts, or concrete.

161. "Road Tests on Traffic Paints Show Value of Zinc Oxide for Durability." New Jersey Zinc Co., Paint Progress, v. 5, no. 2, p. 12, 1944.

Paint containing zinc oxide has properties of improved wear, weather resistance, and opacity to the ultra-violet rays of the sun. A test (road) of paints containing 0 percent, 10 percent, 20 percent, 30 percent, and 40 percent zinc oxide shows that the paint with 40 percent zinc oxide lasted much longer than the others.

162. Slate, F. O. "Thermosetting Synthetic-Resin Paints for Concrete Pavement Markings." Proc. Highway Research Board, v. 24, pp. 213-225, 1944.

The object of this study was to determine the causes of failures of concrete paints and to find paints and painting methods to overcome these causes. Both laboratory and field tests show that paints fail principally by scaling due to loss of adhesion in the presence of water. Laboratory and field tests designed to compare the durabilities of highway paints showed that the thermosetting and thermoplastic synthetic resin paints had far better water, alkali and abrasion resistance than standard paints.

1945 163. "Seabees Develop Machine to Paint Traffic Stripes." Engineering News-Record, v. 135, p. 503, Oct. 18, 1945.

This Seabee-developed machine is compact and easy to operate. It is towed by a Jeep. In addition to the driver of the towing Jeep, only two operators are required. A small gasoline-engine-driven compressor provides air at a pressure of from 75 to 150 psi.

164. Slate, F. O. "Concrete - Highway - Marking Paints." Roads & Bridges, v. 83, pp. 61-63, 96, 98, 100, 102, 104, 106-8, 110, April, 1945.

A report by the U. S. Highway Research Board. The research was designed to find the causes of failure of concrete paints now used and to find paints and. painting methods to overcome these causes. The work was carried out in 1943 and 1944.

Both laboratory and field tests showed that these paints fail principally by scaling due to loss of adhesion between the paint film and the concrete. The presence of water is necessary for this loss of adhesion. The water traveling upward carries soluble salts, these salts are deposited upon evaporation of the water. The paint film offers resistance to the passage of water vapor and to the growth of the salt crystals, the resulting forces may break the bond between paint and concrete. The surface of the concrete itself may be disintegrated by the growth of these salt crystals. The thickness of the paint film which governs its resistance to water vapor has a marked influence on the rate of scaling of some paints. Laboratory and field tests, designed to compare durability of standard with proposed concrete highway paints showed that the thermosetting and thermoplastic synthetic resin paints tested had better water, alkali, and abrasion resistance than standard paints. In his conclusion the author states that the baking type paints and the strongly polar thermo-plastic resin paints tested were suitable, satisfactory and superior for concrete highways. (Editors Abstract).

165. "Special Equipment Designed for Painting Highway Center Stripes." Engineering News-Record, v. 134, p. 894, June 28, 1945.

The centerline of roadway is marked with diluted white paint dripping on a bicycle wheel. A truck equipped with an air compressor is used to spray on finished stripe.

166. "Study of White Traffic Lines." Roads & Bridges, v. 83, p. 243, June, 1945.

A resume' of an article by G. Bird and D. J. MacLean, Road Research Laboratory, British Department of Scientific and Industrial Research. The main purpose of the paper was to demonstrate the possibilities of a novel laboratory approach

1945 to the study of traffic markings in general. The studies reported were concerned with the relationships between night visibility and line spacings under blackout conditions.

167. Walz, K. "Examination of Pigment for Traffic Paint." Asphalt u. Teer Strasenbautech, v. 43, pp. 231-245, 1943. (C.A.38:6111). (Nat'l Paint, Varn. & Lacquer Assoc. Abs. Rev. no. 99, p. 6, 1945).

Exhaustive laboratory and road tests made on 12 traffic paint formulations revealed that thermal, hydro, and abrasion resistance tests are the best indicators of the actual behavior of traffic paints. An important variable was the type of surface on which the paint was applied. A diagram and description of the artificial weathering apparatus is included.

1946 168. Cummins, R. P. "Missouri Paints with Narrow Rig." Engineering News, v. 138, p. 211, Feb. 6, 1946.

