

THERMOSETTING SYNTHETIC-RESIN PAINTS FOR CONCRETE PAVEMENT MARKINGS

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SYNOPSIS

The objective of this study was to find the causes of failure of the concrete paints in use at present and to find paints and painting methods to overcome these causes.

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 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 carried 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 durabilities 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.

INTRODUCTION

In the interests of safety, it has been found desirable to mark pavements, dividing them into lanes and areas, and putting instructions of various types such as lines, words, or symbols directly on the pavement surface. To serve their purpose, these markings must be plainly visible to drivers by day and night. A large amount of money is spent in placing and maintaining these lines. Often a marking becomes dim, but cannot be replaced immediately because of weather or other conditions. It is thus desirable, for reasons of both safety and economy, to find a more durable, more visible marking for pavements. Only portland cement concrete pavements (both new and old) are considered in this report.

Many methods for marking pavements have been tried with various degrees of success. Among them are: (a) hot asphalt applied to concrete (16)²; (b) white or other colored stone

chips pressed into asphalt just previously applied hot (19); (c) other pigmented, hot, thermoplastic materials (such as resin-wool grease combinations) applied to concrete (5, 18); (d) raised concrete curbs and islands (23, 30, 31); (e) markings made by mixing pigments into the surface of fresh, unset concrete (24); (f) paints of many kinds (7, 9, 14, 21, 26); (g) metal or glass reflectors fastened to the pavement surface (27); (h) galvanized steel strips (28); (i) painted canvas glued to the pavement (29); (j) contrastingly colored brick in brick and concrete pavements (17); and (k) combinations of the above methods, such as islands set with reflectors or painted in various ways, or paint lines reflectorized with glass beads (12, 15, 30, 31).

Paints are used more than any other material for traffic markings. Many paints now used have drying-oil bases, such as linseed or tung oil, and are modified with natural or synthetic resins such as Copal, Manila, alkyd, phenolic, or oil-reactive ester (dryers may be added). Often a lacquer or spirit varnish (pigmented solution of nitrocellulose or other resin) is used. It is usually specified that

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² Numbers in parentheses refer to the list of references at the end of the paper.

markings shall dry tack-free in 10 to 30 min. so that traffic will not be delayed long. This is made possible by the use of large amounts of volatile solvents that are compatible with both the resin and the oil. Thus, upon evaporation of the major portion of the solvent, the paint will not track, but a period of several hours is required for nearly complete oxidation-polymerization of the drying oil, or for complete volatilization of the solvent.

APPROACH USED IN THIS WORK

Two problems are here encountered: marking a new concrete pavement while it is being constructed, and marking an old concrete pavement. The techniques used in these two cases vary greatly. Apparently much success has been obtained by mixing a pigment into the wet concrete before it sets (24). Glass beads have been partially embedded into the wet, pigmented concrete, giving excellent light reflection (24). By the use of proper pigments, this method seems satisfactory for marking new concrete pavements. However, many miles of unmarked pavements are in existence, and very frequently a marking, not anticipated when the road was built, is needed. Therefore, most of the work was centered on old pavements.

Of the previously used methods listed, all but methods (e) and (j) can be used on old concrete. However, observation has shown that greatest visibility, combined with the range of colors desired, can be obtained with a painted line. The night visibility of light-colored paint lines may be improved by embedding small glass beads about one-half their depth in the still-wet paint film. Paint lines must be renewed frequently because the paint either loses its adhesion to the concrete and scales off, or is worn off by traffic abrasion.

In this work studies were made to: (a) determine the causes of failure and non-failure of paint on concrete and (b) find a different paint or better method of application which would result in greater permanence and visibility than those materials and methods now in use. This necessitated two separate pieces of related research. They are discussed under the headings, "Causes of Loss of Adhesion of Paint to Concrete" and "Properties of Synthetic Resin Paints for Concrete Highways."

Failure of paint on concrete occurs whenever the paint line is no longer visible enough

to mark the pavement satisfactorily. This may occur if the paint flakes off by scaling (lack or loss of adhesion), is worn off, changes appearance by internal changes such as a change in color of the pigment, or is obscured by surface dirt. Most paint lines now in use are satisfactory in the two latter respects, but not in the two former. Except on some city streets and other places where much abrasion is encountered, loss of adhesion with resultant scaling is the primary cause of failure of concrete paints, although scaling is more extensive in wheel tracks than between or on either side of them (7).

Results of these and other laboratory tests show that alkali and water attack is not great enough to effect appreciably the film itself of a good quality paint. However, they might markedly affect the paint-concrete bond. It was concluded that a strong bond either is not being formed, or is being broken. Preliminary work indicated that the presence of water was necessary for failure of these paints by scaling. The work therefore was designed to study the effect of contact with water, the passage of water vapor through the paint film, and the effect of growth of salt crystals under and through the film upon evaporation of water through this film from water under the pavement.

A study of their properties indicated that thermosetting, synthetic resin paints should be superior in adhesion and abrasion resistance to the oleoresinous and cold-cut resinous paints now in use for highways. Comparative laboratory and field tests were performed to determine the validity of this indication.

