EFFECTS OF CALCIUM CHLORIDE ON CONCRETE

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SYNOPSIS

The paper, in two parts, presents test data on effects of calcium chloride on concrete.

Compressive and flexural strengths of specimens cured with integral or surface calcium chloride at temperatures of 100 deg. F. and 25 to 35 percent relative humidity were of the same order as those of specimens subjected to 3 days of wet burlap curing stored under the same conditions. Also, under similar conditions, specimens treated with surface applications of calcium chloride after overnight wet burlap treatment exhibited greater wear resistance at 28 days of age than specimens cured with wet burlap.

Observations of the effects of calcium chloride and water gain on the corrosion of reinforcing steel showed slight rust deposits at early ages whenever calcium chloride was used in the higher slump concretes showing excessive water gain. Specimens examined at the age of one year indicated that this corrosion was not progressive. The void space adjacent to steel created by excessive water gain was found to be conducive to corrosion. When plain concrete was used, this corrosion was mild; when concrete containing calcium chloride was used, the corrosion was slightly greater. Where concrete was in intimate contact with the steel, no corrosion occurred, regardless of whether plain concrete or concrete containing calcium chloride was used.

CURING AT ELEVATED TEMPERATURE AND LOW HUMIDITY

In the technology of concrete, "curing" refers to the conditions during the early hydration of cement which promote hardness, strength and other properties essential to satisfactory service. Curing methods constitute the measures taken to insure or facilitate hydration. Curing protection is especially important during the early age of the concrete and where highly drying atmospheric conditions exist because rapid loss of water by evaporation would arrest hydration of the cement and create objectionable shrinkage stresses.

Although the benefit of wet coverings of burlap is generally recognized, large scale construction or restricted water supply in the field may introduce difficulties which often impair the effectiveness of wet burlap curing. Calcium chloride has been used integrally to accelerate the hydration of the cement and, as a surface treatment, to form a moisture film on the concrete, thus controlling evaporation of internal moisture. The practical advantage of calcium chloride methods of curing is that no supervision is required to insure effectiveness after the material is spread on or mixed in the concrete.

Tests of calcium chloride curings under laboratory conditions 70-deg. F. temperature and 50–60 percent relative humidity have been reported (*1*).[1] Data are presented in this report on the compressive strength, flexural strength and hardness of concrete cured with integral and surface calcium chloride at elevated temperature of 100 F accompanied by low relative humidity of 25–35 percent. Because of its wide acceptance, 3-day wet burlap curing was used as a reference. The study is mainly concerned with the effectiveness of the recommended methods of calcium chloride curing in conjunction with preliminary wet burlap as outlined in ASTM C82-38 and C83-38. However, for purposes of comparison, tests were also made on concrete cured with calcium chloride without the preliminary wet burlap.

Materials and Test Methods—The cement used in these tests was obtained from a local warehouse and conformed to ASTM specification C-150-42 for Type I cement. Commercial flake calcium chloride was obtained from one source. Potomac River sand of gradation conforming to Federal Specification SS-A-281a was used with crushed limestone

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[1] Italicized numbers in parentheses refer to the list of references at the end of the paper.

coarse aggregate from Martinsburg, West Virginia. This was used in two sizes (1½-in. and ¾-in.) and had a bulk specific gravity of 2.72 and an absorption of 0.2 percent. The aggregates were combined with the cement to form a workable mix, proportioned 1:2.49.3.12 by weight, having a nominal cement factor of 6 bags per cu. yd. and water–cement ratio of 0.54 by weight or 6 gal. per bag of cement. The slump was maintained at approximately 3 in.

TABLE 1
IDENTIFICATION AND DESCRIPTION OF THE VARIOUS CURING PROCEDURES APPLIED TO 6-IN. BY 6-IN. BY 20-IN. CONCRETE PRISMS STORED AT 100°F WITH 25-35 PERCENT RELATIVE HUMIDITY.

