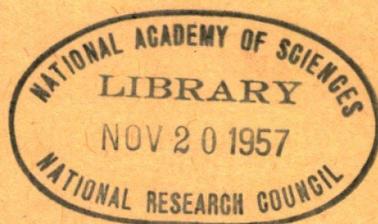


**HIGHWAY RESEARCH BOARD**  
**Bulletin 75**

***Effect in Concrete of  
Pellet and Flake Forms of  
Calcium Chloride***



**National Academy of Sciences—  
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# Effect of Pellet and Flake Forms of Calcium Chloride in Concrete

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THIS paper covers the effect of both the pellet and flake forms of calcium chloride as admixtures on the following properties of portland-cement concrete (with and without an air-entraining admixture): (1) compressive strength at 1, 3, 7, 28, and 90 days; (2) modulus of rupture at the ages listed; (3) modulus of elasticity (sonic) at the ages listed; (4) entrained-air content of fresh concrete; and (5) slump of fresh concrete as a measure of consistency. In addition, a short investigation was made on the relative effects of water and moist curing.

Increases in compressive strength resulted from the use of calcium chloride, in either flake or pellet form, as an admixture. When used in ordinary concrete, the flake form was more beneficial at ages of 28 and 90 days than the pellet form. When used in air-entrained concrete, the pellet form was more beneficial.

Although the moduli of rupture of ordinary concretes at ages of one to seven days were increased due to the use of calcium chloride as an admixture, the moduli of rupture of concretes 28 and 90 days old were, in general, reduced by the addition of flake chloride. Negligible changes or lesser reductions were caused by the addition of pellet chloride.

Significant decreases in modulus of rupture of air-entrained concretes 28 and 90 days old resulted from the use of some amounts of flake chloride; no significant changes in modulus resulted when the pellet form was used.

The moduli of elasticity (sonic) of ordinary concretes at ages of one to seven days were increased by the addition of either flake or pellet calcium chloride to the mix. The effect in general of both flake and pellet chloride at 28 and 90 days was not significant.

Air content of ordinary concrete and air-entrained concrete was generally increased by the addition of either flake or pellet chloride to the mix.

The slump of ordinary concrete was increased by the addition of certain amounts of flake chloride and decreased by the addition of certain amounts of pellet chloride. Other amounts of both forms of chloride had negligible effects. The slump of air-entrained concrete was increased by addition of chloride, except 4-percent pellet chloride; this amount caused a decrease in slump as compared to concrete containing no chloride.

● IT was the purpose of this study to determine the effects of the pellet and flake forms of calcium chloride, when used as admixtures, on various properties of portland-cement concrete. In general the properties studied were: compressive strength, modulus of rupture, modulus of elasticity (sonic), percent of entrained air, and consistency.

## History

It would be rather difficult to determine

who first discovered the effects of calcium chloride on portland-cement concrete, but published reports on the subject date back prior to 1900. Much of the early research was done in Europe, but reports began appearing in American periodicals and other publications during the first part of the century.

In 1923, Clemmer and Burggraf (1) reported on the use of calcium chloride as a curing agent and as an accelerator of concrete. This study included compressive-strength tests and flexural-

strength tests of concrete cured with calcium chloride, but only compressive-strength tests of concrete in which calcium chloride was used as an admixture. In addition to the strength tests, the effect of calcium chloride on such properties as time of set, internal temperature, and change in weight was noted.

In 1924, another notable study was reported by D. A. Abrams (2). This was primarily a study of the effect of calcium chloride on compressive strength of concrete cured under normal conditions, but the effect on time of set and flow, as a measure of consistency, was included. In this study, properties of the concrete (besides the amount of calcium chloride used) which were varied were: mix, consistency, water-cement ratio, curing, brand of cement, and age of concrete at test. This report contains a bibliography of previous work.

A study of the effect of calcium chloride, as an admixture, on the transverse strength of concrete was reported in 1926 by L. C. Stewart (3). In addition to various percentages of calcium chloride, Stewart used different brands of cement and different curing temperatures in his study.

A more-recent study was that in 1934 by Rapp (4) which included the effect of calcium chloride on heat of hydration, setting time, consistency, and compressive strengths of concretes and mortars at various ages.

In 1941, Yates (5) reported on the effect of calcium chloride on compressive strength of concrete stored at low temperatures. Cornthwaite and Yates (6) reported the following year on the effect of calcium chloride on the compressive strength of concrete having a low water content, the compressive strength of concrete block, and the crushing strength of concrete pipe. At the same time, Valore and Yates (7) also reported on the effect of calcium chloride, at various ages, on the modulus of elasticity (sonic) of concrete.

Vollmer (8) conducted studies on the slump, flow, water requirements, specific weight, and compressive strength of concrete as affected by calcium chloride.

In 1950 the results of various studies conducted over a period of about 25 yr. were reported by Stanton (9). This report included the effect of calcium chloride on compressive strength, shrinkage, modulus of rupture, and modulus of elasticity. Pre-

vious to this report little had been published on long-time studies of the effect of calcium chloride and on results of compressive strength at ages of less than 24 hr. This report contained information on both topics. Stanton's report (9) was comprehensive and included information on many brands of cement as well as several different types of cement.

Besides the reports listed, much other information concerning the effect of calcium chloride on portland-cement concrete has been published. These reports have appeared in engineering and scientific periodicals, in bulletins of universities and colleges, and in special pamphlets published by various organizations.

The calcium chloride used in most studies to date has been described as commercial calcium chloride. As most calcium chloride produced in the past has been in the form of flakes, it is assumed that most previous studies have been concerned with the effect of flake calcium chloride on concrete.

Recently commercial calcium chloride has become available in the form of pellets of varying size. Pellet calcium chloride, as well as having a different shape, has a different purity than the flake form. The latter contains about 77 percent pure anhydrous calcium chloride while the pellet form is about 96 percent pure.

Because of the different physical characteristics and different chemical purity, there was a possibility that pellet chloride might have a different effect on certain properties of portland-cement concrete than normal commercial flake chloride. This was one of the reasons that this study was undertaken.

### Specific Objectives

As stated before, the main objective of this study was to determine the effects of the pellet and flake forms of calcium chloride on portland-cement concrete. It was necessary to limit this study to the effects on what were considered some of the more-important properties of concrete, even though it is recognized that many others are affected.

The specific objectives of this particular study consist of the determination of the effects of various amounts of pellet and flake calcium chlorides on the following properties: (1) compressive strength at

the ages of 1, 3, 7, 28, and 90 days; (2) modulus of rupture at the ages of 1, 3, 7, 28, and 90 days; (3) modulus of elasticity (sonic) at the ages of 1, 3, 7, 28, and 90 days; (4) entrained air content of fresh concrete; and (5) slump of fresh concrete as a measure of consistency.

In addition to these, a short investigation was made on beams in order to determine the relative effects of water curing and moist curing on the modulus of rupture and modulus of elasticity (sonic) of beams.

## MATERIALS, MIX DESIGN, AND TEST METHODS

### Materials

**Cement.** Standard Type I cement was used in all specimens. The cement was delivered in two lots, all of which came from the same commercial source. All compressive test cylinders were made from one lot of cement and all the beams from the other lot.

**Aggregates.** All the aggregates needed for the entire project were received in one shipment. These natural aggregates came from Green Oak, Michigan, and conformed approximately to the Michigan State Highway Department specifications 2NS for sand and 6A for gravel. Specification 6A requires that 95 to 100 percent of the gravel pass the 1.5-in. sieve.

