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Surface Discoloration of Concrete Flatwork

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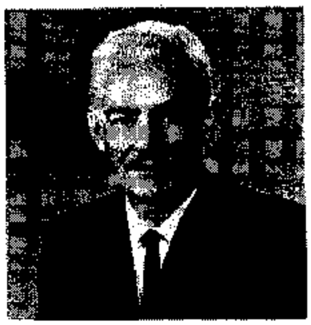

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SYNOPSIS

Laboratory studies of mottling discoloration of horizontal concrete slabs are described, showing that discoloration is increased by hard troweling, by use of calcium chloride admixtures, or by poor curing of the slabs. Local discoloration can also be caused by non-uniform curing conditions.

Avoiding the use of calcium chloride in hard-troweled flatwork would eliminate much flatwork discoloration. If calcium chloride is necessary, curing procedures recommended to minimize local discoloration are water ponding or use of sprayed membrane curing compounds. The effect of calcium chloride is dependent on the alkali content of the cement.

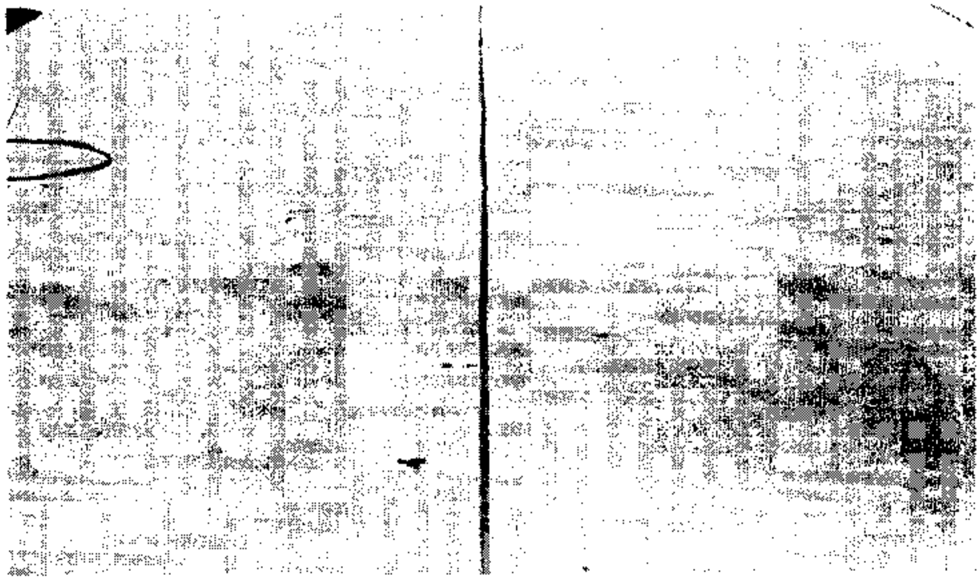
Immediate and thorough washing of the concrete surface with water seems the easiest way of "erasing" discoloration. Special chemical treatments to erase discoloration are of additional benefit.

INTRODUCTION

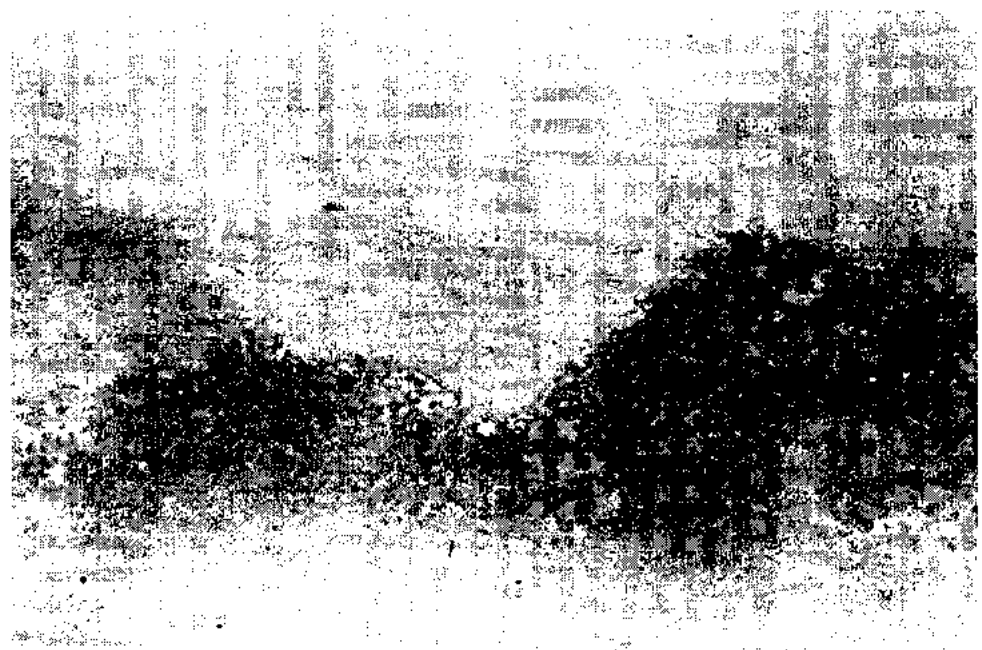
Surface discoloration of concrete flatwork is frequently a problem of concern. The surface discoloration discussed here is the non-uniformity of color or hue in a single concrete flatwork job. This discoloration may take the form of: (1) gross color changes in large areas of concrete caused as in Fig. 1(a) by changes in the concrete mix; (2) spotted or mottled discoloration where light or dark blotches appear on the flatwork surface, as in Fig. 1(b); and (3) early discoloration by light patches of "efflorescence." These discolorations appear soon after the flatwork has been placed and are due in the latter two cases to the procedures used to cast, finish, and cure the slab.

Some of the more obvious types of discoloration, such as dirt being blown or tracked onto fresh concrete surfaces, will not be discussed here. Stains caused by spilling oil, paint, or other liquids on concrete are also beyond the scope of this paper.

The investigation was undertaken to determine the effects of various concreting procedures and concrete materials on flatwork discoloration, to study the primary causes of discoloration, to develop an understanding of the mechanisms causing discoloration, and to explore the methods of preventing or remedying discoloration. Field experience suggested that steel troweling, calcium chloride admixtures, and curing conditions are of importance, and these were chosen as primary variables.



(a) Overall View. Concrete in foreground contained calcium chloride, that in back did not.



(b) Closeup of surface.

Fig. 1 — A Driveway with Gross Color Contrast and Mottling Discoloration.

SCOPE

To attain better control of environment, and be able to explore more variables, this work was confined to the laboratory. Concrete slabs, mostly 1 foot square and 3 inch deep, were used to study the effects of finishing techniques, admixtures, curing, cement properties, etc.

BASIC FACTORS AFFECTING THE COLOR OF A CONCRETE

Three concrete variables found to be important in establishing the color of concrete are the original color of the cement, the water–cement ratio, and the extent and rate of hydration of the ferrite phase in cement.

Color of the Cement

Individual cements may differ in color. Thus, substituting one cement for another may change the color of concrete.