EXPERIMENTAL WORK ON CAUSES OF LOSS OF ADHESION OF PAINT TO CONCRETE

Materials

The compositions and descriptions of the paints used are given in Table 1.

The paints were applied in the field on concrete pavements. For laboratory work, various types of portland cement specimens were made. Halves of standard tension briquettes (approximately 1-in. cubes) were used in the tests. The mixtures, by weight, were as follows:

- (a) neat-cement—3:1 cement to water;
- (b) cement mortar—3:3:1 cement, concrete sand, water;

- (c) cement mortar—6:3:1 cement, concrete sand, water; and
 (d) waterproofed-cement mortar—50:1:25 cement, zinc stearate, water.

TABLE 1
 COMPOSITION AND DESCRIPTION OF PAINTS USED
 (Percentages by weight)

No.	per cent	Description
1.	33	Urea Formaldehyde solution
	33	Alkyd solution
	34	Lead Chromate
2.	67	Melamine Formaldehyde solution
	33	Lead Chromate
3.	33	Melamine Formaldehyde solution
	33	Alkyd solution
	34	Lead Chromate
4.	67	Melamine Formaldehyde solution
	33	Titanium Dioxide
5.	67	Melamine Formaldehyde solution
	33	Graphite
6.	17	Vinyl Chloride-acetate
	2	Dibutyl Phthalate
	27	Acetone
	35	Toluene
	19	Lead Chromate
6A.	No. 6	Baked instead of air-dried
7.	21.3	Coumarone-Indene (hard)
	7.4	ADM # 100 oil
	16.5	Acetone
	10.2	Toluene
	9.2	Naphtha
	17.0	Lithopone
	18.4	Lead Chromate
8.	18.5	Coumarone-Indene (soft)
	1.9	Kettle Bodied Linseed Oil
	9.9	VM and P Naphtha
	45.0	Xylene
	24.7	Lead Chromate
9.	31	Alkyd (water emulsion)
	7	Water
	4	Mica
	13	Silica
	45	Lead Chromate (Reduce 2-1 with water for brushing.)
10.	23	Phenol Formaldehyde resin
	7	Turpentine
	47	Butanol
	23	Lead Chromate
11.	38	Phenol Formaldehyde solution
	7	Turpentine
	32	Butanol
	23	Lead Chromate
12.	A	standard yellow highway marking paint of good quality. Kettle treated, oleoresinous paint.
13.	A	war-time product, by the manufacturer of No. 12.
14.	A	standard yellow highway paint of poor quality. Kettle treated, oleoresinous paint.

The specimens were rodded by hand into molds, wrapped in wet cloth for 24 hr. and given an under-water cure of seven days followed by 24 hours wrapped in wet cloth, and then were stored

in the laboratory for various lengths of time from one month to one year.

Procedure

Laboratory tests were performed to determine why proper adhesion is not always attained and maintained. For the evaporation tests, the specimens with their tops painted were placed to about one-half their depths in

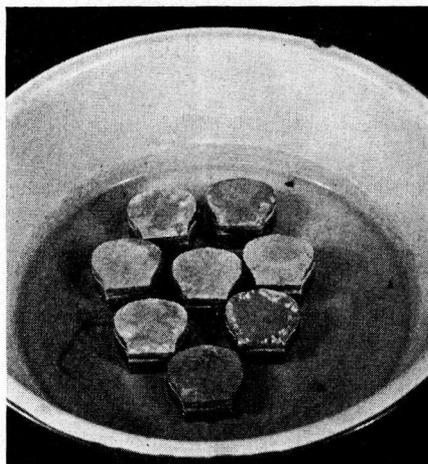


Figure 1. Apparatus for Water Exposure Tests for Concrete Paints



Figure 2. Salt Crystals Deposited on a Paint Film by Capillary Evaporation of Tap Water Thru Cement Mortar. 100X

water in pans as shown in Figure 1. (Note the salt crystals.)

First, a specimen coated on top with a standard air-drying traffic paint was placed for three weeks in tap water. The paint film scaled off after the bond was broken. Large accumulations of salt were in evidence on the remainder of the film (Fig. 2), which was raised high off the cement surface (Fig. 3). This surface was badly disintegrated and

crumbly as is shown in Figure 4. (Refer to IV in the adhesion outline under "Discussion of Adhesion and Use of Synthetic Resin Paints.")