A 36-ft. long narrow-tread, self-powered machine is used by the Missouri State Highway Department for painting stripes on pavements. It applies the centerline and intermittent no-passing lines at the same time.

169. "Curbs Sandblasted Before Repainting Yellow No-Parking Zones." Roads & Streets, v. 89, p. 71, Aug., 1946.

Colorado Springs, Colorado wanted to remove their yellow "no parking" paint and repaint. The solution worked out was to close off a block at a time on one side of the street and sandblast the curbs clean.

The procedure was to set up a row of stands along the outer edge of the parking lane and rope off that lane early enough in the morning so that parked, locked cars wouldn't hamper the job. Then the outfit came along and speedily blasted the curbs along the block.

170. Lee, R. "Standard White Traffic Marker Used by Oklahoma City." Public Works, v. 77, no. 5, p. 37, May, 1946.

Drawings and specifications for a white traffic marker to be placed on paved narrow streets not wide enough for angle parking. The material consists of white portland cement and white sand, with a mixture of one part cement and two parts sand.

171. Star, D. E. "Special Performance Testing of Paints." Paint Manuf., v. 16, pp. 425-430, 1946; v. 17, pp. 24-5, 1947.

Accelerated weathering and wear resistance of road line paint are discussed.

1947 172. Hafeli, John M. "Traffic Paints. A Study of Typical Formulations." By Gum (Reichold Chemicals, Inc., Detroit, Mich.) v. 18, no. 2, pp. 3-6, 1947.

A short oil, fast drying, modified alkyd and a nonphthalic alkyd with a medium drying rate were compared to standard 20-gal.-oil-length, modified-phenolic, china wood oil varnish in 5 white and in 5 yellow pigment blends commonly used.

173. Hayward, A. T. J. & A. R. Lee. "Plastic and Surface Dressed White Line Road Markings." The Public Works, Roads and Transport Congress, Wed., 23rd. July, 1947, at 3:00 P.M. under the auspices of the Society of Chemical Industry (13): Also, The Surveyor (London) Vol. 106, no. 2896, August 8, 1947.

A review of the wartime development of plastic line and surface dressed white lines. Plastic lines have proved most successful. Surface dressed lines have been successful under proper experimental conditions but have not yet been developed commercially. Under proper control both types are more economical than paint because of longer service. Further improvement in the plastic line can be expected.

174. "Highway Traffic Striping." Engineering News-Record, v. 138, no. 6, pp. 80-83, Feb. 6, 1947.

Details are presented on traffic striping equipment used in New York, Virginia and Missouri. Broken dot and dash marking is made automatic by a cam arrangement that opens and closes the spray gun at regular intervals.

1947 175. Leech, C. B., Jr. "Standard Truck Serves Virginia." Engineering News-Record, v. 138, p. 210, Feb. 6, 1947.

Machine used to paint traffic lines on Virginia Highways permits one stripe to be added alone or two lines to be painted simultaneously with either line made solid or intermittent.

176. "New Jersey's Singing Highway: Route No. 6." Am. City, v. 62, p. 133, Dec., 1947.

A 2-ft. wide space is left between lanes for the full depth of slab. This space is filled with regular grey concrete covered with an inch of corrugated white concrete. This lane marking has been found to be both permanent and economical.

177. "New Paint Process Proves Economical." Mich. Municipal Review, v. 20, no. 12, p. 137, Dec., 1947.

Working closely with manufacturers of paint and glass beads, the Highway Department has adopted a formula of six pounds of beads per gallon of paint. Tests prove that this mixture is satisfactory for one year of wear on heavily-travelled truck-lines.

Reflectorized paint lasts two to three times as long as ordinary paint. This saving on labor and equipment cost due to the greater durability of the paint made the total yearly cost very little higher than the total yearly cost for ordinary paint.

178. Nicholson, Frank. "Semi-Permanent White Line Pavement Markers (Rubber)." Roads & Road Constr., v. 25, no. 300, pp. 458, Dec., 1947.