Since the beam forms were 3- by 3-by 15-in., it was necessary to reportion the coarse aggregate for this part of the study. Twenty percent of the adjusted coarse aggregate passed the 1-in. sieve and was retained on the  $\frac{3}{4}$ -in. sieve, 30 percent was retained on the  $\frac{1}{2}$ -in. sieve and 50 percent of the coarse aggregate for the beams was retained on the No. 4 sieve. No change was made in the fine aggregate, 97 percent of which passed the No. 4 sieve.

**Flake Calcium Chloride.** One brand of commercial flake chloride was used for this study. About 40 percent of the flake chloride was retained on the  $\frac{1}{4}$ -in. sieve and about 7 percent passed the No. 20 sieve. This form of chloride contained 77.2 percent pure anhydrous calcium chloride.

**Pellet Calcium Chloride.** One brand of commercially available pellet chloride was used for the pellet phase of this study. The pellet-form chloride had a particle-size distribution such that all but a trace

of it passed the  $\frac{1}{4}$ -in. sieve with about 7 percent being retained on the No. 20 sieve. The purity of the pellet chloride was 96.1 percent.

**Vinsol Resin Air-Entraining Agent.** Neutralized Vinsol resin (NVX), in the amount of 0.01 percent by weight of cement, was used as the air entraining agent. The powdered resin was dissolved in a measured amount of water before being introduced into the mixer.

### Mix Design

The concrete mixes were proportioned according to the mortar-voids method as practiced by the Michigan State Highway Department. All mixes were designed for a cement content of  $5\frac{1}{2}$  bags per cu. yd. of concrete and so that the control batches in all phases of the study would have about a 4-in. slump. The relative water content for non-air-entrained concrete was 1.3 and for air-entrained, 1.2. In the case of the non-air-entrained concrete cylinders, this design was equivalent to a water-cement ratio of 5.98 gal. per sack of cement and dry weight proportions of 1 : 2.46 : 3.77, while for the air-entrained concrete cylinders the mix had a water-cement ratio of 5.50 gal. per sack and proportions of 1 : 2.30 : 3.77. The non-air-entrained concrete beam mix had a water-cement ratio of 6.13 gal. per sack and dry weight proportions of 1 : 2.56 : 3.66; the corresponding values for the air-entrained beam mix were 5.56 gal. per sack and 1 : 2.40 : 3.66.

### Mixing and Curing

All the concrete was mixed in the same 1-cu.-ft. tilt-drum mixer. The dry materials were added first, followed by the water, dry calcium chloride, and then, for air-entrained concrete only, the Vinsol resin. The mixing time was 2 min. for the cylinder mixes and 5 min. for the beam mixes. The longer mixing time was necessary in the case of the beam mix because the finer aggregate used tended to adhere to the mixer.

All the specimens, unless otherwise stated, were cured in a moist room having a constant temperature of 70 F. and a relative humidity of about 98 percent.

## Types, Molding, and Identification of Specimens

**Compression Test Cylinders.** After the completion of the mixing, the fresh concrete was dumped into a large metal pan, shoveled over to eliminate segregation, and placed into 6- by 12-in. cylindrical steel molds having smooth steel baseplates. The test cylinders were molded according to ASTM Designation C 31-49.

Concrete test cylinders were identified according to type of cement, type and amount of calcium chloride contained, series number, and age of test. Each series consisted of five batches of concrete: a control batch of concrete containing no chloride and batches containing 1, 2, 3, and 4 percent, respectively, of commercial calcium chloride by weight of cement. Each specimen was identified by code symbols; for example, I-PD2-4-7 indicated Type I cement, pellet form of calcium chloride, chloride added to mix in dry form, 2 percent chloride added, series No. 4, and test age of 7 days.

**Flexural Test Beams.** The fresh concrete used to mold the beams was handled in the same way as that used for the cylinders. Wooden forms 3- by 3- by 15-in. and lined with a waterproof paper were used to mold the beams. The forms were filled half at a time with each half being rodded 50 times with a round-end,  $\frac{1}{4}$ -in. steel rod, a trowel was then run along the edges of the forms to insure against honeycombing, and finally the top was struck off and finished with a steel straightedge.

There was a series of beams that corresponded to each series of cylinders and a similar identification code was used except for the prefix B to indicate beam.

## Test Methods

**Measuring Slump and Air Content.** Immediately following the dumping of the concrete and remixing by hand, two slump tests were made on the fresh concrete. The average value was recorded. These tests were in accordance with ASTM Designation C 143-39.

At the same time the air content of the concrete was determined by means of a Klein pressure-type airmeter in accordance with ASTM Designation C 231-49T.

**Compressive Strength Tests.** Cylinders

were removed from the moist room (or forms in the case of the 1-day tests) and the tops capped immediately with plaster of paris. The average diameter of the cylinder was obtained by measuring the diameter at the top, middle, and bottom in such a way that each diameter made an angle of 120 deg. with the preceding one.

After the caps had dried for about 2 hr., the cylinders were tested in a hydraulic testing machine with the load applied at the rate of 35 psi. per sec. The maximum test load applied to the specimen was recorded to the nearest 500 lb. for cylinders failing above 60,000 lb. and to the nearest 100 lb. for cylinders failing at lesser loads.

**Modulus of Elasticity.** The dynamic (sonic) modulus of elasticity of all beams was determined immediately after removing from the moist room (or forms in the case of 1-day tests), drying, and weighing. This test was in accordance with ASTM Designation C 215-47T.

**Modulus of Rupture.** The size of the beams, as mentioned before, was 3- by 3- by 15-in. These beams were tested in flexure by placing them on their sides on supports 12 in. apart and applying concentrated loads at the one-third points. The testing apparatus was essentially the same as that described in ASTM Designation C78-49.

The beams were tested on their sides so that any top to bottom variation in the concrete would be compensated for. The load was applied through a hydraulic hand pump in a total time of about 20 sec. for the strongest beams and correspondingly less for the others.

## Obtaining Average Results

The values reported are in most cases the mean values of six test results. In several cases, for reasons such as accidental breakage, the values reported are the mean of four or five test results. These cases are not specifically pointed out, because in carrying out the analysis of variance, the significance was based on the lesser number of specimens.