Further tests of a similar nature were made, using paints Nos. 1, 2, 3, 12, and 13. When

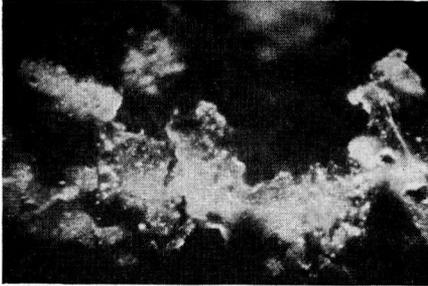
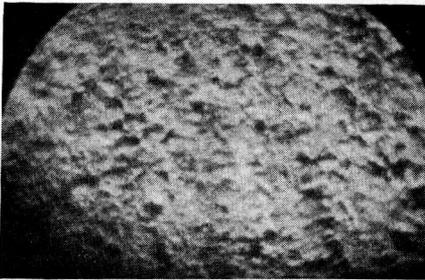
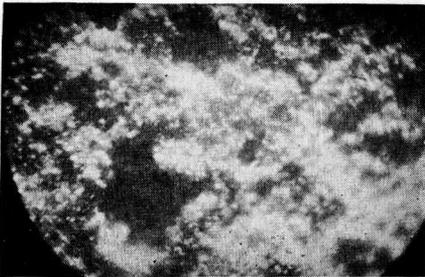


Figure 3. Paint Failure Caused by Capillary Evaporation of Tap Water Showing the Film Raised Completely Off the Cement Mortar Base. 100X



before



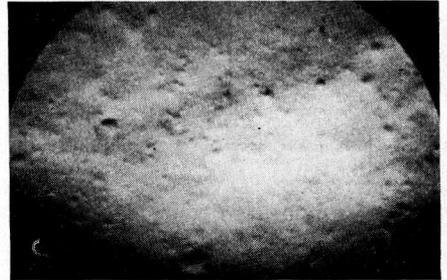
after

Figure 4. A Cement Mortar Surface Badly Disintegrated by Growing Salt Crystals Formed by Capillary Evaporation of Tap Water. 100X

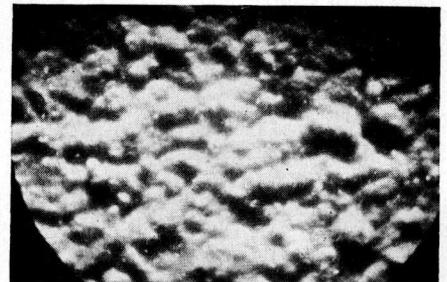
No. 12 was placed in the water one hour after painting, many small bubbles in the paint film, apparently caused by air that was displaced by rise of capillary water, were observed. In a few days Nos. 12 and 13, and to a very slight extent Nos. 2 and 3, developed

patches of a red-orange color, which later turned green. The red-orange color proved to be caused by conversion of the lead chromate pigment to a double salt, lead hydroxide-lead chromate, by action of the alkaline water from the cement. The green color was caused by reduction of the chromate.

Figure 5 shows photomicrographs of baked and air-dried paints (Nos. 1 and 12). It appeared that the former film was clinging to the mortar base throughout, while only one-half to one-third of the area of the latter



baked



air-dried

Figure 5. Comparison of Areas of Contact of Baked and Air-dried Paint Films to a Cement Mortar Base. 100X

appeared to be touching the base at all. The rest seemed to be raised as small bubbles. Note that small holes are located at the tops of these bubbles, which were apparently formed by displacement of air by rise of capillary water before the paint was set, and then burst, leaving the small holes at the top. This indicates that much better adhesion can be attained with baked than with air-dried coatings on concrete under the conditions of this test. (See IIIC in the adhesion outline under "Discussion of Adhesion and Use of Synthetic Resin Paints.")

Changes in the paint films were observed visually, and a permanent record was kept by photomicrographs and photomacrographs. Visual comparisons and ratings were made of the specimens in the laboratory.

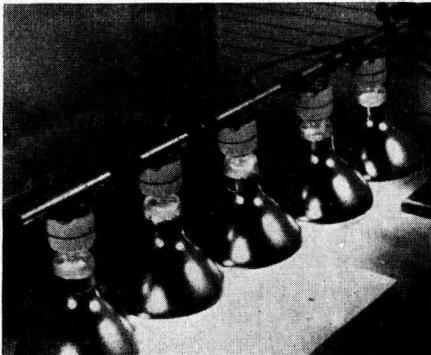


Figure 6. Arrangement of Lamps on Adjustable Structures for Laboratory Experimentation.

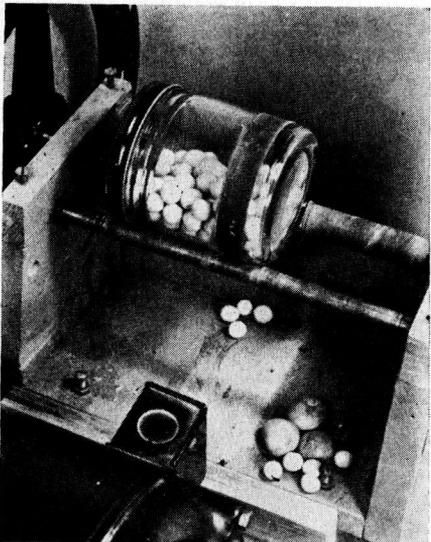


Figure 7. Ball Mill Used for Grinding Paints

EXPERIMENTAL WORK ON PROPERTIES OF SYNTHETIC RESIN PAINTS FOR CONCRETE HIGHWAYS

The infra-red lamps used were 5-in. max. dia. G. E. type R-40, 250 watt bulbs with built-in evaporated-aluminum reflectors. They were wired in parallel circuit and placed on an adjustable support as shown in Figure 6. A home-made ball mill, used for mixing and

grinding the paints, is shown in Figure 7. The machine used to measure the abrasion resistance of the paints was a standard U. S. Dorry Hardness Machine, slightly modified (7).