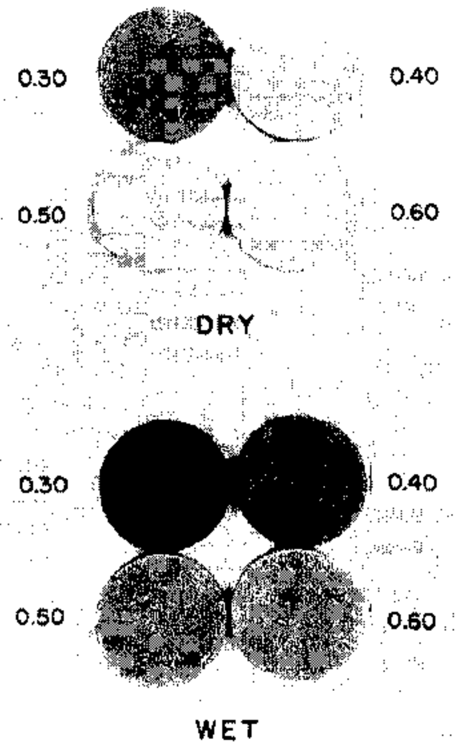


Fig. 2 — Effect of Water–Cement Ratio on Color of Seven-Year-Old Pastes.

Water–Cement Ratio

A low water–cement ratio paste is almost always darker than a high water–cement ratio paste made with the same portland cement. This is evident in Fig. 2, which compares the color of mature pastes, both wet and dry, made with water–cement ratios of 0.3, 0.4, 0.5, and 0.6 by weight. All pastes were made with the same cement. Construction practices producing localized areas of variable water–cement ratio within a slab are potential causes of discoloration.

Hydration of Cement Ferrites

Unhydrated ferrite phases (iron compounds) in cements are blackish-brown. They are primarily responsible for the dark color of unhydrated cement. Hydration lightens their color; fully hydrated ferrites, prepared as slurries of the pure phases, range in color from white to dark red-brown. Thus, lightening of the ferrite phase by hydration is apparently the major cause of cements and concretes becoming lighter in hue as they hydrate.

Not all the ramifications of such color changes are as yet clearly understood. The presence and concentration of lime and chemical admixtures may affect the final color of the ferrite hydrates and hydrated cement, as should such factors as carbonation or the temperature at which hydration occurs.

Calcium chloride is an established "accelerator" that speeds up the hydration of the silicates in cement. However, calcium chloride *retards* the hydration of the aluminate and ferrite phases in cement. Retarded ferrite phases that remain unhydrated in cement will remain dark.

Cement alkalies moderate the actions of calcium chloride in concrete by reacting with calcium chloride, thus precipitating calcium hydroxide and leaving sodium or potassium chloride in solution. These reaction products do not significantly retard the hydration of the ferrite phase in cement, and thus should not greatly delay the lightening of the ferrites and cements by hydration.

Fig. 3 illustrates the effect of calcium chloride and alkalies on ferrite hydration. Shown are curves of conduction calorimeter rate of heat release for mixtures of synthet-

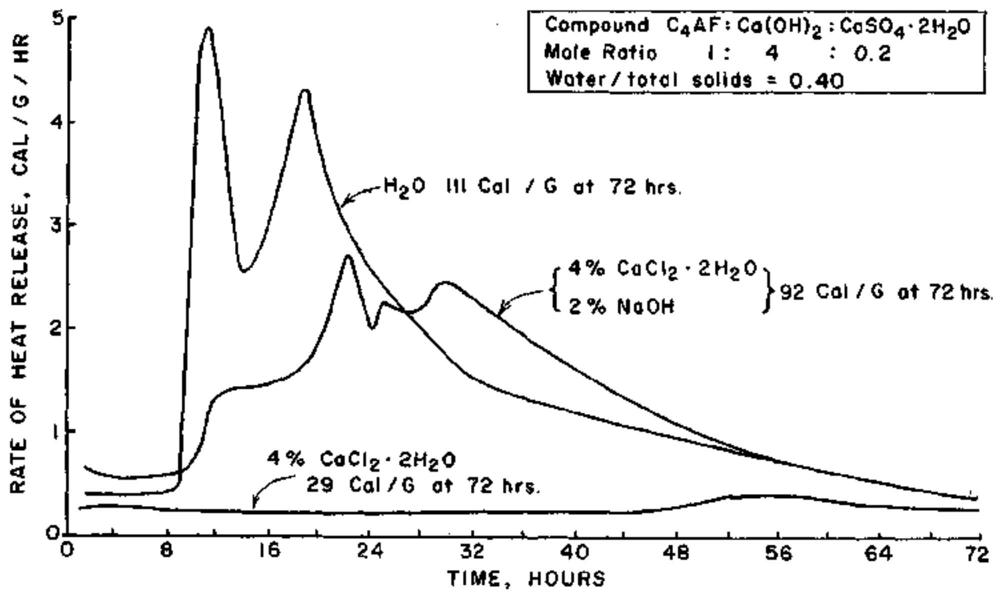


Fig. 3 — Effect of $CaCl_2$ and NaOH on Hydration of C_4AF.

ic C_4AF* (of the fineness of cement), gypsum, and excess calcium hydroxide reacting in the presence of the indicated solutions. These data show that the C_4AF in this system hydrates rapidly after about 8 hours in water. When the same mixture reacts in 4 percent calcium chloride solution instead of water, the hydration rate is greatly reduced. After 3 days, the hydration in calcium chloride solution is only one-fourth that of the same mixture in water. However, if 2 percent NaOH is added to the 4 percent calcium chloride solution, the alkali almost overcomes the retardation caused by the calcium chloride alone.

If the ferrite phases are initially unduly retarded, there may be difficulty in subsequently hydrating them enough to lighten them. Rapidly hydrating silicates, accelerated by calcium chloride admixtures, preempt much of the water otherwise available for hydrating the ferrite phases. Physical compaction, such as troweling, can decrease the water-cement ratio of the top surface of the slab to the point where water and space necessary for the hydration of ferrite phases are not available. This situation may produce indefinite delays in hydrating and lightening this surface portion of the concrete.

*The formula C_4AF is cement chemist's shorthand for 4 $CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$ (tetracalcium aluminoferrite), considered to represent fairly well the composition of the ferrite phase in portland cement.

MATERIALS AND TEST PROCEDURES

Concrete Materials

Six Type I cements were used in this study. Their alkali contents are given in Table 1.

Well-graded Elgin sand and Elgin dolomitic gravel (¾-inch maximum size) were the concrete aggregates.

For this work, most concrete mixes had a cement factor of 5 bags per cubic yard of concrete and a slump of about 3 inches.

Tests indicated that the air content of the concrete was not an important factor in discoloration. Most concretes for these studies contained 5 percent of air entrained through the use of neutralized Vinsol resin added at the mixer.

Unless otherwise stated, concretes with "calcium chloride admixture" contained 2 percent flake calcium chloride ($CaCl_2{\cdot}2H_2O$) by weight of cement. This calcium chloride was dissolved in the batch water.

All concrete was mixed in a small pan-type concrete mixer in a laboratory having

TABLE 1—ALKALI CONTENTS OF TYPE I CEMENTS USED
(ASTM Standard C 114-65)

Cement Designation	Cement No.	Alkali Designation	Water Soluble Alkalies, %			Alkalies, %		
			Na_2O	K_2O	Total as Na_2O	Na_2O	K_2O	Total as Na_2O
A	LTS 13	Low	0.003	0.02	0.01	0.04	0.19	0.17
B	LTS 14	High	0.01	0.66	0.44	0.06	1.30	0.92
C	20132	Medium	0.05	0.20	0.18	0.26	0.50	0.59
D	20133	Low	0.02	0.04	0.04	0.10	0.14	0.19
E	20134	High	0.05	0.96	0.68	0.11	1.38	1.02
F	20135	Medium	0.09	0.29	0.28	0.26	0.55	0.62

a temperature of 73 F and relative humidity of 50 percent.