Curing Identification	Description
D	*Surface calcium chloride* Flake calcium chloride was spread uniformly over the top surfaces of the specimens at the rate of 2 lb.per sq. yd. after the surface water had disappeared.
E	*Integral calcium chloride.* Two percent calcium chloride by weight of cement was dissolved in the mixing water of the concrete. Wet burlap in two layers was spread over the top surfaces of the specimens for 18 hr. and then removed. This method followed ASTM Method C82-38 except that the burlap was removed 6 hr. earlier.
F	*Integral and surface calcium chloride.* Flake calcium chloride (1½ percent) was dissolved in the mixing water and flake calcium chloride was spread uniformly on the surface at a rate of 1½ lb. per sq. yd. when the surface water had disappeared.
G	*Reference method.* Two layers of burlap were spread over the top surface of the specimen and kept wet for 3 days at which time the burlap was removed.
H	*Burlap and surface calcium chloride.* Wet burlap was applied until the specimens were 18 hr. old, when the burlap was removed and calcium chloride applied uniformly to the surface at rate of 2 lb. per sq. yd. This method followed ASTM C83-38 except that the burlap was removed 6 hr. earlier.
I	*Laboratory air.* No surface curing.

Prior to mixing, concreting materials were stored in sealed containers for 48 hr. at 100 F so that the temperature of the freshly mixed concrete ranged from 90 to 95 F. Concrete prisms, 6 by 6 by 20 in., were cast in accordance with ASTM method of test C39-44 except that the specimens remained in the molds for the full curing period and were stored in a small insulated room where the temperature was controlled at 100 ±2 F with relative humidity between the limits of 25 to 35 percent. During the actual molding operations, the temperature dropped slightly and the relative humidity rose as much as 10 to 15 percent as a result of evaporation of moisture from the specimens; both returned to normal within 6 hours.

Twenty-four hours after casting the concrete prisms, a seal of caulking compound approximately ½ in. wide and ¼ in. thick, was placed over the line between the top edge of the specimens and the molds with a pressure gun. Duplicate specimens were made during the same day in steel molds for test at ages of 3 and 28 days. Duplicate specimens were also made in concrete molds in two rounds approximately one month apart.

The concrete molds were constructed of 3- by 3- by 30-in. concrete beams which were saturated with water, stacked and sealed with graphite grease in such a manner as to form water-tight molds of the desired dimensions.

The various curing methods are identified and described in Table 1. Flexural Strength tests were made according to ASTM standard method C78-44 except that the finished surfaces of the specimens were placed at the bottom in tension instead of on the side.

The compressive strength tests of concrete using portions of beams broken in flexure were made according to ASTM method C116-44.

The tests for abrasive resistance were made on 2-in. cubes cut from the beam ends remaining from the strength tests. Tests were made on three specimens for each curing method at age of 28 days, using the apparatus described by Kessler (*2*). By this method one face of each of three specimens is applied to a rotating disk and an aluminum-oxide abrading agent supplied.

Analysis of variance techniques (*3*) were used in analyzing the data to determine (1) whether a real difference between average strength values existed that could be attributed to the effect of curing methods, and (2) whether there were statistically significant differences between means of strength values obtained from the calcium chloride curing methods and from the wet burlap curing.

A t-test (*4*) was made to determine which treatment means were significantly different from the mean of the wet burlap treatment at the 10 percent level of significance.

RESULTS

Strength Tests—The results are shown in Tables 2, 3, and 4.

Tests of the specimens stored in water-soaked concrete molds showed rather wide differences in duplicate tests of each curing method. Variations in absorptive quality of the molds may have affected the results. Although more specimens are required to establish the significance of these tests, surface curing is seen to be advantageous even when free moisture is available for curing on the sides and bottom of the specimen.

In each analysis of variance the over-all variation was separated into components representing (1) comparison of laboratory air treatment (I) with the other five, (2) comparison of the wet burlap treatment (G) with the remaining four, (3) comparison of the remaining four amongst themselves, and (4) "experimental error" as measured by differences between duplicate tests.