The paints used are described in Table 1.

Laboratory Tests

In order to determine the time required to bake a paint film, it is desirable to know how rapidly the surface being painted can be heated. To ascertain this, the lamps were mounted over a slab of concrete 4 in. by 3 ft. by 7 ft. in size. The temperatures obtainable depend upon the height and spacing of the lamps, and the position of the concrete under the lamps.

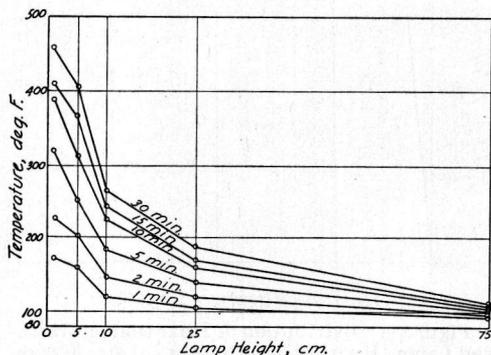


Figure 8. Variation of Temperature with Lamp Height for Various Heating Times.

Since a straight path, no wider than the lamps, was to be irradiated, the lamps were mounted touching each other in a straight line. The height of the lamps was varied to determine the optimum height. The results are shown in Figure 8.

The efficiency of heating in different places under the same lamp is shown in Figure 9. The dip in the center is readily explained by the fact that the space immediately under the center of the lamp is out of focus. Since the reflector is built in, the lamp has a fixed focus. The focal length is about 12 in. However, as shown in Figure 8, more efficient heating is obtained at close range even though the lamp is out of focus.

Complete heating and cooling curves of a concrete surface are shown in Figure 10. This experiment was performed using the optimum conditions of lamp arrangement.

No visible harm resulted to the concrete from the heating and cooling under the conditions of this test.

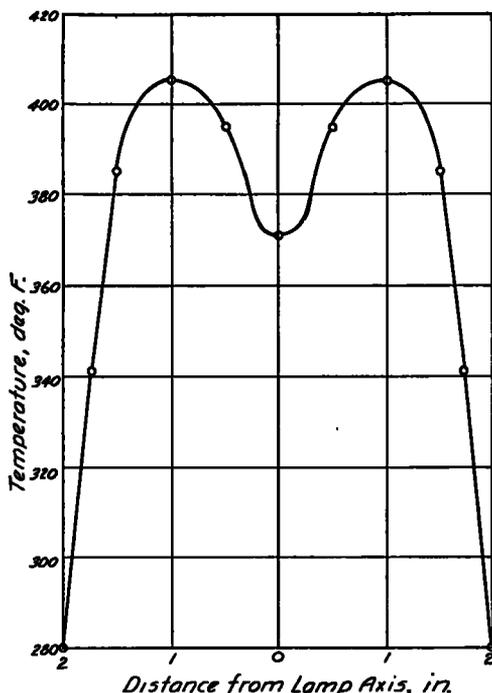


Figure 9. Distribution of Heat from an Infra-red Lamp (Heating time 10 min. Lamp Height 1 cm.).

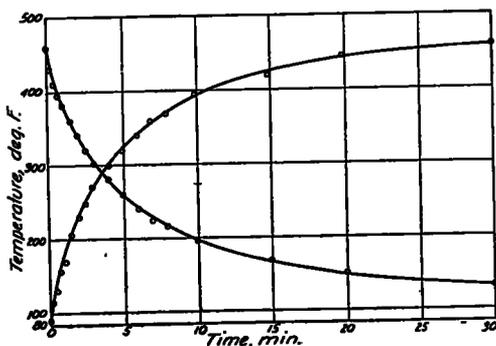


Figure 10. Heating and Cooling Time of a Concrete Surface. Heating was done by infra-red lamps at a height of 1 cm.

The next step was to determine the time required to air-dry the paints before they could be baked. If the paints were heated before enough of the solvent had evaporated, they would be expected to blister. The tests were

performed by painting tension specimens of mortar, drying them for different lengths of time, baking them, then observing them for blistering. The initial tests showed no correlation between drying time and amount of blistering. About two-thirds of the specimens showed at least a trace of blistering, but the ones that were air-dried for 30 min. showed no improvement over ones that were air-dried for one minute. Therefore, the blistering was not caused by rapid volatilization of solvent remaining in the paint film because of too short a period of air-drying.

A possible source of the trouble was moisture held in the pores of the concrete. This moisture would be volatilized under the lamps and thus being expanded greatly would force its way through the partially set paint film. The film would have partially set by the time the water was volatilized because the film received all its heat directly by radiation from the lamps, while the water received part of its heat by much slower conduction through the concrete. The moisture content of the specimens was found to be about 3.5 per cent. Another series of tests was run in which the concrete specimens were heated under the lamps for 10 min. before being painted, to drive out the entrapped moisture. They were cooled, painted, air-dried for various lengths of time, and then baked. No blistering was noted on these paints when air-dried for any period from 5 sec. to 5 min.