Casting

Almost all specimens were concrete slabs 1 foot square. These small slabs could be handled easily, yet were large enough to finish with ordinary hand tools.

Most of the slabs were cast in 3-inch-deep, waterproofed plastic-coated plywood molds. However, to explore the effects of slab thickness and water absorption from a slab by a dry subbase, 1-foot-square molds of suitable depth were used to accommodate slabs 3 inches and 6 inches deep without any subbase, and slabs of these depths cast above a 3-inch-deep compacted dry sand subbase.

Several of the slab surfaces were "jitterbugged" to establish whether this pre-finishing procedure (which pushes down the larger aggregate particles, thus bringing mortar to the surface) has a significant effect upon concrete discoloration. A wire potato masher with openings of ½ inch served as the miniature jitterbug. By this means, a mortar layer averaging ⅜ inches in depth was brought to the surface of the jitterbugged slabs.

Finishing

Most slabs were given a hard trowel finish, using the following procedure. Immediately after consolidation by rodding, the concrete in the mold was struck off and given a quick, rough finish with a cork float. At this time the slabs were lightly edged to embed the larger aggregate particles at the slab borders. At about the time the bleed water receded into the slab surface, the slabs were given a light preliminary steel troweling and another edging pass. Unless the time of troweling was under study, the final troweling was done at the earliest time at which a suitable finish could be obtained. Only hand tools were used for finishing.

Curing

Experience has indicated that curing of concrete influences the tendency to discolor. The curing procedures used in these laboratory tests were:

(1) Air curing. After finishing, concrete was left uncovered in the molds for about 16 hours, the molds were stripped, and the concrete slabs were allowed to dry and cure in the 73° F, 50% R.H. environment. Concrete that received this treatment is hereafter called *air-cured.*

(2) Hot room curing. After finishing, uncovered slabs were stored in the molds for about 16 hours in a hot room maintained at 100° F and 20% R.H., then stripped and stored completely uncovered in the hot room.

(3) Polyethylene cure. After finishing, the slab and mold were wrapped with polyethylene film, to minimize moisture loss, with no contact between the polyethylene film and the slab surface. At 16 hours, the molds were removed and the specimens were stored uncovered in the same room in which they were cast. In some instances, the specimens were put back under the polyethylene covers for an additional two days.

(4) Burlap-polyethylene cure. After finishing, the slabs were put under a framework on which pieces of wet burlap were draped. Moisture was sealed in by an outer covering of polyethylene film. After either 1 day or 3 days of burlap-polyethylene cure

the specimens were exposed to the room environment of 73° F and 50% R.H.

(5) Moist room cure. After finishing, the slabs were put in a moist room at 73° F and 100% R.H. Until demolding on the day after casting, the specimens were stored under tenting material that kept the surfaces of the slabs from being disfigured by water droplets.

(6) Membrane curing. Within 1 hour after finishing, proprietary membrane curing compound was flowed onto the surface with a fine paintbrush. No other protection was provided for the concrete, which was stored in the laboratory at 73° F and 50% R.H. The membrane was eventually removed by use of a solvent in order to study the surface.

Subsequent Exposure or Treatment of Slabs

The uniformity or discoloration of *dry* specimens was considered to be the criterion of greatest importance; therefore the specimens were dried before examination.

After the initial extent of discoloration had been determined, the specimens were treated by various procedures to determine if the discoloration could be relieved. Such treatments usually consisted of washing with water, treatment with strong alkali solutions, acid washing, or the application of other chemicals.

A number of the dried specimens were stored in the Skokie Outdoor Exposure Plot to determine the effect of weathering on discoloration.

PRIMARY FACTORS CONTRIBUTING TO DISCOLORATION OF FLATWORK

In these studies, no single factor seemed to cause discoloration. However, combinations of factors caused very severe discoloration. Factors found to influence discoloration were calcium chloride admixtures, cement alkalies, hard-troweled surfaces, inadequate or inappropriate curing, concreting practices and finishing procedures that cause surface variation of water–cement ratio, and changes in the concrete mix. The following discussion describes the influence of these factors on concrete discoloration.

Calcium Chloride and Alkalies

These studies disclose two major types of mottling discoloration that can result from the interaction between cement alkalies and calcium chloride, or from the separate effects of these two components. The first type consists of light spots on a dark background and is characteristic of mixtures in which the ratio of cement alkalies to calcium chloride is relatively low. The second consists of dark spots on a light background and is characteristic of mixtures in which the ratio of cement alkalies to chlorides is relatively high. These types will be called "light spot" and "dark spot" discoloration, respectively.

The detailed discussion to follow will show that in addition to the initial ratio of these two factors, certain aspects of placing, finishing, and curing appear to affect this ratio and thus influence the type, degree, and location of mottling discoloration that may develop. Whether an area will be light or dark depends upon the amount and degree of formation and deposition of alkali chlorides and alkali carbonates at the surface, and upon the hydration of the ferrite phase in the particular area. Both types of discoloration are shown in Fig. 4. All slabs in Fig. 4 were hard troweled and air-cured (conditions that promote discoloration).

Fig. 4(a) shows the surface of a concrete slab made with low-alkali cement A without calcium chloride. The slab is free of discoloration. Washing did not alter its appearance (see Fig. 4(b)).

Fig. 4(c) shows a similar concrete slab made with high-alkali cement B, also without calcium chloride. This slab is definitely discolored with dark spots, but the discoloration is temporary and disappears when the slab is treated five times by alternately hosing it thoroughly with water and drying it overnight (see Fig. 4(d)).

The slab of Fig. 4(e) is exactly like that of 4(a) except that it contains calcium chloride. The extreme discoloration is characterized by light spots directly over coarse aggregate particles near the concrete surface. The dark surface matrix is over relatively deep mortar. Severe discoloration (Fig. 4(f)) was still evident on this slab surface after the 5-day washing and drying treatment just described.

Fig. 4(g) shows the surface of a concrete slab made with high-alkali cement B and with calcium chloride. Except for the calcium chloride, the slab is identical with the (c) slab. The washing and drying treatment alleviated the original discoloration (see Fig. 4(h)), but not as easily or successfully as for slab (c).

Slabs (e), (f), (g), and (h) of Fig. 4 contained 2 percent flake calcium chloride by weight of cement. Higher percentages of this accelerator are rarely intentionally used in concrete. Available evidence indicates that the magnitude and permanence of discoloration increases as the calcium chloride concentration increases from 0 to 2 percent, provided other factors remain constant.

The dark spot discoloration shown in Figs. 4(c) and 4(g) appears to be caused by alkali salts that migrate to the drying concrete surface and concentrate in the more porous or checked areas of the surface. These deposits of salt are relatively transparent and continuous. Their optical behavior is apparently similar to that of water or clear oil, which will darken paste when absorbed. Microscopic examination indicated that the materials causing dark spots on slabs without calcium chloride (Fig. 4(c)) were alkali carbonates – reaction products of cement alkalies and carbon dioxide from the air. Dark spots on slabs containing calcium chloride (Fig. 4(g)) are primarily crystalline potassium and sodium chloride – reaction products of cement alkalies and calcium chloride. The simplest remedy for either type of discoloration is to wash away the discoloring salt with water. One washing was often sufficient for the dark spot type of discoloration which occurred in the absence of calcium chloride. If the concrete contained calcium chloride, repeated washings were necessary to remove the dark spots completely. Somewhat inconclusive data suggest that this washing treatment becomes less effective as the concrete ages.