A description of a patented rubber marker - 18 in. x 5 in. ridged with hip ends. Vulcanized to the under surface is a sheet of strong, untreated, cloth fabric which extends 2 in. beyond the sides and end for fixing to the pavement surface. The details of the fastening process are given. This consists mainly of painting the surface with a bituminous emulsion and covering the fabric with a bituminous grit. A 3-in. twist screw is driven through the marker into the road surface at each corner. Cost data are given. The expected life is 10 years.

179. O'Brien, M. A. "Traffic Striping Developments." California Highways & Public Works, May-June, 1947.

The development of standards for traffic marking, specifications for materials, as well as equipment used has been given much attention during the last 20 years. California experience with the dashed line has been very satisfactory, as it provides good visibility under varying conditions at a 60 percent reduction in material costs. The requirements for traffic paint include such items as quick drying, long life, good adherence to various surfaces without serious discoloration, and bead retention. Changes in standard markings have caused many changes in equipment. The operator must be able to make the following transitions in sequence of work without stopping the machine: 1. Place a single broken stripe; 2. Place a double stripe consisting of a broken stripe on the left and a solid stripe on the right; 3. Place double solid stripes; 4. Place double stripes consisting of a broken stripe on the right and a solid stripe on the left. A bead dispenser is described, and photographs of an improved striping machine are included.

180. "Pavement Striping Methods." Roads and Streets, v. 90, no. 4, pp. 78, 80, 82, 84, 88, April, 1947.

There is a wide variety of special equipment being employed by different state highway departments. These are discussed, along with the use of reflector beads. The paint shortage is being gradually overcome.

181. "Ribbed White Concrete Markers Guide Traffic Day and Night." Constr. Methods, v. 29, no. 10, pp. 88-90, Oct., 1947.

Highway slabs are 10-in. deep and 12-ft. wide, and were poured so as to leave a two foot space between parallel lanes. After road forms were stripped, this 2-ft. strip was filled with a 9-in. layer of ordinary concrete topped with 1-in. of Atlas white cement mortar to act as a permanent lane separator, or marker. These white strips were scored with a hand tool to make a shallow sawtoot surface.

1947 182. "Traffic Paint Performance." Am. City, p. 133, April, 1947.
Simple tests have been devised for determining the resistance to abrasion, the drying time, and the resistance to road service of traffic paint. These tests are described in this article.

183. "Traffic Striper - News Article." Engineering News-Record, v. 138, p. 338, Feb. 27, 1947.
This traffic striper was built by Carl Sohmer of Tacoma, Washington. Operated by three men, the machine uses about 80-gal. of paint to line about 12 blocks, moving at a speed of a block a minute.

184. Waters, C. R. "Dash Line Road Striping Made Easy." Engineering News-Record, v. 138, p. 208-210, Feb. 6, 1947.
Controls for paint spraying have recently been developed by the State Public Works Department in western New York to mark traffic lines on pavements, so that the length of dash lines may be varied and so that the paint may be started at any place to duplicate dash lines previously placed on pavements.

185. Ziegler, C. M. "Reflector Beads Widely Used in Michigan's Pavement Marking Program." Roads & Streets, v. 90, p. 71-74, Jan. 1947.
This article gives details of the extensive use of reflectorizing beads and an excellent explanation of the underlying principle that has brought reflectorizing materials to the fore.

1948 186. Allen, J. H. "Jacksonville's Life Saving Traffic Markings." Am. City, v. 63, p. 151, April, 1948.
Traffic fatalities have decreased 69 percent since the application of a new traffic marking system. Now in use is a 4-in. continuous white center line covered with glass beads. The cost of reflectorization is 6½ cents per sq. ft.

187. "California Traffic Markers Paint a Variety of Lines Automatically." Western Construction News, v. 23, no. 7, p. 99, July, 1948.
Refinements and improvements in Division of Highway traffic markers enable operators to paint many types of striping without stopping the machine for adjustments. The machine and its operation are described.

188. Crabtree, W. O. "Traffic Paint." Am. Paint Journal, v. 32, p. 43, 1948.
The important properties of traffic paints are reviewed and discussed; also the use of reflectorizing beads. It is concluded that white paint gives better visibility than yellow paint.