If baking of paints on concrete highways is ever put into practical use, the additional operation of pre-baking the concrete would greatly increase the cost of the method. Further work was done to determine the necessity for this operation and to eliminate it if possible.

It has been shown that the water-vapor permeability of a paint film varies inversely with its thickness. Therefore, it was assumed that perhaps blistering of these films on concrete that was not pre-dried could be prevented by increasing the permeability of the film to water vapor by making it thinner. The following tests were devised to determine the correctness of this assumption.

Four different thermosetting paints—Nos. 1, 2, 3, and 6—were tested. Each paint, as described in Table 1, was thinned one-half applied to four neat-cement-mortar specimens containing different amounts of water and

then baked for 10 min. The results are given in Table 2. The subscripts "s" and "t" on the paint numbers, refer to the viscosity, standard and thinned, respectively. Concrete specimens in series A were pre-baked for 10 min. under the lamps and therefore were dry. Those in series B were painted as they were at room conditions (containing 3 to 4 per cent of water). The concrete specimens of series C were set in a shallow pan of water for 15 min. At the end of this time, capillary water could be seen to have risen at least three-fourths of the way to the top of the specimen. The specimen was removed from the pan, painted at once, and baked immediately after being painted. In series D the specimens were completely immersed in distilled water for 15 min., removed, the top

by Goetz (7) in order that the results could be compared with those he obtained on various traffic paints.

(a) Water resistance

Test tubes, about one inch in diameter and six inches long, were dipped in the paints and immediately turned upright to drain and dry. The oleoresinous paints, Nos. 12, 13, and 14, were allowed to air-dry for seven days before being tested.

The specimens thus prepared were partly immersed in distilled water. After the completion of the test, the exposed and unexposed parts of the paint films were compared for changes. Table 4 shows the results.

(b) Alkali resistance

Specimens were prepared as described above, and partly immersed in solutions of

TABLE 2
EFFECT OF MOISTURE ON THE BUBBLING OF
PAINTS BAKED ON CONCRETE

Paint No.	Series	Results	Paint No.	Series	Results
1s	A	No bubbling	3s	A	No bubbling
1s	B	No bubbling	3s	B	No bubbling
1s	C	Slight b.	3s	C	Slight b.
1s	D	Harmful b.	3s	D	Harmful b.
1t	A	No bubbling	3t	A	No bubbling
1t	B	No bubbling	3t	B	No bubbling
1t	C	No bubbling	3t	C	No bubbling
1t	D	No bubbling	3t	D	No bubbling
2s	A	No bubbling	6s	A	No bubbling
2s	B	Slight b.	6s	B	No bubbling
2s	C	Harmful b.	6s	C	No bubbling
2s	D	Not tried	6s	D	No bubbling
2t	A	No bubbling	6t	A	No bubbling
2t	B	No bubbling	6t	B	No bubbling
2t	C	No bubbling	6t	C	No bubbling
2t	D	Not tried	6t	D	No bubbling

wiped off with a cloth, painted, and baked at once.

Following this, the minimum baking time of the paints was determined. The same type of specimen was used as for the drying-time experiments. The paints were baked for various lengths of time, cooled, and then tested for completeness of "set" by rubbing them with a cloth moistened with acetone. If any of the paint came off, or if the surface was dulled, the paint was reported not set. Those that were unaffected were reported set. The results are shown in Table 3.

The following tests were performed to obtain comparisons, by means of standard laboratory tests, between typical highway paints now in use and those being tested for possible future use. The tests were run as described

TABLE 3
RADIATION TIME NECESSARY TO SET BAKING-
TYPE PAINTS

(Using a 250-watt infra-red lamp at a height of 1 in.)

Paint No.	Baking Time
	<i>min.</i>
1	10
2	10
3	6
4	6
5	5
10	10
11	10

sodium hydroxide. The results are shown in Table 5.

(c) Abrasion resistance

These tests were run as described by Goetz (7). The results are shown in Table 6.

Field Tests

The paints were applied at two different locations and were inspected at various intervals of time. A photographic record was kept and is given in part.

Series No. 1 consisted of one stripe each of 13 different paints applied by brush on Sept. 17, 1943 in the concrete courtyard behind Purdue University's Civil Engineering Building. Traffic here is light although there is considerable abrasion. The lines were placed so that the north half would be exposed to traffic while the south half would not. The

TABLE 4
WATER RESISTANCE OF PAINTS

Paint No.	Effect When Immersed in Distilled Water	
	20°C., 24 hours	100°C., 2 hours
1	No effect	No effect
2	" "	" "
3	" "	" "
4	" "	" "
5	" "	" "
6	" "	" "
6A	" "	" "
7	Very slight softening	Softened slightly
9	No effect	No effect
10	" "	Wrinkled slightly, loss of adhesion
11	" "	No effect
12	Faded slightly	Slightly faded, roughened. Not softened
13	Faded more than No. 12	Faded badly, slight loss of adhesion
14	Wrinkled, slight loss of adhesion	Not faded. Slight loss of adhesion and slightly softened