The light spot type of discoloration (Fig. 4(e)) is particularly difficult to remedy. However, washing or weathering causes the dark background areas of these slabs to lighten very slowly, approaching the color of the lighter spots. It appears that discoloration by salts, such as that described for the dark spot type of discoloration, is relatively minor. The first washdown with water perceptibly lightens the slab, probably by removing the relatively small amount of salt at the slab surface.

The large areas of extremely tenacious dark background remaining after the first washdown do not appear to be the result of salt deposits. Apparently, these are areas of paste containing large amounts of retarded dark ferrite phases, because troweling has densified the surface making it difficult for hydration to continue.

The light spots on the surface of Fig. 4(e) coincide exactly with particles of coarse aggregate close to the slab surface. These relatively impermeable particles interfere with the normal migration of chloride salts toward the drying surface of a concrete slab, resulting in differences in the extent of hydration of both the ferrite and silicate phases. This produces light spots (low calcium chloride content) over the aggregate, which contrast with dark (high calcium chloride content) surface areas over deep mortar. The migration of chloride salts toward the drying surface of the slab significantly increases the surface concentration of these salts. Limited chloride analysis indicates that surface mortar of air-dried slabs has three to four times the original concentration of chloride.

Immediate and thorough flushing with water tends to lessen the light spot type of discoloration. Complete eradication may require special chemical treatments discussed later.

In summary, the type of discoloration produced is influenced by both the alkali content of the cement and the calcium chloride content. For example, air-cured slabs made with low-alkali cement A and ½ percent calcium chloride have dark spot discoloration, and ones made with 2 percent calcium chloride have light spot discoloration. At the other extreme, air-cured slabs made with high-alkali cement E and very high percentages of calcium chloride (about 5 percent or greater) show light spot discoloration in contrast to the dark spot discoloration with lower amounts of calcium chloride. The factor mainly determining the type of discoloration in the slab is the ratio of the alkalies to the calcium chloride present in the concrete. High and low ratios produce dark spot and light spot discolorations, respectively.

Additional confirmation of the effects of the ratio of alkali to calcium chloride was obtained by adding sodium hydroxide (0.8 percent as Na_2O) to air-cured slabs made with low-alkali cements A and D. Dark spot discoloration resulted. Discolorations produced by adding sodium hydroxide to the mix were similar to those encountered with cements having a high content of

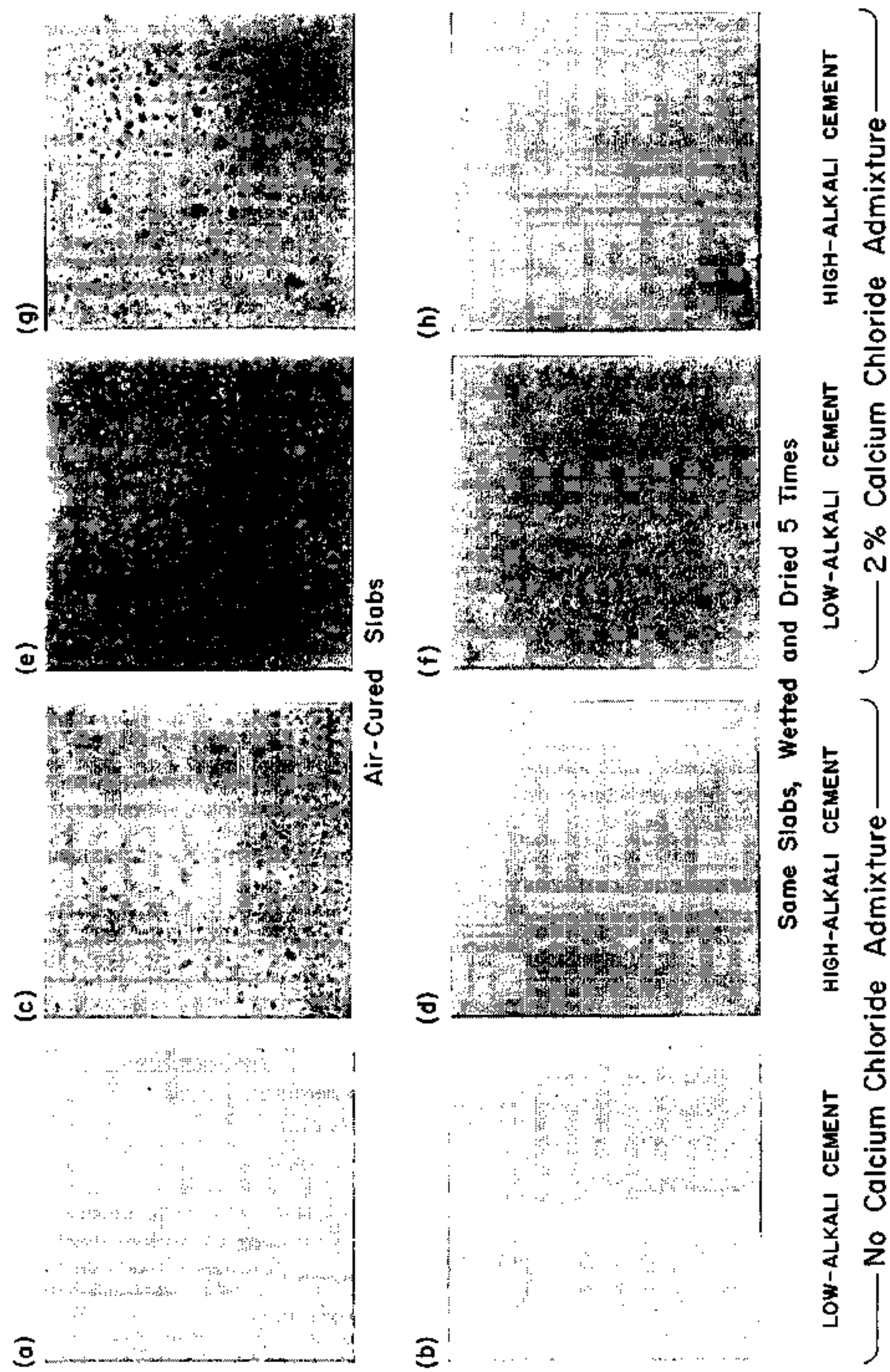


Fig. 4—Effect of Calcium Chloride Admixture on Hard Troweled Slabs.

potassium oxide. This suggests that sodium and potassium are equivalent in their effects on discoloration.

The conversion of calcium chloride to potassium or sodium chloride appears to be the probable cause of basic changes from light spot to dark spot discoloration. This was investigated by using 1 and 2 percent sodium chloride in slabs made with low-alkali cement A. Dark spot discoloration resulted, which was remedied by four washing and drying treatments.

Further complications are introduced because the ratio of alkali to calcium chloride *at the concrete surface* is the important factor. Curing effects, temperature of the slab, and other factors should affect the rate of migration of salts to the surface and the rate of hydration of the cement, both of which may govern the type of discoloration. One good example of such rate effects is the variable discoloration noted for concretes made with calcium chloride and medium-alkali cements C and F. Air-cured slabs had dark spot discoloration. Hot-room-cured slabs of the same concrete had light spot discoloration.