## PRESENTATION AND ANALYSIS OF RESULTS

In order to properly evaluate the results

**TABLE 1**  
**SUMMARY OF COMPRESSIVE STRENGTH DATA**

Test Period	Pellet or Flake Cacl 2	Type One Cement Without Air Entraining Agent						Type One Cement With Air Entraining Agent					
		Flake Calcium Chloride			Pellet Calcium Chloride			Flake Calcium Chloride			Pellet Calcium Chloride		
		Compressive Strength	Increase in Strength	Difference to be Significant <sup>a</sup>	Compressive Strength	Increase in Strength	Difference to be Significant <sup>a</sup>	Compressive Strength	Increase in strength	Difference to be Significant <sup>a</sup>	Compressive Strength	Increase in Strength	Difference to be Significant <sup>a</sup>
Days	%	psi.	%		psi.	%		psi.	%		psi.	%	
90	0	5248	0.0	378 psi.	4848	0.0		4456	0.0		4347	0.0	242 psi.
	1	5124	-2.36	or	4962	2.35	b	4486	0.673	b	4594	5.68	or
	2	5704	8.69	7.20 %	5298	9.28		4523	1.50		4666	7.34	5.57 %
	3	5704	8.69		5183	6.91		4666	4.71		4687	7.82	
4	5680	8.23		5272	8.75		4655	2.22		4736	8.95		
28	0	4437	0.0	277 psi.	4123	0.0		3800	0.0	108 psi.	3742	0.0	209 psi.
	1	4486	1.14	or	4233	2.43	b	3766	-0.895	or	4061	8.52	or
	2	4787	7.89	6.24 %	4578	11.0		3878	2.05	2.84 %	4066	8.71	5.59 %
	3	4933	11.2		4275	3.69		3765	-0.921		4052	8.28	
4	4727	6.54		4218	2.30		3944	3.79		4108	9.78		
7	0	2885	0.0	261 psi.	2693	0.0	152 psi.	2680	0.0	217 psi.	2689	0.0	174 psi.
	1	3443	19.3	or	3330	23.7	or	3010	12.3	or	3092	15.0	or
	2	3672	27.3	9.05 %	3418	28.9	5.64 %	3041	13.5	8.10 %	3340	24.2	6.47 %
	3	3670	27.2		3198	18.8		3016	12.5		3068	14.1	
4	3463	20.7		3073	14.1		2695	8.02		2970	10.4		
3	0	1712	0.0	144 psi.	1628	0.0	181 psi.	1742	0.0	228 psi.	1727	0.0	103 psi.
	1	2372	38.6	or	2417	48.5	or	2346	34.7	or	2379	37.8	or
	2	2670	56.0	8.41 %	2612	60.4	11.1 %	2350	34.9	13.8 %	2603	50.7	5.96 %
	3	2667	55.8		2540	56.4		2267	30.1		2444	41.5	
4	2625	53.3		2450	50.5		2264	30.0		2341	35.6		
1	0	514	0.0	94 psi.	677	0.0	109 psi.	628	0.0	168 psi.	734	0.0	157 psi.
	1	760	47.8	or	1121	65.6	or	966	53.8	or	1084	47.7	or
	2	978	90.3	18.3 %	1326	95.9	16.1 %	1027	63.5	26.8 %	1253	70.7	21.4 %
	3	1095	113.0		1308	93.2		1081	72.1		1266	72.5	
4	1056	105.4		1361	101.0		1126	79.3		1336	82.0		

<sup>a</sup>For example: Any two results must differ by at least the amount shown if the chloride has had any significant effect on the result.

<sup>b</sup>Analysis of variance shows no significant difference among results, i. e. the results are essentially the same as far as the percentage of chloride used is concerned.

obtained in this study, an analysis of variance was carried out on the data. This analysis determined which of the averages obtained were significantly different (at the 5-percent level.) It should be kept in mind when observing the data and graphs presented that apparent differences may, or may not, be significant.

A significant difference, at the 5-percent level, means that the probability for such a difference to exist due to chance alone was 0.05. It may also be stated in this way: The probability that the differences were due to the treatment involved (in this case, the addition of various amounts of calcium chloride) was 0.95.

### Effect on Compressive Strength

Type I Cement - Flake Calcium Chloride. The general effect of flake calcium chloride at various ages up to 90 days may be seen by referring to Figure 1 and Table 1.

The results obtained by testing concrete at 1 day showed that there were significant increases in compressive strength due to the use of calcium chloride as an admixture. The addition of three percent showed the greatest increase in strength, 113 percent, over concrete containing no chloride.

At 3 days, concretes containing chloride were also stronger, with the effects of 2, 3, and 4 percent being about the same. Two percent was considered the optimum amount and caused a 56-percent increase in strength as compared to 0 percent.

When the concrete had reached an age of 7 days, the use of chloride in any of the amounts listed resulted in significant increases in strength over concrete containing none. The differences among the strengths of the concrete containing the various amounts of chloride were not significant, which would indicate that 1 percent was the optimum amount. The increase in strength obtained by using 1-percent chloride was 19.3 percent.

At 28 days the use of 1-percent chloride caused no significant increase in strength, but the use of 2 percent of chloride resulted in a 7.9-percent increase, which was significant. The differences obtained between 2, 3, and 4 percent were not significant.

At 90 days the situation was similar to

that at 28 days, with the exception of the slight, and insignificant, decrease in strength of concrete containing 1 percent of the admixture. Concrete containing 2 percent of chloride was 8.7 percent stronger than concrete containing none. This was a significant increase.

Pellet Calcium Chloride. The average results obtained using pellet calcium chloride as an admixture was plotted in Figure 2. The corresponding data is given in Table 1.

The 1-day tests showed no significant differences among the results obtained using 2, 3, and 4 percent admixtures, but the use of 2 percent did result in a significant increase over both 1 and 0 percent. The increase caused by the use of 2 percent rather than 0 percent was 96 percent.

At the age of 3 days, 2 percent was again shown to be the optimum amount and resulted in a 60.4 percent increase in strength.

At 7 days the results obtained using 1 percent and 2 percent of the admixture were not significantly different. As was the case with flake chloride at this age, the optimum amount of admixture seemed to be 1 percent. The use of 1 percent resulted in an increase in strength of 23.6 percent over concrete containing none.

Although apparent differences occurred among concretes containing various percentages of chloride, or no chloride, at ages of 28 and 90 days, the analysis of variance showed that these differences were not significant.

Type I Cement Plus Vinsol Resin Air Entraining Agent - Flake Calcium Chloride. The average values for compressive tests of air entrained concrete with flake chloride as an admixture are shown in Figure 3 and Table 1.

The analysis of variance indicated that 1 percent was the optimum amount to add in order to increase compressive strength at an age of 1 day. It resulted in a concrete 53.8 percent stronger than concrete containing no chloride.

For concrete 3 days old, all of the percentages of chloride used resulted in a stronger concrete than when none was used. None of the various percentages differed significantly from each other, but all differed significantly from 0 percent. The optimum amount used was 1



curves for various ages of concrete and amounts of the admixture are shown in Figure 4; corresponding data are given in Table 1.

For increased compressive strength at 1 day of age, the optimum amount of chloride used was 2 percent. Its use resulted in a concrete 70.7 percent stronger than concrete containing none.

At 3 days the optimum amount for increased compressive strength was still 2 percent but, unlike the 1-day tests, the use of 3 percent and 4 percent resulted in significant decreases in strength, as compared to the strength of concrete containing 2 percent. Concrete containing 2 percent pellet chloride was 50.7 percent stronger than concrete containing none.

The situation at 7 days was almost the same, but in this case the use of 2 percent of the admixture resulted in a 24.2-percent increase in strength over concrete containing none.

By the time the concrete was 28 days old, all of the percentages of chlorides had essentially the same effect; consequently, 1 percent was considered the optimum amount. At this age the increase in compressive strength due to using 1 percent rather than none was 8.5 percent.

The general situation was much the same at 90 days with the increase due to using 1 percent admixture, rather than none, being 5.7 percent.

#### Effect on Modulus of Rupture

Type I Cement - Flake Calcium Chloride. As may be seen by referring to Figure 5 and Table 2, the addition of flake calcium chloride to concrete yielded a concrete having greatly increased flexural strength, as measured by the modulus of rupture, at the age of 1 day. Analysis of variance of the results showed that the increases due to 3 and 4 percent were not significantly different and indicated that 3 percent was the optimum amount used. An increase of 127 percent in the modulus of rupture was obtained by using 3 percent chloride rather than none.

At 3 and 7 days of age, none of the flexural strengths of the various concretes differed significantly.