TABLE 5
ALKALI RESISTANCE OF PAINTS

Paint No.	Effect When Immersed in	
	0.1% NaOH, 20°C., 2 hrs.	1% NaOH, 20°C., 2 hrs.
1	Softened very slightly	Darkened. Softened slightly
2	" " "	Softened slightly
3	No effect	No effect
4	" "	" "
5	" "	" "
6	Only effect is a slight darkening	Orange color. Not softened
6A	" "	" "
7	Softened slightly	Orange color, speckled. Softened
9	Not dissolved but wrinkled badly and adhesion lost	Dissolved
10	Like No. 9, but not so bad	Like No. 10 in 0.1% NaOH
11	No effect	No effect
12	Softened very slightly	Only a loosely held white wrinkled skin remained
13	Softened slightly	Not quite as bad as No. 12, but same conditions
14	Like No. 9	Completely dissolved

TABLE 6
ABRASION RESISTANCE OF PARTS

Paint No.	Dry	Wet
	Av. wt. loss (g.)	Av. wt. loss (g.)
1	0.002	0.005
2	0.004	0.008
3	0.004	0.004
4	0.005	0.007
5	Paint scaled off	Paint scaled off
6	-0.008 ^a	-0.006 ^a
6A	-0.048 ^a	-0.40 ^a
7	0.308	0.421
9	0.064	0.122 (Wore thru to can)
10	Paint chipped off	Paint chipped off
11	Blistered when baked	Blistered when baked
12	0.103	0.128
13	0.131	0.150
14	0.195	0.281

^a Small grains of sand were embedded in paint films after test. No apparent wear.

lines were three-inches wide and three-feet long, with three inches between lines. The concrete was dried by being baked for 15 min. under the lamps before painting (for the baking paints). The baking paints were baked with the lamps at a height of 1 in. The north half of the lines was baked 10 min., the south half 20 min. The air temperature was 70°F.; the concrete surface temperature was the same.

The following notes were taken: Drying time (tack-free) of air-drying paints—No. 6, 5 min., No. 7, 10-12 min., No. 8, 3-4 days; No. 9, 5-6 min., No. 12, 10-15 min.; No. 13, 10-15 min. Paints Nos. 10, 11, and 12 had settled very badly in the can. Nos. 1 and 2 remained somewhat soft (but tack-free) for 15-25 min. after the lamps were removed. Glass beads were sprinkled on the north end of wet paints Nos. 4, 11, and 12. Paints Nos. 10 and 11 were themselves a brownish color, which became even darker and duller upon being baked. Tests showed this quality to be inherent in the resins used.

Figure 11 is a photograph of these lines six months later, after they had been weathered for a winter. Most rapid failure, by far, occurred in February and March.

Series No. 2 consisted of one stripe each of 16 different paints applied by brush on Feb. 9, 1944, on US highway No. 52 at Fowler, Indiana. The west half of the pavement (which consisted of 9 ft. of concrete about 10-years old, and a 2-ft. widening strip about two-years old) was used, directly in front of the State Highway Garage. Paint No. 8 was omitted because it dried too slowly. Nos. 15 through 19 were all standard traffic paints put down for another purpose.

Paints Nos. 1 through 9 were applied as 3½-in. lines, while Nos. 12 through 19 were 6 in. wide. For the baking paints the concrete was dried for 10 min. before being painted, then the freshly-painted lines were baked for 10 min. with the lamps at a height of 1 in. The paints were applied at approximately the following rates in gallons per mile, based on a 4-in. line: Nos. 1-9 (except 6 and 6a), 10-12; Nos. 6 and 6a, 15-20; Nos. 12-19, 15. Nos. 6 and 6a were applied this heavily (two coats) because one coat did not seem to cover properly. The concrete was pre-dried for both field tests of the baking paints because it had not yet been learned that this was not always necessary.

A heavy snow fell the day following the

painting and remained for two weeks. At the end of this two-week period the following notes were taken: Nos. 6 and 6a were almost completely gone (both had been applied heavily). Flakes of paint about one inch in diameter were scattered over the ditches. Nos. 12 through 19 had all failed badly. Nos. 7 and 9 had failed slightly. Nos. 1 through 4 looked like new. All failures were worse on the new, 2-ft. extension (newer concrete, more salts, broomed heavier, more snow piled here longer from snow plows). Careful inspection of failures showed that the bond had failed. Loss of adhesion had resulted in extensive scaling.

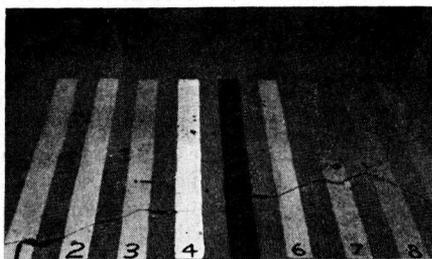


Figure 11. Field Comparison of Paints, Series No. 1, Age Six Months.