Finishing

Hard Troweling. Discoloration is primarily a problem with hard-troweled slabs that have been either left smooth or broomed lightly. It is rarely of importance in concrete flatwork with rough-textured surfaces produced by floating, burlap drags, or rough brooming. Dark and light spotting that typifies discoloration may appear on rough-textured flatwork, but is easily lost among the closely grouped highlights and shadows on rough-finished concrete. Moreover, the rather porous, uncompacted surfaces of rough-textured concrete flatwork tend to have less spotting than well-compacted, hard-troweled surfaces of similar concrete.

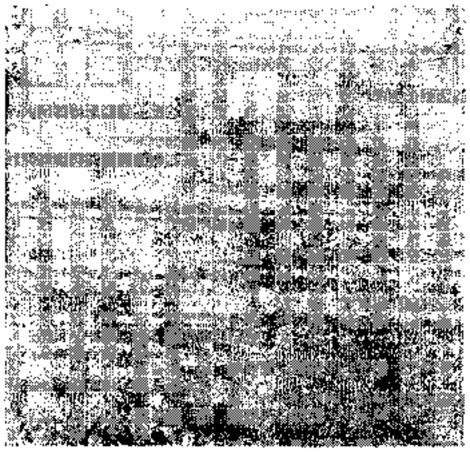
Fig. 5, showing slabs that were cast at one time, with identical concrete, illustrates the effects of variations in finishing time upon the eventual discoloration of the concrete. Low-alkali cement A and calcium chloride admixture were used in these air-cured slabs.

Fig. 5(a) shows a slab that was steel troweled before the concrete was stiff enough to take a slick trowel finish. Slab 5(b) was finished 15 minutes after the (a) slab. Both slabs had a rough "orange peel" finish. The (c) and (d) slabs in Fig. 5 were finished 45 minutes and 60 minutes, respectively, after the (a) slab. While both these slabs took an acceptable trowel finish, an intermediate time would have been best. The sequence of photographs 5(a) through 5(d) shows that overall concrete discoloration of the light spot type gradually becomes more pronounced as a greater amount of compactive effort is expended in troweling. The progressively darker background discoloration with harder finishing might be caused by the progressive compacting of the paste, which leaves less water for hydration of the ferrite (which the calcium chloride retards).

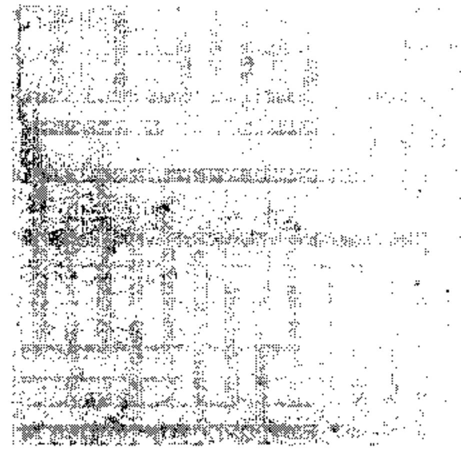
Limited data indicate that concretes made with high-alkali cements are less susceptible to accentuation of dark spot discoloration by hard troweling.

Trowel Burning. Extreme discoloration is caused by trowel burning, a blackening of the surface resulting from attempts to hard-trowel concrete after it has become much too stiff to trowel properly. Trowel metal rubbed off onto the stiff concrete is a conventional explanation for trowel burns. Some of the trowel burn discoloration undoubtedly is due to abraded metal. However, since a troweled surface can be "burned" by rubbing it vigorously with plate glass, densifying a paste by troweling to a point where the water–cement ratio is drastically decreased appears to be the most important cause of trowel burning. Even the best curing does little to lessen trowel burn discoloration. Such burns are also nearly impossible to remedy by subsequent treatments.

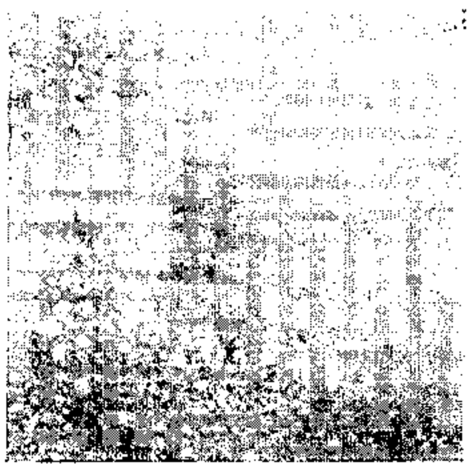
Since it is difficult to remove trowel burns, ways to avoid burning are very important. Concrete that will stay finishable long enough for proper troweling should help in avoiding the conditions leading to trowel burns. A "finishable" concrete can be described as one with a buttery texture that is sufficiently stiff so that a slick troweled surface does not degrade to a rough "orange peel" surface before the concrete sets, and yet is still plastic enough to fill small surface irregularities without excessive work. Cement composition is one factor that may influence concrete finishability. For example, high calcium aluminate portland cements produce surfaces that are buttery for relatively long periods. At the other extreme, the acceleration of hydration of cement silicates by calcium chloride causes concrete to be buttery and finishable for only short time periods.



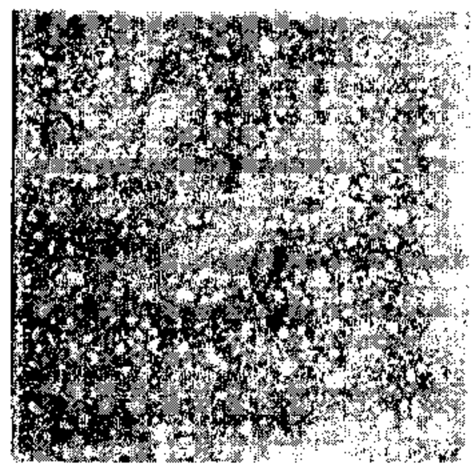
(a) Troweled 2 hours after casting.



(b) Troweled at 2 hours and 15 minutes.



(c) Troweled at 2 hours and 45 minutes.



(d) Troweled at 3 hours.

Fig. 5—Delayed Hard Troweling Increases Troweling Effort and Concrete Discoloration.

To minimize trowel burns: (1) have an adequate finishing crew, (2) reduce evaporation losses with sunshades and windbreaks, and (3) avoid the use of calcium chloride where possible.

Curing Procedures

Curing procedures have a significant effect on discoloration. This study indicates that the curing procedures that are most efficient in preventing evaporation from the entire concrete surface also produce the most uniform slabs.

Effectiveness of Various Curing Procedures. Fig. 6 shows the effects of different curing procedures on the mottling discoloration of cement B and A concretes containing calcium chloride admixture. Both air-cured specimens, (a) and (e), were badly discolored. High-alkali concrete slabs that were given 1 day of polyethylene curing, (b), or burlap-polyethylene curing,