189. "Marking Highways for Safety; Calif. Traffic Striper Uses Compressed Air." Comp. Air Mag., v. 53, pp. 116-118, May, 1948.
This is the latest California traffic striper. All parts are exposed for easy adjustment, cleaning and removal. It is pushed by a truck. Broken or continuous lines may be painted. An attachment for dropping reflector beads is on the machine.

190. "New Traffic Paint." Roads & Streets, v. 91, no. 8, p. 105, Aug., 1948.
"Oncrete for Concrete" traffic paint marketed by Lowebco, Inc.,of Chicago, made in yellow, white and black.

191. "These Improved Traffic Striping Machines are 100 Percent Air Operated." Roads & Streets, v. 91, no. 5, p. 96, May, 1948.
Two excellent examples of recent traffic striping machines are pictured here. Both are operated by compressed air. Either will paint or positively retrace a single broken stripe, a double white stripe consisting of a broken stripe on the left and a solid stripe on the right, or a double white stripe and a double white stripe consisting of a broken stripe on right and a solid stripe on left.

192. "Traffic Paints - A Report on Their Formulation." Am. Gum Importers Laboratories, Inc., Natural Resin Series No. 8, Oct., 1948.
The American Gum Importers have for the past 10-yrs. been experimenting

1948 with traffic paints. The unique properties of certain natural resins to give the maximum in adhesion and toughness seemed to point directly to their use in traffic paints. These traffic paint studies were separated into 3 main branches of investigation: (1) the cold-cut vehicles which were alcohol and Ketone soluble; (2) the cold-cut vehicles which were petroleum thinner and coal tar soluble; and (3) the series based on cooked varnish.

193. Tremper, Bailey and Minor, C. E. "Experience with Reflectorized Traffic Paints." Proc. Highway Research Board, v. 28, p. 262, 1948.

Glass beads increase the night visibility of painted traffic stripes to a greater degree than other available material. Smaller beads offer advantages in economy and service life over the larger sizes formerly used.

Beads were originally applied by gravity to the fresh surface of the stripe. This method, called "over-lay", has been succeeded by a "premix" method in which the beads are mixed with the paint just prior to application. The "fog-coat" method may be used as an alternative for the "pre-mix." In this method, beads are placed by over-lay in a second light application.

Data are given on the use of the "pre-mix" and "fog-coat" methods.

1949 194. "Bleeding Tests for Traffic Paints." Better Roads, v. 19, p. 10, Oct., 1949.

The direct cause of bleeding is the solution of the bitumens that are soluble in the vehicle of the paint. Tests run by the Michigan State Highway Dept. indicated that tar-surfaced roads bleed much more severely than do asphaltic surfaces. No traffic paint tested, except water soluble types, was found to be 100 percent bleed resistant over a tar surface.

195. Byerly, Fred S. "Laboratory Testing of Resistance of Traffic Paints to Bleeding." ASTM Bulletin, no. 160, pp. 52-6, Sept., 1949.

This article outlines some work done by group IV, Subcommittee IV, Committee D-1, ASTM leading to the development of ASTM standards on bleeding of traffic paints.

Photographic standards are given for evaluating the degree of resistance of traffic paints to bleeding. These pictorial references consist of four photographs illustrating the following degrees of bleed resistance:

No. 8 (Slight bleeding)	No. 6 (Moderate bleeding)
No. 4 (Bad bleeding)	No. 2 (Very bad bleeding)

This article describes the work which resulted in writing ASTM Method D969-48T. Coal tars bleed much more severely than do asphalts.

196. "Centerline Marking Units Added to Step Up This Major Service." Missouri Highway News, v. 7, no. 6, p. 1, 3, Aug., 1949.

Small replica of large 34-ft. overall machine is now being dispatched to each of various divisions. These machines, designed by Maintenance Bureau and constructed by Equipment Bureau's headquarters garage personnel, will expedite marking process.

197. "Center Striping of Highways and Municipal and Industrial Plant Roadways." Nat. Safety News, v. 59, pp. 39-40, 42, April, 1949.

Description of types of equipment used for application and renewal of pavement markings.

198. Custer, H. R. and Zimmerman, E. K. "Field Evaluation of Traffic Paints of Known Composition." Proc. Highway Research Board, pp. 274-281, 1949.