The tests at 28 days showed that the use of any amount of chloride appeared

to decrease the flexural strength significantly. The use of 1 percent, as compared to 0 percent, caused a 9.29 percent reduction in modulus of rupture, and the use of greater amounts caused larger reductions.

At 90 days the situation was about the same, except that the use of 1 percent chloride was not detrimental. The use of 2 percent chloride resulted in a reduction in modulus of rupture of 13.9 percent when compared to concrete containing no chloride.

Pellet Calcium Chloride. The variations in modulus of rupture using this type of chloride are shown in Figure 6 and Table 2. All of the amounts of pellet chloride used caused large increases in flexural strength at the age of 1 day. Three percent was the optimum amount used and resulted in the largest gain in strength, 113 percent when compared to concrete containing no admixture.

Also at 3 days, the use of all percentages of chloride resulted in a strength increase. Those due to using 1, 2, and 3 percent were essentially the same; consequently, 1 percent was considered the optimum amount. It resulted in a 23-percent increase in strength. Concrete containing 4 percent chloride, although stronger than concrete containing none, was considerably weaker than concrete containing 1, 2, or 3 percent.

The addition of pellet chloride, except in the amount of 4 percent, had no significant effect upon flexural strength at an age of 7 days. The addition of 4 percent caused a 15.5 percent reduction in modulus of rupture.

At 28 days, the use of 2, 3, and 4 percent resulted in significantly weaker concrete, but the use of 1 percent was not detrimental. Two percent chloride caused an 8-percent reduction in flexural strength.

The use of 1 and 2 percent pellet chloride had no significant effect on the flexural strength of concrete at 90 days, but the use of 3 and 4 percent did result in significant reductions. A reduction of 6.6 percent was caused by using 3, rather than 0, percent chloride.

Type I Cement Plus Vinsol Resin Air Entraining Agent - Flake Calcium Chloride. Figure 7 and Table 2 show the results obtained using flake chloride as an admixture. Concrete tested at 1 day

**TABLE 2**  
**SUMMARY OF MODULUS OF RUPTURE DATA**

		Type One Cement Without Air Entraining Agent						Type One Cement With Air Entraining Agent					
		Flake Calcium Chloride			Pellet Calcium Chloride			Flake Calcium Chloride			Pellet Calcium Chloride		
Test Period	Pellet or Flake CaCl <sub>2</sub>	Modulus of Rupture	Increase in Modulus	Difference to be Significant <sup>a</sup>	Modulus of Rupture	Increase in Modulus	Difference to be Significant <sup>a</sup>	Modulus of Rupture	Increase in Modulus	Difference to be Significant <sup>a</sup>	Modulus of Rupture	Increase in Modulus	Difference to be Significant <sup>a</sup>
Days	%	psi.	%		psi.	%		psi.	%		psi.	%	
90	0	1043	0.0	89 psi.	998	0.0	56 psi.	958	0.0	54 psi.	944	0.0	
	1	957	-8.24	or	1004	0.803	or	911	-4.91	or	890	-5.72	b
	2	898	-13.9	8.53 %	967	-2.91	5.62 %	935	-2.40	5.64 %	852	-9.75	
	3	889	-14.8		930	-6.62		840	-12.3		864	-8.47	
	4	888	-14.9		921	-7.53		854	-10.9		876	-7.20	
28	0	958	0.0	89 psi.	855	0.0	55 psi.	861	0.0		829	0.0	57 psi.
	1	869	-9.29	or	817	-4.44	or	848	-1.51	b	812	-2.05	or
	2	822	-14.2	9.29 %	787	-7.95	6.43 %	800	-7.08		786	-5.19	6.88 %
	3	750	-21.7		767	-10.3		795	-7.67		794	-4.22	
	4	735	-23.3		752	-12.1		785	-8.83		744	-10.3	
7	0	726	0.0		710	0.0	80 psi.	730	0.0	55 psi.	718	0.0	67 psi.
	1	658	-9.3	b	709	-0.141	or	753	3.15	or	741	3.20	or
	2	696	-4.3		698	-1.69	11.3 %	729	-0.137	7.53 %	731	1.81	9.33 %
	3	678	-6.61		664	-6.48		676	-7.40		666	-7.24	
	4	638	-12.1		600	-15.5		628	-14.0		643	-10.4	
3	0	476	0.0		442	0.0	38 psi.	429	0.0	55 psi.	476	0.0	60 psi.
	1	500	5.04	b	544	23.1	or	597	39.2	or	599	25.8	or
	2	533	12.0		542	22.6	8.60 %	585	35.9	12.8 %	638	34.0	12.6 %
	3	551	15.8		552	24.9		592	38.0		576	21.0	
	4	518	8.82		498	12.7		607	41.5		545	14.5	
1	0	146	0.0	41 psi.	168	0.0	31 psi.	197	0.0	24 psi.	204	0.0	22 psi.
	1	209	43.2	or	259	54.2	or	290	47.2	or	299	46.6	or
	2	281	92.5	28.1 %	325	93.5	18.5 %	331	68.0	12.2 %	378	85.3	10.8 %
	3	331	126.8		358	113.1		364	84.8		374	83.3	
	4	344	135.6		345	105.4		379	92.4		371	81.9	

<sup>a</sup>For example: Any two results must differ by at least the amount shown if the chloride has had any significant effect on the result  
<sup>b</sup>Analysis of variance shows no significant difference among results, i. e. the results are essentially the same as far as the percentage of chloride used is concerned.

showed that all of the various percentages of admixture used caused significant increases in the modulus of rupture. Results obtained with 3 percent and 4 percent were essentially the same, however, and 3 percent was considered the optimum amount. Its use resulted in an 85-percent increase in strength.

The analysis of variance showed that all the amounts of chloride used had substantially the same effect at an age of 3 days. The increase in strength due to the addition of 1 percent, the optimum amount, was 39 percent.

At an age of 7 days none of the amounts of chloride added caused significant increases in strength, while the use of 4 percent was detrimental, causing a 14-percent reduction in modulus of rupture.

Analysis of variance of the 28-day-test results showed that there were no significant differences among the various concretes.

Results at 90 days indicated that the addition of 1 and 2 percent of the chloride admixture caused no significant differences in strength. The addition of 3 or 4 percent chloride reduced the modulus of rupture appreciably. Concrete containing 3 percent was 12.3 percent weaker than concrete containing none, a significant decrease.

Pellet Calcium Chloride. The results obtained using this form of chloride are plotted in Figure 8 and Table 2. Again at 1 day of age the concretes containing chlorides were significantly stronger than concrete containing none. The use of 2, 3, and 4 percents resulted in concretes having essentially the same strength and all appreciably stronger than concrete containing 1 percent. Concrete containing 2 percent of the admixture showed an increase in modulus of rupture of 85 percent when compared to concrete containing 0 percent.

At 3 days of age, concretes containing 1 percent and 2 percent chloride showed no significant difference. One percent was considered the optimum amount and its use resulted in a 25.8 percent increase in flexural strength.

Analysis of variance of results obtained at 7 days indicated that the use of 1, 2, and 3 percent chloride did not cause a significant change in flexural strength, but a significant decrease was obtained when using 4 percent.

At 28 days the flexural strengths of all concretes, except that containing 4 percent chloride, were essentially the same. The use of 4 percent caused a decrease in modulus of rupture of 10.3 percent when compared to concrete containing no chloride. This was a significant decrease.

The results obtained from the 90-day tests showed that there were no significant differences among the concretes tested.

### Effect on Modulus of Elasticity (Sonic)

Type I Cement - Flake Calcium Chloride. Figure 9 and Table 3 show the general effects of flake chloride on the modulus of elasticity (sonic) of non-air-entrained concrete.