TABLE 2

FLEXURAL STRENGTHS OF 6-IN. BY 6-IN. BY 20-IN. CONCRETE PRISMS SUBJECTED TO VARIOUS CURING METHODS AND STORED IN SEALED STEEL MOLDS AT 100°F AND 25 35 PERCENT RELATIVE HUMIDITY UNTIL TEST.

Curing Identification					
D	E	F	G	H	I
psi	psi	psi	psi	psi	psi
3-Day Flexural Strengths					
490 455	435 410	435 420	395 380	435 455	315 315
475	425	430	390	445	315
28-Day Flexural Strengths					
475 530	495 535	475 475	525 520	500 530	315 430
500	515	475	520	515	375

With the exception of the results of the 28-day compressive strength test (using concrete molds where molds seemed to have introduced variability) the burlap and calcium chloride methods of curing generally gave results significantly (5 percent level) higher than the results obtained with the laboratory air storage treatment.

With the exception of method D in the 3-day compressive strength test (steel molds) and F in the 28-day compressive strength tests (steel molds), which had means significantly (10 percent level) lower than the mean for the wet burlap treatment, all strength values for the calcium chloride treatments can be said to be of the same order of magnitude as those for the wet burlap treatment; at least there is no evidence here to the contrary.

TABLE 3

COMPRESSIVE STRENGTHS OF 6-IN. BY 6-IN. MODIFIED CUBES OF CONCRETE SUBJECTED TO VARIOUS CURING METHODS AND STORED IN SEALED STEEL MOLDS AT 100 F. AND 25 35 PERCENT RELATIVE HUMIDITY UNTIL TEST.

Curing Identification					
D	E	F	G	H	I
psi	psi	psi	psi	psi	psi
3-Day Compressive Strengths					
2740 2980	3450 3580	2880 3200	3220 3100	3140 3200	2900 2750
2860	3515	3040	3160	3170	2825
28-Day Compressive Strengths					
4350 5120	4800 4600	4500 4600	4950 5400	5150 4730	4000 3720
4735	4700	4550	5175	4940	3860

TABLE 4

STRENGTHS OBTAINED FROM CONCRETE SPECIMENS CAST AND STORED IN CONCRETE MOLDS AT 100°F AND 25-35 PERCENT RELATIVE HUMIDITY

Curing Identification					
D	E	F	G	H	I
psi	psi	psi	psi	psi	psi
28-Day Flexural Strengths					
535 575	565 605	560 575	495 640	650 635	450 465
555	585	570	570	645	460
28-Day Compressive Strengths					
3640 4950	3840 4650	4830 4600	3800 4720	4330 4800	2900 4300
4295	4245	4720	4260	4565	3600

Wear Tests—Weight losses (resulting from abrasion) of 28-day old specimens are given in Table 5 for several time intervals. Figure 1 shows a comparison of these weight losses at 7 min. after the preliminary abrasion for 45 sec. which was required to insure plane surfaces of all the specimens.

An analysis similar to that in the case of the strength tests was made for the wear tests, neglecting the results of the 45-sec. abrasion. All treatments, excepting E which is a borderline case, can be said to produce means significantly (10 percent level) different from the laboratory air treatment mean. The calcium chloride methods can be said to produce results of at least the same order of magnitude as the wet burlap treatment. There is no evidence here to indicate that the treatments differ, with the exception of the results of treatment H (burlap and surface calcium chloride) which is significantly (10 percent level) higher than the reference method. The specimens with calcium chloride surface curings, H, D, and F had the highest wear resistance of any of the curings tested. The loss in weight of these specimens ranged from 24 to 39 percent less than the weight loss obtained with the specimens which were cured by exposure to laboratory air (method I).