This report is a summary of progress made on a cooperative project between the Penn. Dept. of Highways and the Titanium Pigment Corp.

Traffic paints of known composition are evaluated and developed from field service tests. For comparative evaluation, each paint must be applied in the same manner, with equipment similar to that normally used by highway departments.

It has been possible to develop traffic paint formulations of merit, and to indicate improvements for the future.

1949 199. "Experience with Reflectorized Traffic Paint." Public Works, v. 80, no. 22, p. 40, July, 1949.

A study has been made by the State Department of Highways of Washington on reflectorized traffic paint as it has been used by the Department on its roads. From this it has been concluded that glass beads increase the night visibility of traffic paints to a greater degree than any other available material.

200. "A Further Report on the Formulation of Traffic Paints." Am. Gum Importers Laboratories, Inc., Natural Resin Series No. 10, Sept. 1949.

Additional exposure evaluations have been made. These exposures, involving variations in pigmentation and adjustments in vehicle preparation, attempt to discover more effective traffic paints. Both cooked and cold-cut vehicles were again studied and their performances compared with the best of those experiments discussed in the previous traffic paint paper.

Considerable thought was given to pigmentation changes in this latter series. Attempts were made to answer questions as to the relative merits of various extenders. Mica, Magnesium Silicate and pumice were among those chosen for study.

201. Hank, R. S. and Bennett, F. E. "Highway Striping." Pacific Road Builder & Engineering Review, v. 73, no. 2, pp. 22-23, Aug., 1949.

Cooperative field study program carried out by Texas Highway Department and Goodyear Tire & Rubber Co. Primary purpose of study is to attempt to correlate factors of weather, cleanliness of surface, rate of application, and type of road surface with durability of specification paints.

202. Hank, R. S. and Bennett, F. E. "What Lowers Traffic Paint Durability?" Am. City, v. 64, p. 173, Sept., 1949.

Texas has developed a new traffic paint calling for Pliolite S-5, a paint resin manufactured by the Goodyear Tire & Rubber Co. The new formulation is called "YP-3." The vehicle is based on materials new to the traffic paint field. The pigmentation selected included diatomaceous silica.

203. Hill, John M. & Ecker, Howard W. "A Direct Reading Portable Photoelectric Photometer for Determining Reflectance of Highway Centerline." ASTM Bulletin No. 159, pp. 69-72, July, 1949.

The development of a reflective centerline material required a means of evaluating properly the reflection obtained with various beaded materials as compared to conventional highway striping paints.

The photometer described here may be used on the highway in daylight for evaluating night brightness of highway centerline stripes. An unskilled operator obtains the reflectance value from a meter in less than 2 seconds.

The instrument is calibrated in terms of a perfectly diffused white surface of 100 percent diffusing-reflecting factor.

204. Lyon, V. H. and Robinson, D. L. "A Study of Glass Beads for Reflectorizing Traffic Paint." Proc. Highway Research Board, pp. 245-273, 1949.

The Missouri Highway Dept. reports on a study of the physical and chemical properties of glass beads, in an attempt to evaluate the available products and arrive at satisfactory specifications.

Eight different glass beads grading from No. 20 to No. 100 sieve were applied by gravity to fresh Missouri specification yellow traffic paint. Of the eight beads studied, two composed of glass of normal silica content performed satisfactorily, and two with low silica content looked promising.

205. Mummery, W. R. "Oleo-casein Paint." New Zealand J. Sci. Technol, 308, pp. 297-309, 1949.

During the war years when materials for paint manufacture were restricted, an oleo-casein paint consisting of linseed oil in a water emulsion stabilized by casein solution and mixed with a pigment blend of lithophone, whiting, and barytes gave satisfactory results as a traffic-line and general road-side paint.

206. Neal, Harry E. "Ohio Pavement Striping Equipment." Traffic Engineering, v. 20, no. 1, p. 17-18, 37, Oct., 1949.

Techniques of mechanization and mass production are being applied to the

1949 business of striping State highways. The newest unit for pavement striping on Ohio highways is built on 5-ton chassis with 105-in. wheelbases. It can apply two colors and three lines simultaneously where passing is restricted in each direction. It is capable of laying pavement markings at 10-12 mph.