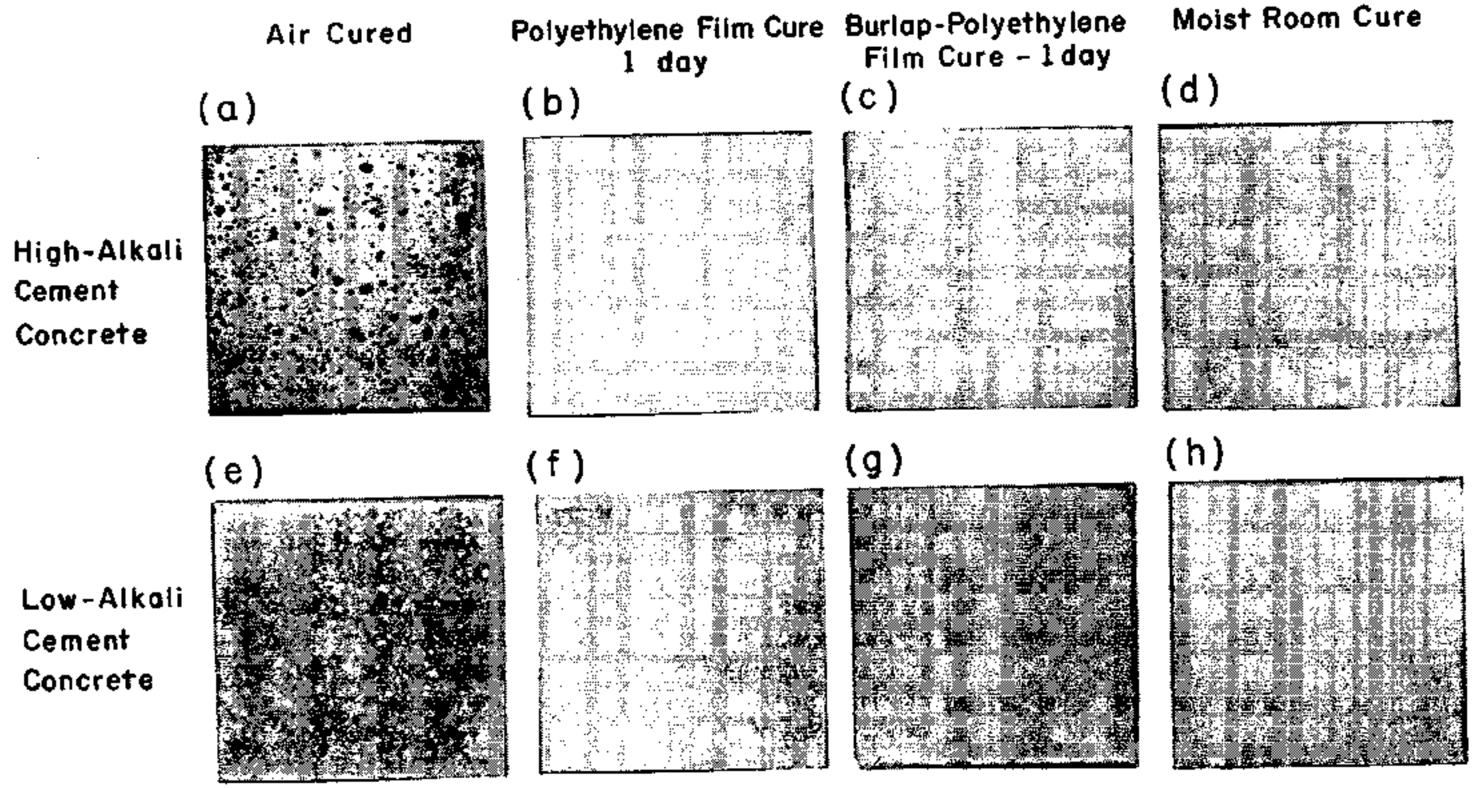


Fig. 6 — Effect of Curing on Discoloration of Hard Troweled Slabs Containing 2 Percent Calcium Chloride Admixture.

(c), or were moist room cured, (d), displayed little discoloration, indicating the effectiveness of most curing procedures in preventing such discoloration.

One day of burlap-polyethylene curing, (g), and moist curing, (h), appeared reasonably effective in preventing discoloration in low-alkali concrete slabs. One day of curing under a polyethylene film, (f), was not sufficient. The inadequacy of the 1-day polyethylene cure in this instance suggests that thoroughness of curing is essential to prevent discoloration of low-alkali calcium chloride slabs.

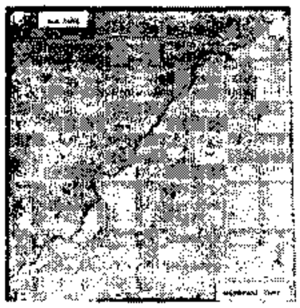
Figs. 7(a) and 7(b) show the results of membrane curing concretes made with high-alkali B and low-alkali A cement and a calcium chloride admixture. About 1 hour after troweling, half of each slab was painted with a membrane curing compound. After 1 day, the curing compound was removed with a solvent.

Originally, the membrane-coated portion of each slab was extremely uniform in color. When the membrane was removed, the low-alkali slab (b) remained free of discoloration, except for three membrane filled pinholes. Slab (a), however, shows small dark alkali-salt smudges that kept reappearing after they had been washed away with water. Four washings were required to permanently eliminate these smudges.

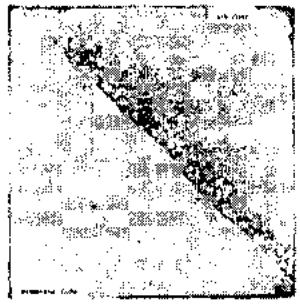
Early removal of membrane coatings is not normal for concrete flatwork. Prolonged membrane protection appears to make the coated portions even less susceptible to later salt discoloration if the membrane is subsequently removed.

Uneven Curing. The overall color of the air-cured portion of the slab in Fig. 7(a) stayed noticeably darker than the membrane-coated portion. This condition is probably permanent. It is a good example of discoloration from uneven curing. To prevent discoloration from this cause, membrane curing compound should be applied evenly and adequately, moist coverings should be kept uniformly wet, and plastic film covers should be thoroughly anchored.

"Greenhouse Effect." Careless placing of plastic curing film on the surface of the flatwork concrete containing calcium chloride may cause unsightly efflorescence deposits in addition to mottling discoloration. A high fold in a waterproof curing sheet can serve as a little "greenhouse." On



(a) High-Alkali Cement



(b) Low-Alkali Cement

Fig. 7 — High- and Low-Alkali Cements Used in Concrete Slabs with 2 Percent Calcium Chloride. A Portion of Each Slab Was Painted with Membrane Curing Compound, Which Was Removed with Solvent After One Day.

a hot day, under direct sunlight, the fold becomes the location of a water evaporation-condensation cycle. The heat of the sun, aided perhaps by the heat of hydration of the concrete, evaporates water from the concrete under the fold. The water vapor then condenses on the cool high part of the fold and eventually runs down the sides of the film to collect at the points of intersection of the concrete and the film, or in low places in the concrete surface. Such localized dry and wet areas on fresh concrete surfaces may cause concrete discoloration.

Laboratory tests were made to evaluate this "greenhouse effect." Fig. 8(a) shows a round hard-troweled slab, $4\frac{1}{2}$ in. thick, being cured beneath a folded sheet of clear polyethylene. The concrete in this slab was made with high-alkali cement B and calcium chloride. Application of the polyethylene sheet to the concrete was delayed until the concrete surface was firm enough not to adhere to the polyethylene. A heat lamp shining on the concrete surface from a distance of about 4 feet provided the radiant energy needed for the evaporation–condensation cycle; a fan cooled the high part of the fold.

Fig. 8(a) is a photograph taken about 5 hours after the start of curing. The dark spots in the figure are due to liquid that filled the narrow spaces between the curing sheet and the concrete surface. Slight ebbs and flows, which were apparent during observation, indicate that the water was definitely cycling beneath the polyethylene cover; however, at this stage of the cure relatively stable boundaries were established between water-filled dark spaces in contact areas and the light, droplet-speckled tented areas where evaporation was taking place.