At an age of 1 day the modulus of elasticity was increased significantly by the use of chloride as an admixture. Concretes containing 2, 3, and 4 percent were not significantly different, but their moduli were significantly higher than those containing either 0 or 1 percent. Two percent was the optimum amount added and caused an increase in modulus of elasticity of 38.1 percent as compared to concrete containing no chloride.

Results at 3 days of age indicated that the use of all of the various amounts of chloride caused significant increases in the modulus of elasticity. The optimum amount of chloride was considered to be 1 percent as none of the results obtained using the various amounts of chloride differed significantly. It resulted in an increase of 15.7 percent in modulus of elasticity as compared to concrete containing no chloride.

By the time the concrete had reached the age of 7 days, only that containing 1 percent had a significantly higher modulus of elasticity than concrete containing none. The increase was 5.5 percent.

At 28 days no significant increases in moduli of elasticity resulted from the addition of flake calcium chloride; however, a significant decrease was caused by the addition of 4 percent.

Analysis of variance showed that at 90 days there were no significant differences among the results obtained.

Pellet Calcium Chloride. The results obtained using pellet calcium chloride are given in Figure 10 and Table 3.

Tests on 1-day-old concrete showed

that concrete containing 2 percent chloride had the highest modulus of elasticity. Analysis of variance showed that, on the basis of 1-day tests, 2 percent was the optimum amount added. Its use resulted in concrete having a modulus of elasticity 33.5 percent higher than concrete containing none.

elasticity (sonic) of air-entrained concrete.

Tests at 1 day of age showed that concrete containing 3 percent chloride had a modulus significantly higher than the moduli of concretes containing 0, 1, and 2 percent. Three percent was considered the

TABLE 3  
SUMMARY OF MODULUS OF ELASTICITY DATA

Test Period	Pellet or Flake CaCl <sub>2</sub>	Type One Cement Without Air Entraining Agent				Type One Cement With Air Entraining Agent			
		Flake Calcium Chloride	Pellet Calcium Chloride	Flake Calcium Chloride	Pellet Calcium Chloride	Flake Calcium Chloride	Pellet Calcium Chloride	Flake Calcium Chloride	Pellet Calcium Chloride
Days	%	Modulus of Elasticity	Difference to be Significant <sup>a</sup>	Modulus of Elasticity	Difference to be Significant <sup>a</sup>	Modulus of Elasticity	Difference to be Significant <sup>a</sup>	Modulus of Elasticity	Difference to be Significant <sup>a</sup>
		10 <sup>6</sup> psi	psi	10 <sup>6</sup> psi	psi	10 <sup>6</sup> psi	psi	10 <sup>6</sup> psi.	psi
90	0	6 907		6 958		7.013		7 215	
	1	6.568		6 996		7 302		7 122	
	2	6 550	b	7.075	b	7 133	b	7 316	b
	3	6 514		6 756		6 949		7 189	
28	4	6 413		6 763		7 028		7 510	
	0	6 464		6 276		5 763		6.715	
	1	6 339	0 365	6.602		6 254	0 276	6 645	
	2	6 517		6 552	b	5 859		6 486	b
7	3	6 343		6.179		5 953		6 398	
	4	5.929		6.207		6 060		6 298	
	0	5 630		5 615		5 240		5 501	
	1	5 939	0 255	5 852	0.280	5 478	0 183	5 821	
3	2	5 795		5 976		5 542		5 753	b
	3	5 880		5 568		5 398		5 554	
	4	5 394		5.357		5 234		5 470	
	0	4 378		4 374		4 431		4 547	
1	1	5 066	0 243	5 012	0 279	4 988	0.254	5 312	
	2	5 109		5 228		5 035		5 159	0 426
	3	5 049		4 922		4 944		4 858	
	4	5 040		4 849		4 842		5 007	
1	0	2.612		2 765		2 958		3 144	
	1	3 260	0 257	3 367	0 145	3.524	0 156	3 618	0.153
	2	3 607		3 692		3 580		3 906	
	3	3 606		3 586		3 756		3 770	
	4	3 645		3 479		3 687		3 750	

<sup>a</sup>For example: Any two results must differ by at least the amount shown if the chloride has had any significant effect on the result

<sup>b</sup>Analysis of variance shows no significant difference among results, i. e. the results are essentially the same as far as the percentage of chloride used is concerned

One percent was the optimum amount added on the basis of results obtained at 3 days of age; however, significant increases were obtained using all of the various amounts. An increase in modulus of elasticity of 14.6 percent was obtained when using the optimum amount.

At 7 days of age a significant increase in modulus of elasticity was obtained only with concrete containing 2 percent chloride. The amount of this increase was 6.4 percent.

Analysis of variance of the results of 28-day tests showed no significant differences among these results. The same was true for the results of 90-day tests.

Type I Cement Plus Vinsol Resin Air Entraining Agent-Flake Calcium Chloride. Figure 11 and Table 3 show the results of this type of chloride on the modulus of

optimum amount and its use resulted in an increase in modulus of elasticity of 27 percent as compared to the modulus of concrete containing no chloride.

At 3 days of age the maximum increase in modulus of elasticity was caused by the addition of 2 percent chloride. Two percent and 1 percent had essentially the same effect, however, and 1 percent was considered the optimum amount added. Its use resulted in an increase of 12.6 percent in modulus of elasticity.

One percent was also the optimum amount based on results obtained at 7 and 28 days of age. The increases in modulus due to using 1 percent were 4.5 percent for concrete tested at 7 days and 8.5 percent for that tested at 28 days.