TABLE 5

ABRASIVE LOSS OF CURED SURFACES OF CONCRETE SPECIMENS TESTED AT AGE OF 28 DAYS AFTER STORAGE AT 100 ± 2°F WITH RELATIVE HUMIDITY 25-35 PERCENT (LOSS IN GRAMS PER 2-IN. BY 2-IN. FACE)

Curing Identification	45 Seconds			Additional 3 Minutes			Additional 4 Minutes			Average Wear in 7 Minutes
	Highest	Lowest	Av. 3 Tests	Highest	Lowest	Av. 3 Tests	Highest	Lowest	Av. 3 Tests	
	g.	g.	g.	g.	g.	g.	g.	g.	g.	g.
D	1.40	0.50	0.85	1.20	1.05	1.12	1.20	1.15	1.17	2.29
E	0.80	0.75	0.77	1.40	1.05	1.25	1.35	1.20	1.30	2.55
F	0.40	0.40	0.40	1.40	1.05	1.18	1.22	1.05	1.14	2.32
G	0.75	0.58	0.72	1.40	1.03	1.23	1.33	1.08	1.21	2.44
H	0.35	0.30	0.32	1.17	0.75	0.92	1.18	0.53	0.92	1.84
I	1.10	0.75	0.93	1.75	1.55	1.65	1.40	1.30	1 35	3.00

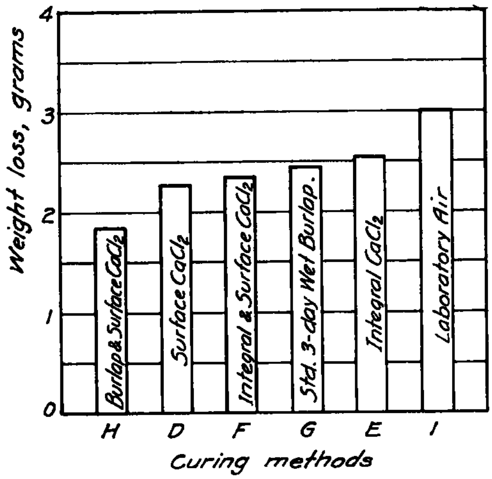

Figure 1. Comparison of Resistance to Abrasion of Concrete Surfaces Cured by Different Methods—Average Weight Loss, grams per 2-in. by 2-in. Face after 7 minutes Abrasions

Summary of Results—The tests indicate that surface curing improves the physical properties of concrete stored at elevated temperature of 100 deg. F and low relative humidity of 25–35 percent.

With specimens made and stored in sealed steel molds, the use of calcium chloride integrally or applied to the surface of specimens after overnight curing with burlap (ASTM standard methods) resulted in 28-day flexural strengths of the same order as those obtained with wet burlap curing for 3 days. The 3-day flexural strengths obtained with the use of surface calcium chloride following overnight wet burlap were approximately 10 percent higher than those obtained with the reference method. The specimens which received laboratory-air curing had strengths ranging from 72 to 89 percent of the strength of the corresponding specimens cured with wet burlap for 3 days. Overnight wet burlap followed by surface calcium chloride resulted in an increase in wear resistance of approximately 25 percent. Generally, the results obtained indicate that calcium chloride is effective for curing concrete at elevated temperature of 100 F. with low relative humidity of 25–35 percent.

EFFECT OF CALCIUM CHLORIDE ON REINFORCING STEEL

There is some opinion among engineers that calcium chloride as an admixture may have a detrimental effect on steel in reinforced concrete. This assumption results from the fact that calcium chloride is a salt which in the presence of moisture is corrosive to steel. Actually, the steel is not long subjected to calcium chloride as a salt, but rather to a mass of concrete in which a small percentage of calcium chloride has been included. There is considerable evidence to indicate that calcium chloride combines chemically with certain constitutents in the cement, and its identity as a salt therefore disappears at an early age (*1*).

Some information on the effect of integral calcium chloride on reinforcing steel is available in contemporary literature (*2*) (*3*) (*4*) (*6*) (*7*). Most of the authors found insignificant and unprogressive corrosion of steel imbedded in dense concrete in which calcium chloride was used. Precautions to avoid air pockets were stated as necessary.