Continuous curing under the heat lamp was maintained for about 17 hours. Fig. 8(b) shows the top surface of the slab shortly after the curing sheet was removed. White areas in this photograph match exactly the areas where a thin liquid layer contacted both the curing film and the concrete. Dark areas occur wherever the polyethylene remained sufficiently out of contact with the concrete surface to permit evaporation to occur. Subsequent scrubbing with water, using a stiff bristle brush, removed some of the concentrated white efflorescence deposits, as shown in Fig. 8(c). Application of very dilute hydrochloric acid removed the remaining efflorescence, as shown in Fig. 8(d). The dark mottling underneath the efflorescence was not removed by the acid wash. Soaking in 10 percent caustic soda solution or allowing water to stand overnight on the slab surface were only moderately successful treatments for reducing efflorescence and mottling discoloration.

Limited tests indicate that it is difficult to greatly discolor calcium chloride-free concrete by the "greenhouse effect."

Miscellaneous Factors that Affect Discoloration of Flatwork

Certain construction procedures may tend to lessen or increase the discoloration of concrete. Such procedures include jitterbugging, subgrade preparation, protection of fresh concrete from evaporation, and changes in concrete materials during casting or finishing of the slab.

Jitterbugging. The use of a jitterbug to bring mortar to the surface of a slab slightly decreased mottling discoloration.

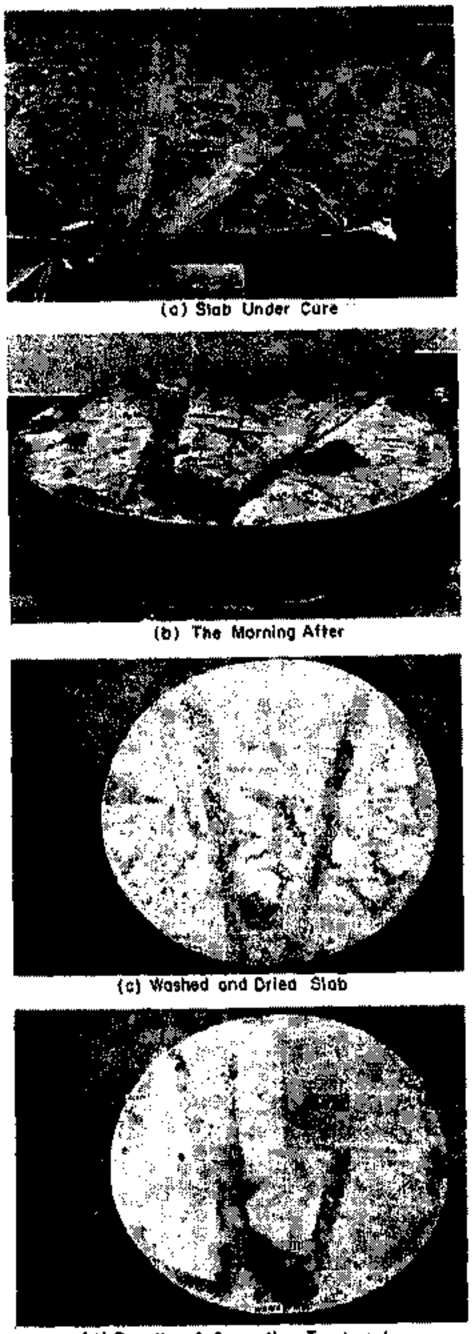
Subgrade preparation. Theoretically, the moisture condition of the subgrade can be considered a factor in discoloration. A dry spot on the subgrade will absorb more water from the overlying concrete slab than a moist section of subgrade. Thus, a slab placed on a subgrade of highly variable absorptive capacity will have areas of relatively high and low water–cement ratio, with consequent light and dark hues.

It was anticipated that 3-inch-deep slabs cast on a 3-inch-deep dry sand subbase would be relatively dark, the 6-inch-deep slabs cast on the same type base a little lighter, and the comparable slabs cast in watertight molds lighter yet. Certain slab groups of this type cast from the same mix behaved in just this way, but there were sufficient exceptions to raise doubts about subgrade absorption as a cause of strong color contrasts. Nevertheless, moistening the subgrade should improve the appearance of the finish, since color variations due to unequal absorption will be moderated or eliminated. Another advantage is that the finish will be more uniform due to greater uniformity of setting, for variable setting can occur if there are surface patches of wet and dry concrete.

Protecting concrete surfaces from wind and sun. Heat accelerates hydration of cement. Heat and wind will dry a concrete surface, decreasing the water–cement ratio and increasing the concentration of salts at the slab surface. Discoloration is possible if one portion of a slab has a different exposure to the wind and sun than another portion. Thus, protecting fresh concrete from the wind and sun are measures that help to reduce discoloration.

Gross mix changes. Sometimes the concrete mix for a job must be adjusted. If the adjusted mix has a color different from that of the original mix, a two-toned job is an inevitable result. The contrast can be moderated by providing a construction joint at the mix change line.

Fig. 1(a) shows an attempt made in the field to shorten overall finishing time, by switching to concrete containing calcium chloride, after first placing concrete without an accelerator. The photograph was made five years after casting. The dark area is a classic example of chloride discoloration. Even if the mottling discoloration had not occurred, the overall dark color of the concrete containing calcium chloride



(a) Slab Under Cure

(b) The Morning After

(c) Washed and Dried Slab

(d) Results of Corrective Treatments

Fig. 8—"Greenhouse Effect" Discoloration of a Hard-Troweled, High-Alkali Cement Slab Containing 2 Percent Calcium Chloride.

would have clashed with the lighter color of the portion of the concrete that did not contain this accelerator.

Retarded concrete has occasionally been used in the same slab with unretarded concrete. This procedure can also result in a two-tone effect.

The practices of dusting surfaces with dry cement to speed finishing, or of smearing mortar or cement paste on the surface of concrete already too hard to trowel properly, will generally result in discoloration.

Outdoor Exposure of Laboratory Specimens

Both discolored and clear slabs were stored outside during the winter and spring of 1965-66. Clear slabs showed no appreciable discoloration after this exposure. Discoloration that could not be remedied by five laboratory washing and drying treatments was not appreciably affected by the outdoor exposure.

CHEMICAL REMEDIES FOR DISCOLORATION

Some success has been achieved in improving the appearance of discolored slabs through the use of a strong lye wash. Dry discolored slabs were covered with a 10 percent solution of sodium hydroxide (caustic soda) for a day or two and then thoroughly washed to remove the caustic solution. During the subsequent drying period, the discolored portion of the concrete often blended with the rest of the slab surface. The older the discolored concrete is, the less effective is this or any other known remedy.

Strong acid washes were found to be a poor treatment for mottling discoloration. Strong acid washes were hard to control, and usually either caused no perceptible improvement in the appearance of the surface or etched so much of the paste away from the slab surface that the finish was lost and considerable aggregate was exposed.

One chemical, with an action much like that of a very mild acid, appears to have real potential in "erasing" discoloration. Di-ammonium citrate, $(NH_4)_2HC_6H_5O_7$, slowly attacks calcium carbonate, calcium hydoxide, and other cement constituents. The chemical is a diuretic, but otherwise relatively harmless to man. When applied to a dry discolored surface, the ammonium citrate penetrates the surface, digests the indicated paste constituents, and makes the surface more porous. After treatment, water can penetrate more readily into the surface region to promote hydration and lightening of cement constituents. An immediate lightening of the surface by this treatment results from the formation and deposition of silica gel and calcium citrate, formed by the reaction of the ammonium citrate and cement paste. After drying, the gel becomes a very tenacious light-colored coating.