For concrete 90 days old, analysis of variance of results showed no significant

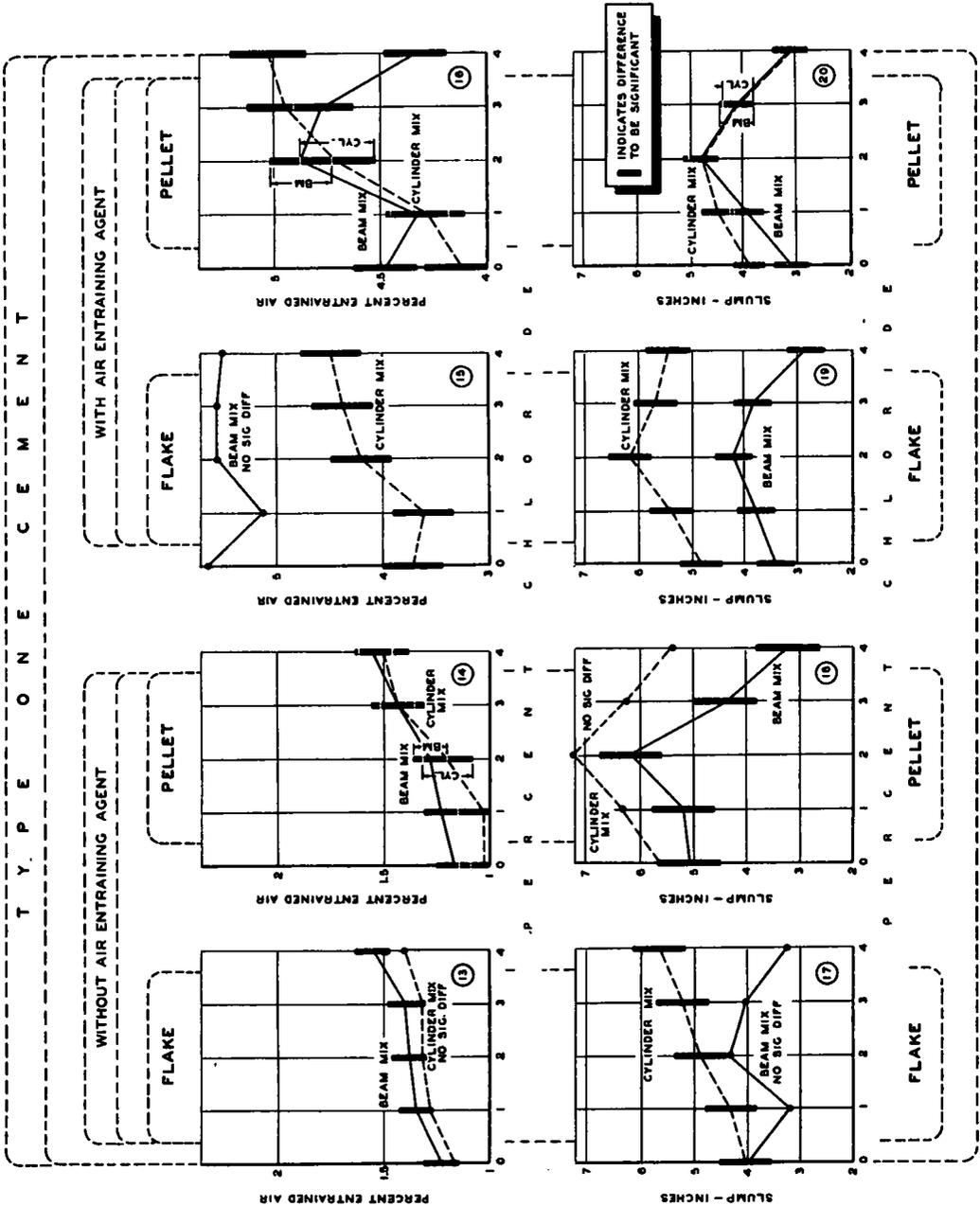
differences in moduli of elasticity of the concretes tested.

**Pellet Calcium Chloride.** The results obtained for moduli of elasticity of concretes containing pellet calcium chloride are given in Figure 12 and Table 3.

At the age of 1 day, all concretes containing pellet chloride had higher moduli of elasticity than concretes containing none.

Two percent chloride, the optimum amount, resulted in a 24.2-percent increase in modulus of elasticity.

The optimum amount of chloride, based on 3-day tests, was shown to be 1 percent. Concrete containing this amount of chloride had a modulus of elasticity which was 16.8 percent higher than that of concrete containing none.



Figures 13 through 20.

There were no significant differences among the results obtained at 7 days with pellet chloride as an admixture in air-entrained concrete. This was also true for the results of 28-day and 90-day tests.

#### Effect on Air Content

**Type I Cement**-The air content of all mixes used in making cylinders and beams was determined. It was not expected that the amounts of air entrained in corresponding cylinder and beam mixes would be the same, because the mixes were not the

not differ significantly from the slump of concrete containing 3 percent chloride.

**Pellet Calcium Chloride.** The results obtained when using this form of chloride are given in graphical and tabular form in Figure 14 and Table 4.

The addition of 3 percent pellet chloride to the mix used for cylinders resulted in a 0.40 percent increase in amount of entrained air. This was a significant increase.

The use of 3 percent of pellet chloride as an admixture in the mix used for beams also resulted in a significant increase in the amount of entrained air. The increase

TABLE 4

SUMMARY OF PERCENT OF ENTRAINED AIR IN CONCRETE DATA

Type of Specimen	Pellet or Flake CaCl <sub>2</sub>	Type One Cement Without Air Entraining Agent				Type One Cement With Air Entraining Agent			
		Flake Calcium Chloride		Pellet Calcium Chloride		Flake Calcium Chloride		Pellet Calcium Chloride	
		Entrained Air	Difference to be Significant <sup>a</sup>	Entrained Air	Difference to be Significant <sup>a</sup>	Entrained Air	Difference to be Significant <sup>a</sup>	Entrained Air	Difference to be Significant <sup>a</sup>
	%	%	%	%	%	%	%	%	%
Cylinders	0	1.17	b	1.03	0.24	3.72	0.56	4.12	0.35
	1	1.28		1.03		3.62		4.28	
	2	1.32		1.20		4.20		4.70	
	3	1.32		1.43		4.37		4.94	
	4	1.40		1.50		4.48		5.02	
Beams	0	1.23		1.17		5.65		4.48	
	1	1.35	0.16%	1.23	0.16	5.13	b	4.33	0.29
	2	1.38		1.28		5.55		4.87	
	3	1.40		1.43		5.55		4.77	
	4	1.55		1.55		5.50		4.33	

<sup>a</sup>For example: Any two results must differ by at least the amount shown if the chloride has had any significant effect on the result.

<sup>b</sup>Analysis of variance shows no significant difference among results, i. e. the results are essentially the same as far as the percentage of chloride used is concerned.

same. Analysis of variance was carried out on both sets of results and the significant differences due to adding various amounts of chlorides obtained. In the discussion which follows, the mixes containing no calcium chloride are used as the basis for comparison.

**Flake Calcium Chloride.** The effect of flake calcium chloride on the percent of air in fresh concrete not containing an air-entraining agent was determined for both the mix used for cylinders and that used for beams. Values of air content for both mixes are shown in Figure 13 and Table 4.

In the mix used for molding cylinders, there were no significant differences among air contents due to adding various amounts of flake chloride.

In the beam mix, which did not contain aggregate of as large a size as the cylinder mix, a significant increase, 0.17 percent, resulted from the use of 3 percent flake chloride. The use of 4 percent resulted in a still greater increase but the slump of concrete containing 4 percent chloride did

due to the addition of this amount was 0.26 percent.

**Type I Cement Plus Vinsol Resin Air Entraining Agent-Flake Calcium Chloride.** Figure 15 and Table 4 show the effect of flake chloride on concrete mixes containing an air-entraining agent.

Results obtained on the mix used for cylinders indicated that the effects of using 3 and 4 percent chloride were essentially the same. A significant increase, 0.65 percent, in air content was caused by the addition of 3 percent of chloride.

The air contents of the mixes used for beams were not significantly changed by the use of flake chloride as an admixture.

**Pellet Calcium Chloride.** The effects on air content of this type of chloride are shown in Figure 16 and Table 4.

The results obtained with the cylinder mixes containing 2 and 3 percent pellet chloride did not differ significantly. The use of 2 percent resulted in a concrete having 0.58 percent more entrained air