The study reported in this paper was made to obtain additional information on the subject, particularly where void space existed adjacent to the steel in the concrete.

Materials

Two types of deformed steel bars and plain cold rolled steel bars were used in the test specimens. Figures 3 and 4 show the types of bars and extent of corrosion.

Limestone coarse aggregate and river-sand fine aggregate were used with a portland cement meeting ASTM Type I requirements. Mix proportions, by weight, were 1:2.49:3.12. Batches were mixed in a one-bag mechanical mixer. Slumps were from 1 to 8 in. for concrete in the 6- by 12-in. cylinder specimens and 8 in. for concrete used in the larger block type specimens cast in deep steel molds. Specimens were cast from concrete, both with and without 2 percent commercial calcium chloride added in the dry form with aggregates at the mixer.

Tests

The test specimens were divided into two groups as follows:

Group I—Wire-brushed and benzine-cleaned ½-in. diameter deformed bars were cast vertically in 6- by 12-in. concrete cylinders made both with and without 2 percent calcium chloride. The steel molds were stripped at 24 hr. after which all specimens were stored in the moist room for 2 days, followed by outdoor storage on a concrete parapet for the duration of the test. Concrete cylinders with and without calcium chloride were broken open at ages of 14 days, 28 days, 6 months and one year. In each case comparative observations were made of the condition of the reinforcing steel taken from concrete specimens cast with nominal slumps of 2 to 3 in., 4 to 5 in. and 6 to 8 in.

Group II—Deformed bars and cold rolled bars, ⅞ in. in diameter, were fixed horizontally near the top and the bottom of deep steel molds, and 8-in. slump concrete (with and without 2 percent calcium chloride) was cast around the bars. Water gain was thus created under the bars by the gradual settlement of the wet con-concrete. These specimens remained in the molds 3 days, then were placed outdoors on a concrete slab for one year.

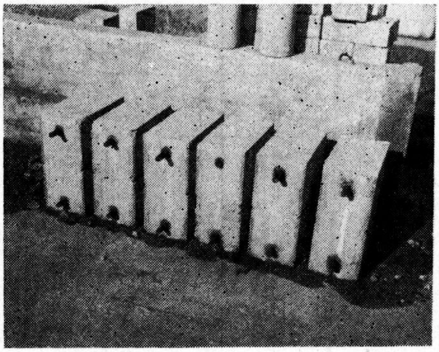

Figure 2. General View of Outdoor Storage of Specimens of Group II

Figure 2 shows the type of specimens, location of bars and general storage conditions for the specimens of Group II. The specimens were made from concretes of high slump in order to study the effect of any void space resulting from water gain under the bars. Using similar specimens Clark (3) found that the average bond resistance of the top bars was approximately two thirds of the bond resistance of the corresponding bottom bars.

RESULTS

Group I—Deformed Bars Cast Vertically in Concrete Cylinders

From visual examination of the specimens, the following comparisons were drawn:

1. For the range of slumps of 1 to 3 in., no corrosion was found on any of the bars taken from concrete either with or without calcium chloride. Where slumps exceeded 3 in. some corroded spots were found on bars taken from concrete in which calcium chloride had been included.