Figure 12 is a photograph of the lines of Series No. 2 taken two months after they were painted.

Visual comparisons of the paints were made, and permanent records kept by photographs.

Concrete-surface temperatures were measured by laying mercury-in-glass thermometers on the concrete. The accuracy of this method was tested by placing small amounts of organic crystals of known melting points on the concrete surface. This indicated that the temperatures obtained by the thermometers were slightly too high, but close enough for the purposes of these tests.

In connection with the technique of photographing paint lines on concrete in the field, it was found that much better contrast between paint and concrete was obtained if the concrete were wet than if it were dry because wet concrete is darker. Water was splashed over the area, then the excess swept off.

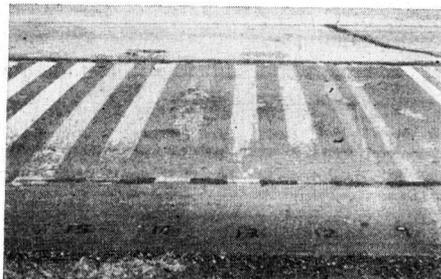
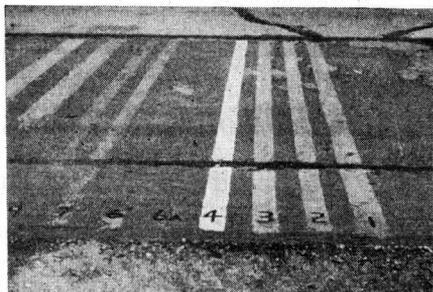


Figure 12. Field Comparison of Paints, Series No. 2, Age Two Months.

DISCUSSION OF ADHESION AND USE OF SYNTHETIC RESIN PAINTS

Before a paint with strong, lasting adhesive forces can be developed, the nature of these forces should be understood. A tentative listing of adhesive forces related to paint films is given below.

- I. Adhesive forces between a paint and a painted surface;
 - A. Mechanical interpenetration. (This

- may and sometimes does depend also on the integral strength of the paint film.) Practical measurement of adhesive forces is involved in IB and IC as well as IA.
- B. Chemical or electrical attractive forces between molecules;
 1. Van der Waal's forces
 2. Hydrogen bonds
 3. Dipoles
 4. Induced dipoles
 - C. Gravitational forces (very small)
- II. Factors that tend to prevent maximum adhesive bonds from being formed;
- A. Smooth surface, thus offering little interpenetration.
 - B. Layers of substances that prevent close contact of base and film;
 1. Air
 2. Water
 3. Grease
 4. Others

Note—Layers of these substances will lessen the adhesive forces of both IB and IC. These forces act appreciably through only very small distances, and a layer of "impurity" only one molecule thick may greatly reduce their magnitude.
- III. Methods of counteracting the factors that tend to prevent maximum adhesive bonds from being formed;
- A. Roughen the surface.
 - B. Clean off all loose particles.
 - C. Remove layers of air, water, grease (baking greatly reduces the thicknesses of layers of the first two).
 - D. Use a vehicle that is a good wetting agent for the substance being painted. Preferably it should replace air, water, grease, and any other films, giving intimate molecular contact between concrete and vehicle (e.g., a water-soluble paint that becomes water-insoluble on being baked will perhaps replace layers of water).
 - E. Use pigment and vehicle as similar to surface being painted as possible regarding polarity. That is, use alkyd and lead chromate on bases of a polar nature but styrene and carbon for coating non-polar bases. (Vinyl and rubber hydrochloride are perhaps the two best coatings for concrete;

both vehicles and concrete are polar).

IV. Forces that tend to break a paint-concrete bond. The nature of these forces is not understood at present, and laboratory tests are being designed to isolate and study them. The soil beneath a concrete pavement is usually damp enough to supply moisture for capillary evaporation through the concrete. Such evaporation can occur to an appreciable extent, as shown by Barre (2) and Dunagan (4).

This evaporation can affect the paint film in different ways. If the film is not very pervious to water vapor, vapor pressure may force it upward. Kelly (10) showed that aqueous solutions from soil and concrete contain salts which are deposited upon evaporation of the water. These salts are deposited under, on, and in the paint films upon capillary evaporation of water from painted concrete. Anderegg (1) reported that excessive surface disintegration of concrete occurs with capillary evaporation; this disintegration was blamed on growth of crystals.

Another possible factor is the effect of alkalinity on bond.

- V. Methods of counteracting the forces that tend to break a paint-concrete bond. (At present it seems probable that any method of excluding water and/or of preventing capillary evaporation of water from the underlying soil upward through the paint-concrete bond will materially prolong the life of the paint).
- A. Break capillarity between the soil and the concrete.
 - B. Waterproof the concrete by chemical admixtures.
 - C. Use a very porous paint that will readily permit passage of water vapor and growing salt crystals.
 - D. Treat cement so that the amount of water-soluble salts is decreased (addition of sulfates? (1)).

The effect of alkalinity on paint-concrete bond has not been taken into account in this paper. More detailed work should be done on this point, in particular to determine the extent of saponification of fatty acids, the effect of this saponification on the paint film itself, its effect on the adhesive bond, and any other effect alkalinity may have.