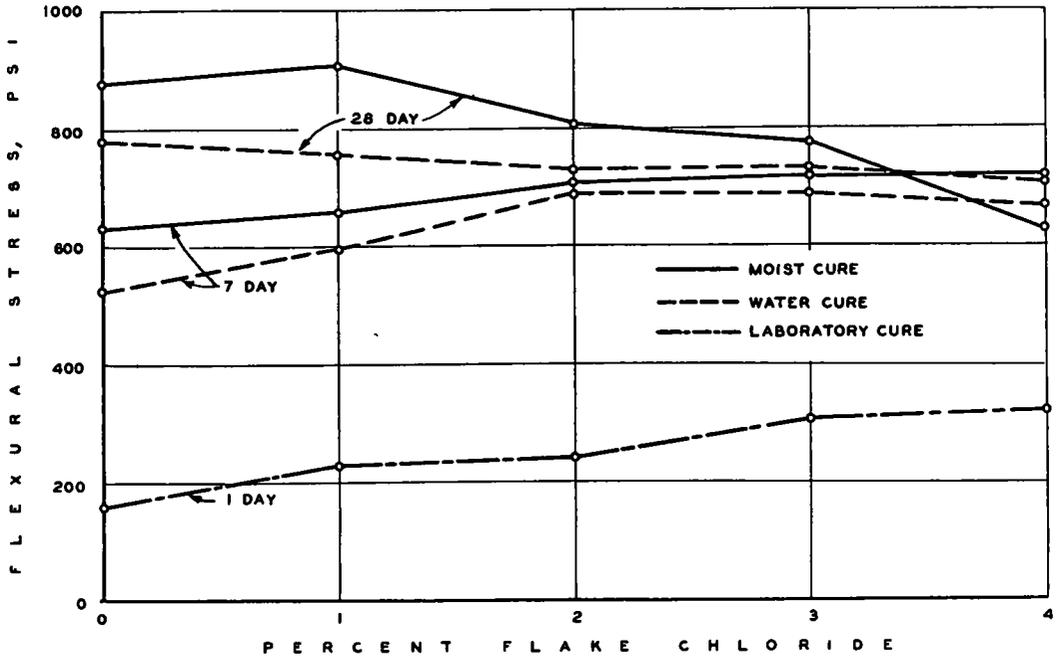


Figure 21.

than concrete containing no chloride. This was a significant increase.

In the mixes used for beams, only that mix containing 2 percent chloride was significantly different from the mix containing none. The increase in air content due to using two percent was 0.39 percent.

#### Effect on Slump

As in the case of air content, the slump was measured on all mixes used to make

the cylinders and beams. It should, perhaps, be repeated that the mix used to make cylinders had a larger-sized coarse aggregate than the mix used to make beams.

**Type I Cement-Flake Calcium Chloride.** Figure 17 and Table 5 show the results obtained when using flake calcium chloride in concrete mixes containing no air-entraining agent.

In the mix used for cylinders, the addition of 3 percent flake chloride caused a significant increase in slump, 5.2 in. as

TABLE 5

#### SUMMARY OF SLUMP OF CONCRETE DATA

Type of Specimen	Pellet or Flake CaCl <sub>2</sub>	Type One Cement Without Air Entraining Agent				Type One Cement With Air Entraining Agent			
		Flake Calcium Chloride		Pellet Calcium Chloride		Flake Calcium Chloride		Pellet Calcium Chloride	
		Amount of Slump	Difference to be Significant <sup>a</sup>	Amount of Slump	Difference to be Significant <sup>a</sup>	Amount of Slump	Difference to be Significant <sup>a</sup>	Amount of Slump	Difference to be Significant <sup>a</sup>
	%	in.	in.	in.	in.	in.	in.	in.	in.
Cylinders	0	4.04	0.95	5.60	b	4.86	0.78	3.92	0.55
	1	4.33		6.33		5.42		4.50	
	2	4.38		7.25		6.18		4.77	
	3	5.20		6.25		5.70		4.10	
	4	5.63		5.38		5.46		3.06	
Beams	0	3.96	b	5.04	1.16	3.46	0.67	3.13	0.64
	1	3.21		5.16		3.83		3.96	
	2	4.33		6.16		4.25		4.79	
	3	4.04		4.38		3.88		4.12	
	4	3.25		3.21		2.88		3.08	

<sup>a</sup>For example: Any two results must differ by at least the amount shown if the chloride has had any significant effect on the result

<sup>b</sup>Analysis of variance shows no significant difference among results, i. e. the results are essentially the same as far as the percentage of chloride used is concerned.

compared to 4 in. for concrete containing no chloride. Analysis of variance showed that the slumps of the finer mixes used for beams did not differ significantly.

Pellet Calcium Chloride. Figure 18 and Table 5 show the average values of slump obtained when using pellet calcium chloride as an admixture.

There were no significant differences among the slumps of mixes used for molding cylinders; however, the addition of pellet chloride in the amount of 4 percent, did cause a decrease in slump from 5 to 3.2 in. This was a significant decrease.

TABLE 6  
MODULUS OF RUPTURE AS AFFECTED  
BY TYPES OF CURING

Type I Cement  
Modulus of Rupture

Test Period	Flake Chloride	Moist Curing	Wet Curing	Laboratory Curing
days	%			
28	0	879	782	
	1	910	756	
	2	810	731	
	3	780	734	
	4	632	710	
7	0	632	543	
	1	659	598	
	2	708	690	
	3	721	690	
	4	721	671	
1	0			155
	1			227
	2			242
	3			307
	4			320

Type I Cement Plus Vinsol Resin Air Entraining Agent - Flake Calcium Chloride. The average values for slumps obtained with air entrained concrete, when using flake chloride as an admixture, are given in Figure 19 and Table 5.

Mixes used for molding cylinders and containing no chloride had an average slump of 4.9 in. Mixes containing 2 percent chloride had an average slump of 6.2 in. This represented a significant increase.

Beam mixes containing 2 percent chloride also had a significantly greater slump than those containing no chloride. In this case the values were 3.5 in. for concrete containing no chloride and 4.6 in. for concrete containing 2 percent.

Pellet Calcium Chloride. The average values for slump for these mixes are given in Figure 20 and Table 5.

Significant increases in slump were caused by the addition of both 1 percent and 2 percent pellet chloride to the mix used for cylinders. The use of 3 percent caused no significant differences, as com-

pared to concrete containing no chloride, but the use of 4 percent resulted in a significant decrease in slump.

In the mix used for beams, the results were somewhat different. In this case, the addition of 1, 2, or 3 percent of pellet chloride caused an increase in slump which was significant as compared to concrete containing none. The addition of 4 percent, however, caused no significant change.

#### Effects of Water Curing and Moist Curing

A short study of the relative effects of water curing and moist curing of beams to be tested in flexure was made prior to the main study reported herein. Analysis of variance was not carried out on the results of this study, the values reported are the average of only three test results, only the flake form of calcium chloride was used, and only non-air-entraining cement was used; consequently, the study is not considered conclusive. It is included, however, as it may be of interest to anyone undertaking a more-comprehensive, but similar, project in the future.

The beam specimens in this case were also 3- by 3- by 15-in. Duplicate specimens were made for each series so that it was possible to cure one in the moist room (70F. and 98 percent relative humidity) and to cure the other submerged in water (70 F.) The specimens were left in the molds in the laboratory for 24 hr. and then removed to be cured. The 1-day specimens, therefore, were cured only in the forms.