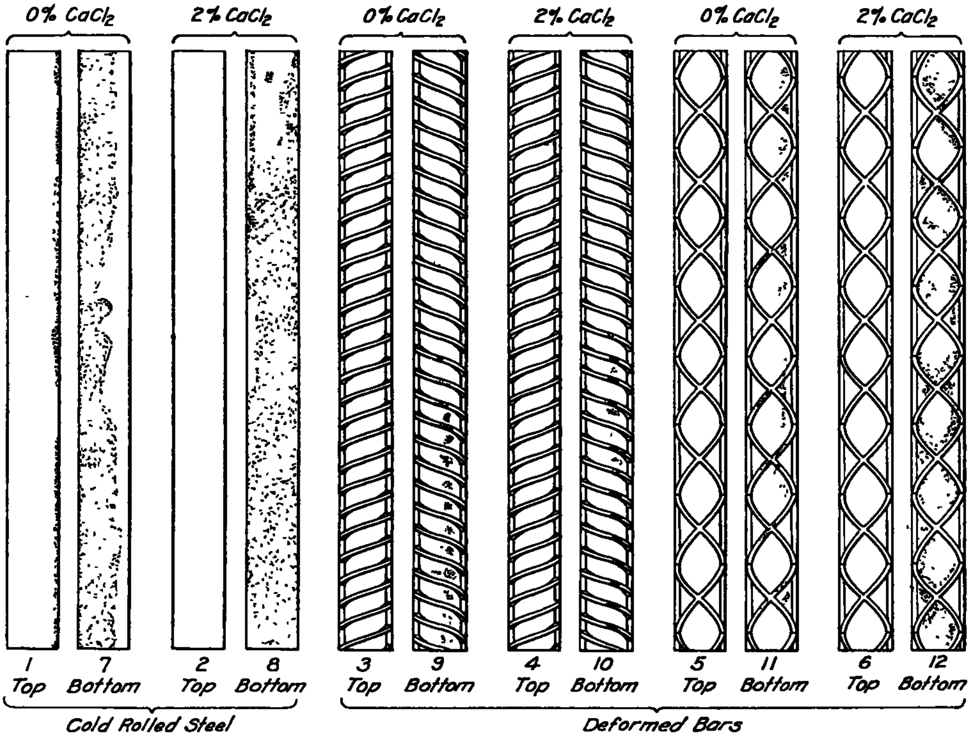

Figure 3. Upper and Lower Surfaces of Steel Bars Cast Near Bottom of Specimens of Group II

2. Corrosion spots were confined to the bottom edges of deformations, indicating water gain as a contributing factor to corrosion.

3. Based on visual observation, corrosion was in no case progressive; specimens examined at the age of 1 year showed no greater corrosion than similar specimens examined at the age of 14 days.

4. Corrosion was slight in extent, consisting of small, scattered brown stains which were barely visible from a distance of 6 feet and could be removed easily by scratching slightly with a knife blade.

Group II—Deformed and Plain Bars Rigidly Fixed in Molds—Concrete of 8-in. slump (with and without integral calcium chloride) was cast around these bars.

1. The upper surfaces of all the top deformed bars (see Fig. 3, views 3, 4, 5, and 6) and with one small exception the entire surfaces of the bottom deformed bars (see Fig. 4, views 21, 16, 22, 17, 23, 18, and 24) were entirely free from corrosion. The upper surface of the cold rolled steel bars was free from corrosion except for one spot on view 14 of Figure 4 and the longitudinal edge of view 1 of Figure 3. This latter condition may have been due to slight displacement of bar in casting concrete and may more properly be included with the adjacent view of the same bar (view 7).

2. Corrosion occurred on the under side of all of the top bars either with or without cal-

cium chloride where maximum water gain was expected. See Figure 3, views, 7, 8, 9, 10, 11, and 12. Views 7 and 8 show rather extensive surface corrosion for the lower surface of the cold rolled bars taken from concrete both with and without calcium chloride. The corrosion on deformed bars taken from concrete without calcium chloride was rated as mild (see views 9 and 11) and the corrosion resulting from concrete with calcium chloride was slightly greater (see views 10 and 12).