207. "Standard Method of Conducting Road Service Tests on Traffic Paint." ASTM D 713-46, 1949 Book of ASTM Standards, Part 4, pp. 395-6.

This method of test is intended for determining the relative values of service of traffic or pavement marking paints under actual road conditions. Samples of the paint being tested are compared under prescribed conditions and periodic observations are made as to the relative performance characteristics as a basis of comparison.

208. "Standard Method of Evaluating Degree of Resistance of Traffic Paint to Abrasion, Erosion, or a Combination of Both, in Road Service Tests." ASTM D 821-47 1949 Book of ASTM Standards, Part 4, pp. 376-9.

The failure described by these reference standards is that condition manifested in traffic paint by more or less gradual surface disappearance, thinning of the film, and exposure of the substrate because of abrasion, erosion or a combination of both. The degree of failure is judged by the amount of substrate that is visible.

209. "Standard Method of Evaluating Degree of Resistance of Traffic Paint to Bleeding." ASTM D 868-48 1949 Book of ASTM Standards, Part 4, pp. 380-1.

The bleeding characteristics described are that condition of discoloration manifested in traffic paint when applied to tar or asphaltic type roads. The number assigned to evaluate the degree of bleeding failure represents in these reference standards a measure of the contrast between the color of a dry film on a non-bleeding surface and the color of the dry film on test surface.

210. "Standard Method of Test for Dry to No-Pick-Up Time of Traffic Paint." ASTM D 711-48, 1949 Book of ASTM Standards, Part 4, pp. 388-9.

This method describes a laboratory test to determine the length of drying time after application for no-pick-up of traffic or pavement marking paint by the tires of an automobile.

211. "Standard Method of Test for Evaluating Degree of Settling of Traffic Paint." ASTM D 869-48, 1949 Book of ASTM Standards, Part 4, pp. 397-8.

This method of test is intended for determining the degree of pigment suspension and ease of remixing a shelf-aged sample of traffic paint to a homogeneous paint suitable for use in the manner intended.

212. "Standard Method of Test for Light Sensitivity of Traffic Paint." ASTM D 712-47, 1949 Book of ASTM Standards, Part 4, pp. 390-1.

This method of test is intended for determining the color change produced by sunlight on paint material intended for use as traffic or pavement marking paint.

213. "Tentative Method of Test for Night Visibility of Traffic Paints." ASTM D 1011-49T, 1949 Book of ASTM Standards, Part 4, pp. 392-4.

This method is intended for testing traffic paint surfaces for luminous directional reflectance, using directions of illumination and view similar to those of night traffic.

214. "Tentative Method of Evaluating Degree of Resistance of Traffic Paint to Chipping." ASTM D 913-47T, 1949 Book of ASTM Standards, Part 4, pp. 384-7.

The failure described by these reference standards is that condition manifested in traffic paint by actual detachment of entire sections of the film usually in small pieces, either from the substrate or from paint previously applied. The degree of resistance to failure is judged by the amount of substrate that is covered.

1949 215. "Tentative Method of Laboratory Test for Degree of Resistance of Traffic Paint to Bleeding." ASTM D 969-48T, 1949 Book of ASTM Standards, Part 4, pp. 382-3.

The method covers a laboratory procedure for determining the degree of resistance to bleeding of traffic paints in which the test panel is cut from "15-lb., coal-tar saturated asbestos or rag felt."

216. Tremper, Bailey and Minor, C. E. "Glass Beaded Traffic Paint." Am. City, v. 64, no. 6, p. 141, June, 1949.

With small beads the range in types of suitable paints is greatly extended since the quality of high capillary rise is of less importance.

The best method of applying these beads has been found to be "overlay" method. The beads are mixed with the paint just prior to application.

217. Vannoy, W. G. "Traffic Paint Tests." Proc. of the First Pacific Area National Meeting of ASTM, p. 47, Oct. 10-14, 1949.

Traffic paint testing procedures are reviewed in an attempt to determine which tests might be considered as standard. Certain laboratory control tests together with small scale road tests are given as the most effective means available at the present time for evaluating traffic paints.