Measurements should be made of the

amount of water vapor passing upward through a paint film on concrete under conditions of evaporation. This should give a measure of the resistance of the film to passage of water vapor under conditions of field use. Comparisons should be made between different paints and between different film thicknesses of the same paint.

Further work is also needed in connection with the deposition of salt crystals under and on the paint film when water is drawn upward by surface evaporation. Tests should be made to show whether a paint film causes the crystals to grow under it and push it upward, or to grow harmlessly on top after passing through the film in solution.

The paints that were mixed in the laboratory were not formulated to be the best possible traffic paints, but were made to be as simple as possible in order to reduce the number of variables. Most of them would have been better paints with at the least the addition of a plasticizer.

If baking paints are ever to be used extensively on concrete highways, some apparatus must be built to do the baking. The following is proposed as a possibility: A long, narrow vehicle, perhaps 25 ft. long and 3 ft. wide, and powered by a gasoline motor, will be used. Mounted at the front will be an apparatus for spraying paint by air pressure. The rest of the vehicle behind the driver will consist of a long, narrow, inverted U tunnel. The infra-red lamps will be located in the top of the tunnel and focused on the paint film. The gasoline motor for the vehicle will drive generators to supply electrical energy to the lamps. The speed of the vehicle will be adjusted to allow sufficient time for baking. Intersection markings may be baked with any simple arrangement of lamps, and electrical energy from any convenient outlet.

The length of baking time is not an essential consideration for intersection markings or other non-continuous markings. However, if baking is to be used for continuous center lines, the baking time should be at a minimum, preferably not over 2 min. The use of melamine-formaldehyde resins seems to offer good possibilities for short baking times.

Consideration should be given to acid catalysis of polymerization of thermosetting synthetic resins. Although some desirable film properties would be sacrificed by this

procedure, no baking would be required and cost of application greatly reduced.

The method of visual comparison for evaluating paints is not satisfactory; better analytical methods should be developed.

The recently developed silicone-esters offer some extremely remarkable durability characteristics, and should adhere strongly to concrete because of similarity of binder and base. They merit extended study as binders for all types of concrete paints.

CONCLUSIONS

The following tentative conclusions are based on exploratory tests made in the laboratory and field.

1. Concrete marking paints, except in areas subjected to heavy abrasion, fail principally by scaling due to loss of adhesion between the paint film and the pavement.
2. Laboratory tests indicate that loss of adhesion of concrete paints results partly from vapor pressure differences on the two sides of the film, caused by the resistance the paint film offers to evaporation of water through itself.
3. Laboratory tests indicate that loss of adhesion of concrete paints results partly from the formation of crystals of soluble salts under the paint film upon evaporation of water from the concrete through the paint film.
4. Laboratory tests indicate that loss of adhesion of concrete paints results partly from the superficial surface disintegration of the concrete by growing salt crystals.
5. Preliminary field tests indicate that marking paints fail sooner on new than old concrete (probably because of the presence of more soluble salts and greater alkalinity).
6. Laboratory and field tests indicate that baked paints, based on thermosetting synthetic resins, are more durable on concrete pavements than standard oleo-resinous concrete marking paints, natural resin marking paints, and most cold-cut thermoplastic synthetic resin marking paints.
7. The baked paints tested, based on thermosetting synthetic resins, were superior in laboratory tests for water,

alkali, and abrasion resistance to standard oleoresinous concrete marking paints, natural resin marking paints, and most cold-cut thermoplastic synthetic resin marking paints.

8. Because of the resistance of the partially set film to expanding water vapor from the concrete, baking paints may blister when baked on concrete unless the film is thin enough to permit ready passage to the water vapor or unless the pavement is dried before application of the paint.
9. The thermosetting synthetic resin paints tested held glass beads firmly.
10. On the basis of theoretical considerations and other experimental data, air-drying, synthetic-resin paints containing strongly polar groups, such as vinyls and chlorinated rubbers, have excellent adhesion to concrete and should be studied in extensive field tests as to suitability for concrete pavement paints.
11. Most rapid heating of a concrete surface was obtained by placing the lamps very close to the paint film (about 1 in.) even though the focal length of the lamp used was about 12 in.
12. In the laboratory, temperatures of 300° and 400° F. on concrete surfaces can be obtained in 5 and 10 min., respectively, using 250-watt infra-red lamps. The temperature will be maintained above 200° F. for at least 10 min. after radiation has ceased.
13. The baking paints used in this investigation can be baked immediately after being applied, without waiting for them to air-dry.
14. The minimum baking times of the paints tested lie between 5 and 10 min., depending on the composition of the paint, when 250-watt, GE R-40 lamps are used at a height of 1 in.
15. These data confirm those obtained by previous investigators (7) in that laboratory test data correlated well with field performance.
16. The usual method of comparison for evaluating paints is not satisfactory; better analytical methods should be developed.
17. Further confirmatory and supplemen-

tary study is necessary to determine the feasibility of using thermosetting synthetic-resin paints for concrete pavement markings.

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