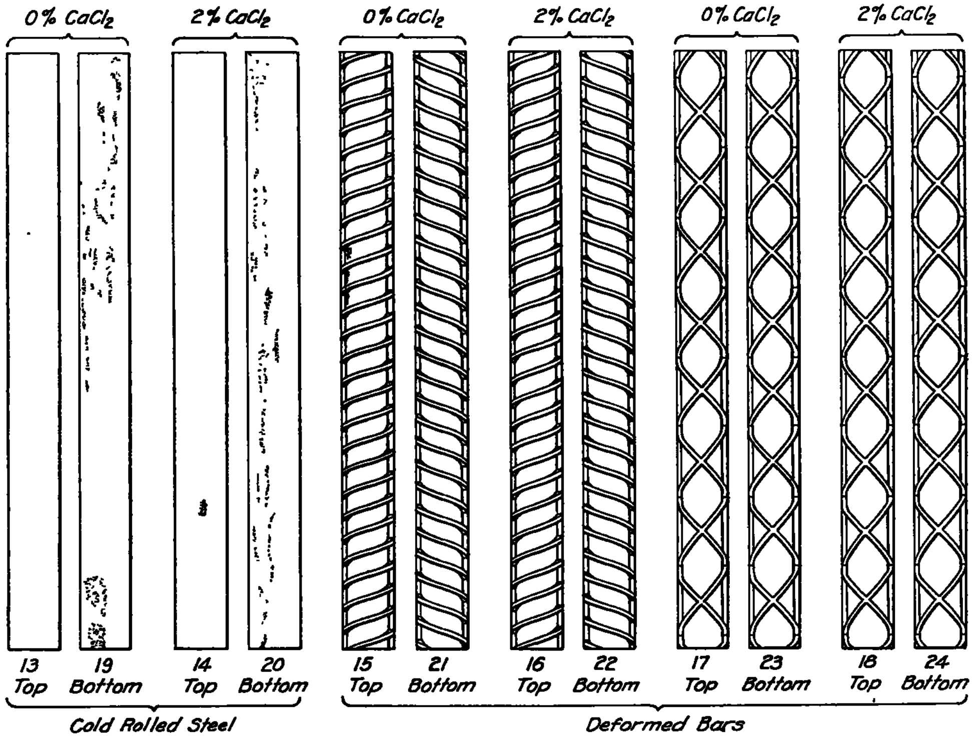

Figure 4. Upper and Lower Surfaces of Steel Bars Cast Near Top of Specimens of Group II

3. The corrosion which was on the under side of the bars and was mainly confined to the under side of the upper bars where maximum water gain was expected.
4. The deformed bars had less discoloration than similarly exposed cold rolled steel bars; the mill scale on the deformed bars undoubtedly afforded some protection.

DISCUSSION

Where concrete was in intimate contact with the steel bars, no corrosion of the latter occurred, regardless of whether or not the concrete encasing the bar contained calcium chloride. For the specimens of Group II, corrosion was generally confined to the steel surface exposed to the void spaces on the under side of the upper bars. In Group I specimens, corrosion was confined to bars encased in concretes containing calcium chloride. Apparently, void space resulting from high water gain is more likely to contribute to corrosion of steel in concretes containing a calcium chloride solution than in concretes without the admixture. However, the corrosion is slight and the observations show that it occurs at an early age and apparently is not progressive.

Quantitative determination of the extent of corrosion was not practicable. Considering the deformed bars, when the rust was removed by light scraping with a knife the resulting steel surface was not appreciably different as viewed by eye at several feet than adjacent areas. Some of the rust could be dislodged by brushing the surface with the finger.

In most cases the affected areas were adjacent to that portion of the concrete where void space was expected. Where good bond of concrete with steel was evident no corrosion of steel occurred either from concrete with or without calcium chloride.

SUMMARY

The tests demonstrate some of the conditions under which corrosion of reinforcing steel in concrete may occur. Void space adjacent to the steel in concrete cast with high slump contributed to corrosion. Under these conditions the use of 2 percent calcium chloride tended to increase the amount of corrosion. However, the corrosion was slight and unprogressive for both the concrete with and without calcium chloride.

Measures that reduce bleeding of concrete minimize corrosion of steel. The drier mixes caused less corrosion to a marked degree. The low slump (1 to 3 in.) concrete either with or without calcium chloride did not cause corrosion of the steel.

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