All of the tests listed herein and considered standard are beneficial and helpful as control tests for traffic paint compositions. This would include the laboratory control tests and the small scale road tests. Such tests are considered important by many consumers.

218. Zimmerman, E. K. "Traffic Paint Studies - Progress Report No. 1", Official Digest, Federation of Paint & Varnish Production Clubs, No. 293, pp. 353-67, 1949.

Tests involving 217 paints were made under cooperative program between Highway Dept. Lab. of the Commonwealth of Pennsylvania and the Titanium Pigment Corp. Satisfactory traffic paints produce satisfactory reflectance or "signal value" at all times and satisfactory durability. "Signal value" is dependent on brightness and reflectance. Traffic paints to be used in concrete pavements must be "textured" by incorporating large-particle-size extenders such as coarse pumice to enhance signal value at night. The necessary high brightness of these paints is achieved through the use of titanium dioxide. Drying and durability requirements indicate an optimum pigment volume concentration of 50 percent with alkyd or oleoresinous vehicles. A zinc oxide content of 20 percent based on pigment weight will give a paint with improved hardness and dry. For bituminous highways, 4 to 6 gal. length varnishes at 50 percent PVC are used with rutile titanium-calcium pigment and no extenders.

1950 219. Corder, Leon W. "Missouri's Big Traffic Striper Has a Litter of Pups." Better Roads, v. 20, no. 8, p. 29, August, 1950.

Ten divisional traffic-line markers now employed by state highway maintenance forces to meet conditions created by expanded mileage of bituminous surfacing. Striping units easily mounted on and removed from half-ton trucks; smaller models incorporate working principles time-tested in large machine operating on statewide basis. Dispersal of work makes quality control more difficult.

220. Hadert, Hans. "Road-Marking Paints." Farbe u. Lack, 56, pp. 497-8, 1950.

A review with formulas.

221. "The Payoff." Engineering News-Record, v. 145, no. 5, Aug. 3, 1950.

Virginia's continuing tests of highway marking paints saved $88,000 last year. Eleven different kinds of plain white and reflectorized paints were studied under varying conditions on six highways.

222. "Plastic Discs Used for Traffic Markers." Roads & Construction, p. 84, March, 1950.

Known as "Dur-o-line" traffic markers the discs are 4½ in. in diameter and are furnished in either white or yellow. The markers have a convex top and a flat bottom with waffle-type ribbing, and are applied by means of a special adhesive and a metal pin in the top center of the disc. A two-man crew can lay a hundred of the discs in an hour without holding up traffic.

1950 223. Talen, H. W. and Brunt, N. A. "Testing the Resistance to Wear of Paints." Verfkroniek, v. 23, pp. 236-8, 1950.

Eight paint samples containing the same pigments but different vehicles were exposed to traffic in a wear test. The paint did not wear off layer by layer, but wore straight through to the base coat. The chemically drying paints were noticeably more resistant than the physically drying. Paints applied by spraying wore better than those applied by brush.

224. "Traffic Line Paints." Public Works, p. 65, May, 1950.

The following conclusions resulted from the reported study:

1. Different types of paint should be specified for concrete and bituminous.
2. While some reflectorizing paints give high night reflectances, some are no better than ordinary paints.
3. The size of bead has an effect on the night reflectance.
4. Field service test is an entirely satisfactory method of evaluating paints.

225. Walter, John. "Research Carried out in Ontario-Highway Problems." Roads and Construction, p. 122, March, 1950.

Problems:

1. Paints have had a wide range of consistency. Thin paint causes excessive fogging, while thick paint causes handling and loading difficulties.
2. Settlement of paint in storage has caused mixing and loading problems.
3. Problems in application due to use of glass beads.
4. Field performance, such as discoloration, bleeding on bituminous pavements, and traffic abrasion.

Observations:

1. Different types of paints are needed for bituminous and concrete pavements.
2. The night reflectances of some reflectorized paints are little or no better than ordinary paints.
3. The size of beads has an effect upon the night reflectance, but further study is necessary.
4. The field service test is entirely satisfactory.