Fig. 9 shows a badly discolored slab, the light portion of which resulted from two ammonium citrate treatments (described below). Some of the lightening is caused by the gel "whitewash," but there has also been a pronounced change in the nature of the discoloration. Further treatments with the chemical, alternated with wetting and drying, produced even more lightening of the concrete surface and made the treated surface even more uniform in color.

The slab in Fig. 9 was given what appears to be the most efficient ammonium citrate treatment. The procedure is: (1) Apply a 20 to 30 percent water solution of di-ammonium citrate on *dry* concrete. (2) Continuously and lightly brush the treated area to maintain a uniform film of clear liquid on the surface. About 5 minutes after application, the liquid on the concrete surface will start to turn into a white gel. More water must be applied so the gel does not stiffen or dry. (3) Continue to stir and brush this coating around on the concrete surface for about 15 more minutes after gelation. (4) Thoroughly clean all the gel from the surface with a stream of water and vigorous brushing.

Because the citrate solution must penetrate the concrete surface for efficient removal of discoloration, the second treatment should be deferred until after the concrete has had an opportunity to dry. After ammonium citrate treatment, the uniformity of the surface can be improved still further by alternate wetting with water and drying. Use of the above treatment on portions of a slab is not recommended, since contrasting light patches of surface will result. The whole slab should be treated to obtain maximum uniformity.

Ammonium citrate treatment has also been used for cleaning concrete surfaces that were discolored by form-oil spots. It may also be useful in treating other blemishes of formed concrete surfaces.

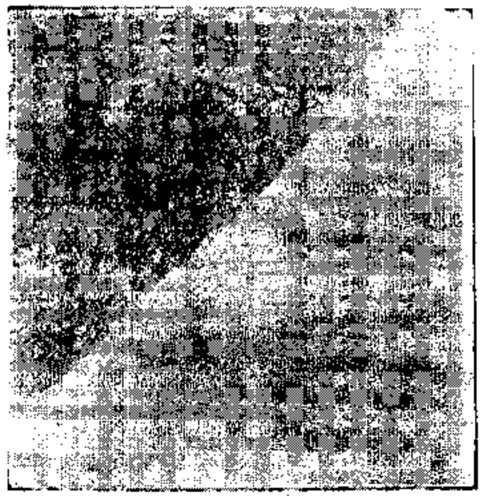


Fig. 9—Half of This Slab Was Treated with Di-Ammonium Citrate to Remove Light Spot Discoloration.

CONCLUSIONS

1. The discoloration of a slab may be minimized or prevented by moistening absorptive subgrades, proper scheduling of placing and finishing, good finishing practice, protection of concrete from drying by the wind and sun, and proper curing.

2. Calcium chloride in concrete is a primary cause of concrete discoloration. The chances for discoloration are much less if calcium chloride is not used.

3. High-alkali contents moderate discoloration in concretes containing calcium chloride by counteracting the retarding effect of the chloride on the hydration of the ferrite phases.

4. Discoloration becomes more pronounced and more permanent with harder finishing.

5. Trowel burns are the most severe and permanent type of discoloration of concrete flatwork.

6. If discoloration occurs because of inadequate curing, intermittent washing with water and drying of the slab surface should be the first remedy tried. Such treatment should be initiated as soon as possible, since the treatment is more effective at an early age.

7. Strong caustic soda solution ponded on discolored concrete sometimes moderates the discoloration. To date, the most

effective chemical treatment found for discoloration has been application of di-ammonium citrate solution.

RECOMMENDATION TO PREVENT DISCOLORATION OF FLATWORK

1. Avoid use of calcium chloride in the concrete, if possible. Calcium chloride acceleration aggravates discoloration of hard-troweled flatwork. (Calcium chlorides may be present either because added intentionally as an accelerator, or unintentionally through use of certain proprietary chemical admixtures that contain it.)

2. Cure the concrete properly and at once, for bad discoloration may occur as early as 16 hours after placing. Curing is essential to prevent discoloration. For concrete flatwork without calcium chloride admixture, ordinary curing procedures, such as coverings of wet canvas, burlap, or sand; ponding with water; or use of a white-pigmented membrane compound appear quite adequate. The "greenhouse effect" is probably minor in the absence of chloride in the concrete; thus curing with plastic sheets should be sufficient so long as overlapped areas are properly taped, the sheet is as flat as possible, and the edges are adequately anchored.

For flatwork concrete that must contain calcium chloride admixture, positive prevention of water evaporation during curing is necessary. Sunshades and windbreaks are desirable to keep the flatwork from drying in localized areas during finishing. Wet coverings of burlap, sand, and canvas should not be allowed to dry in patches. Water ponding and membrane curing compounds are apparently the best curing procedures to avoid discoloration. Eventually, traffic may wear curing compounds from portions of the surface, causing a kind of discoloration. Removing the remaining curing compound with a suitable solvent will restore uniform color to the flatwork slab.

3. To finish properly and prevent trowel burns, the pace of operations must be limited to the finishing capacity of the crew and equipment at hand. Since the time for finishing any concrete that contains calcium chloride is limited, the schedule should be cut back accordingly, or the size of crew increased. The harmful practice of troweling additional cement paste onto the surface should not be permitted.

4. Differently colored concretes should be separated by construction joints. Such color differences should be anticipated when there is a gross change in the mix, a change of cement brands, or an intermittent use of accelerating or retarding chemical admixtures.

RECOMMENDATIONS TO ERADICATE DISCOLORATION

1. For the types of discoloration described in this report, the first (and usually effective) remedy that should be tried is an immediate thorough flushing with water. Permit the slab to dry overnight, then repeat the flushing and drying process until the discoloration is eradicated. The sooner this is done, the better are the chances for success. Use plenty of water — turn the hose on the flatwork and flush it gently for at least a half hour. If possible, use hot water.

2. The first flushing with water may not remove all white efflorescence (probably calcium carbonate) from concrete surfaces. Scrubbing the wet surface with a very stiff nonmetal brush may remove this efflorescence coating. If, and only if, this fails, acid washing may be used. Very dilute solutions of hydrochloric acid (about 1 to 2 percent) will remove carbonate efflorescence from hard-troweled flatwork. Higher concentrations may expose aggregates. Higher concentrations of weaker acids such as 3 percent acetic acid or 3 percent phosphoric acid can be used to remove efflorescence. While not as effective as di-ammonium citrate, the weaker acids just mentioned do lessen mottling discoloration. Weak acids are cheap and treatment with them is easier than treatment with di-ammonium citrate. Trials with weak acid on small test patches in unobtrusive locations on a discolored slab are advisable before adopting the more effective di-ammonium citrate treatment.

3. The type of discoloration that consists of light spots on a dark background may respond less to the water flushing treatment than do other types of discoloration. Limited success has been obtained by treating the dry slab with a 10 percent solution of sodium hydroxide (caustic soda), allowing the solution to remain on the surface a day or two, then thoroughly washing to remove the caustic solution. During the subsequent drying period, the discolored portion often blends with the rest of the slab surface.

4. The best remedy to date involves treating the *dried* surface with a 20 to 30 percent water solution of di-ammonium citrate. The solution behaves like a slow-working acid. One treatment consists of applying the solution to the surface of a dry slab for about 15 minutes. White gel formed by the solution should be diluted with water and continuously agitated by brushing during the treatment. The gel should be scrubbed off with water after the treatment. Water curing between or after treatments increases the treatment's effectiveness. Two or three treatments should be enough; more may tend to expose undue amounts of aggregate, though they may be beneficial with respect to removal of discoloration.

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