226. Wieman, Don. "Traffic Striping." California Highways and Public Works, v. 29, nos. 3, 4, p. 52, March-April, 1950.

New idea for laying out highway traffic stripes which uses a transit sighting on a light truck moving toward the transit, the truck is equipped with a spotting gun and is driven in zig-zag manner across the centerline. The spotting gun is operated electrically by the truck driver on receiving a light signal from the transit man.

1951 227. "Analysis of Plastic White Line Compositions." Road Research Technical Paper No. 23, Road Research Laboratory, Dept. of Sci. and Indust. Research, 1951 (Great Britain).

Satisfactory plastic white lines are composed of mineral aggregate, filler and pigment with a fluxed rosin binder. Durability of line is dependent upon nature and amount of binder. Method of analysis for determining proportions of binder, mineral aggregate and pigment, and for subsequent examination of binder are presented.

228. Ashman, G. W. "Present Preferences for Traffic Paint." Highway Research Board Bulletin no. 36, Pavement Marking, May, 1951.

The results of a survey on traffic paint completed in 1950 are discussed. Replies to questionnaires received from 34 states and 175 paint manufactures indicated a great increase in the use of reflective road markings.

In 1949 and 1950, the ratio of white to yellow traffic paint used was 7 to 3. Preferences on vehicle types remained unchanged. First choice was alkyd resins, second choice was phenolic resins, third was phenolic varnish-dispersion resin type.

229. Byerby, F. S., Baumann, F. H. Diefenderfer, H. H. and Ashman, G. W. "A Laboratory Method of Test for No-Dirt-Retention Time of Traffic Paints." ASTM Bulletin, no. 176, pp. 44-46, Sept., 1951.

A progress report of cooperative tests conducted by a working group of

1951 Subcommittee IV of ASTM. Results indicate several hours additional drying time may be necessary between the stage of no-paint-pickup by tires and stage of no-dirt-pickup from the tires. The apparatus required in the proposed tentative method is that used in the ASTM Standard Method of Test for Dry to No-Pick-Up Time for Traffic Paint (D 711-48).

230. "Marble with Styrene Binder." Modern Plastics, v. 29, no. 4, p. 94, Dec., 1951.
New marker developed by Perma-Line Corp., New York, N. Y. is made of ground marble with a styrene binder. Mixture is placed in prepared grooves in asphalt, concrete or other road surfaces.

231. "Plastic Road Line Markers Tried in Nassau, Queens." Engineering News-Record, v. 146, no. 16, p. 44, April 19, 1951.
Traffic Lines, Inc. of New York on low bid of $4,900 are to install 3.36 mi. of white plastic traffic line markers in Nassau and Queens Counties (N. Y.) by grooving pavement ½ in. deep and 4 in. wide to receive thermoplastic material, 60 to 72 in. long, with placement by rolling material into groove at 425 deg. F.

232. "Recommendation for Plastic White Line Markings." Road Note No. 9, Road Research Laboratory, Dept. of Sci. and Indust. Research, 1951 (Great Britain).
Constituents commonly used are gum rosin fluxed with mineral oil for binder, pigmented with titanium dioxide, and filled with white silica sand or crushed calcite. Materials must be heated to 130 deg. C but prolonged heating at this temperature should not be permitted.

233. Shelburne, Tilton E. "Comparison of Reflectance Readings of Traffic Paints." ASTM Bulletin, no. 173, p. 44, April, 1951.
The reflectance values of plain, beads-on-paint, and beads-in-paint lines, placed longitudinally and diagonally to traffic and under no-traffic-conditions, were measured by means of the Hunter instrument and the Minnesota Mining Co. instrument and the results correlated.

234. Waters, Charles R. "Methods and Application Procedures for Pavement Marking." Highway Research Board, Bulletin no. 36, Pavement Marking, May, 1951. Roads and Eng. Construction, v.89, no. 9, p. 82, Sept., 1951 (Synopsis).
A report of findings determined by questionnaire sent to all states and several foreign provinces and countries. Questionnaire contained more than 70 items relating to types of paint, costs, methods of application, methods of protecting a fresh line, drying time, mixing of beads, and other aspects of pavement striping. The data are presented in tabular form and discussion is included of pertinent information.

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