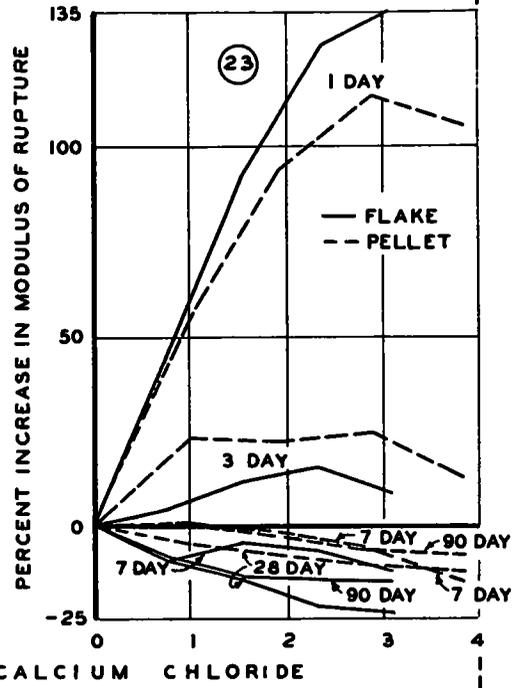
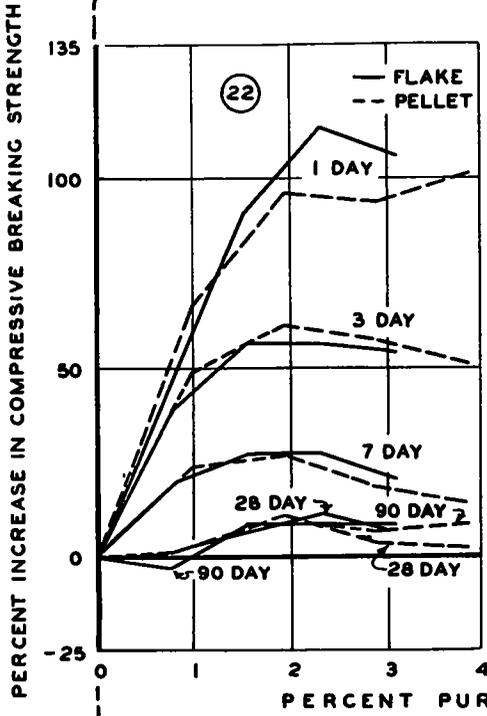
The results of this portion of the study are given in Figure 21 and Table 6. These results will not be discussed nor will any conclusion regarding them be stated.

#### Relative Effects of Flake and Pellet Chloride on Compressive Strength and Modulus of Rupture of Concrete

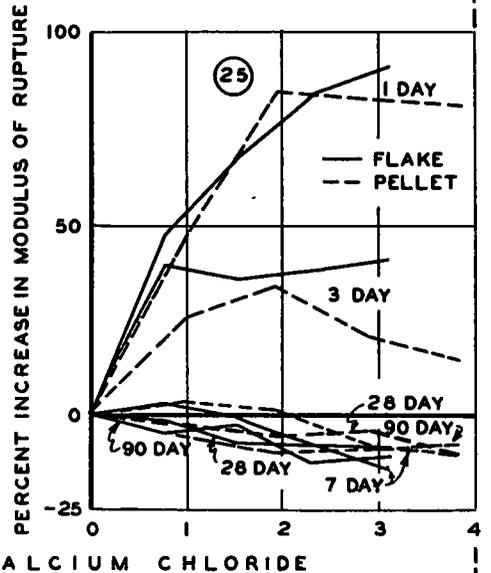
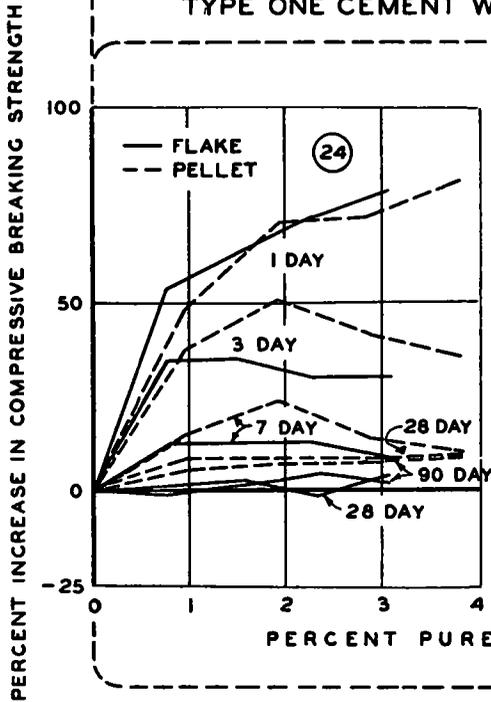
The percent of increase, or decrease, in the compressive strength of concrete and in the modulus of rupture, is included in Tables 1 and 2.

Type I Cement - Compressive Strength. The relative effects of flake and pellet chloride on compressive strength are shown in Figure 22. This figure indicates that the amount of pure anhydrous calcium chloride is the most-important factor causing a

TYPE ONE CEMENT WITHOUT AIR ENTRAINING AGENT



TYPE ONE CEMENT WITH AIR ENTRAINING AGENT



Figures 22 through 25.

variation in compressive strength of non-air-entrained concrete. The form (flake or pellet) seems to have relatively little effect.

Modulus of Rupture. As indicated in Figure 23 the physical characteristics of the chloride, rather than the chloride content, seemed to be the major factor in causing variations in modulus of rupture.

within a narrow range. Because of this, it was more difficult to infer whether the chloride content or the physical characteristics of the admixture were responsible for the change in the modulus of rupture. It appears in general, however, that the use of pellet chloride as an admixture was more efficient and that the physical characteristics had the greater effect.

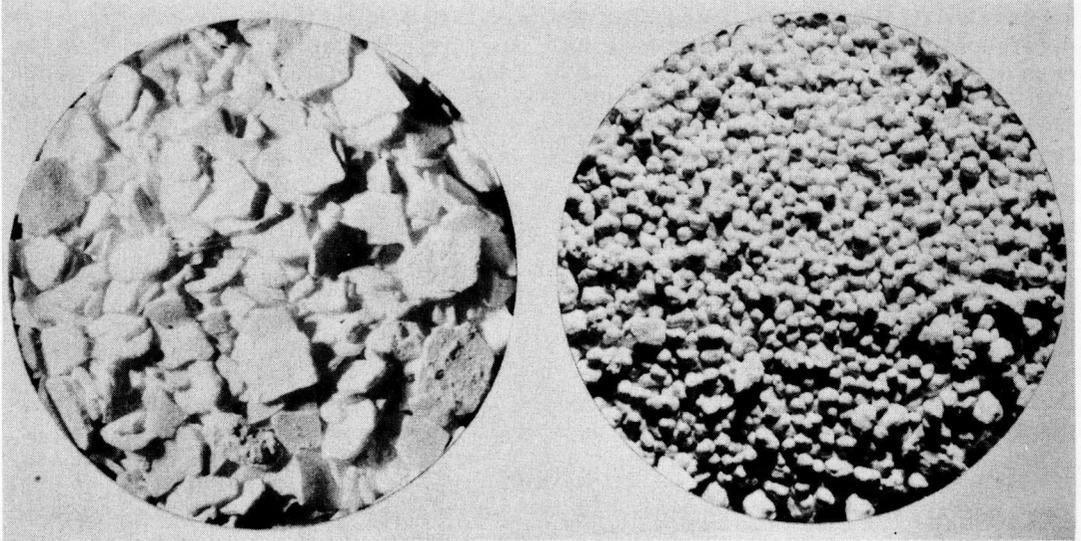


Figure 26. Flake calcium chloride (left) and pellet calcium chloride (right).

Although the flake and pellet forms of chloride had essentially the same effect at ages of 1 and 3 days, the results obtained at 7, 28, and 90 days indicate that the decreases in modulus of rupture caused by the addition of flake chloride are much greater than those caused by the use of pellet chloride containing an equal amount of pure anhydrous calcium chloride.

Type I Cement Plus Vinsol Resin Air-Entraining Agent - Compressive Strength. The results shown in Figure 24 indicate that the effect of calcium chloride on the compressive strength of air-entrained concrete is determined, to a large degree, by the physical characteristics of the chloride. This is especially true of results obtained on the 28- and 90-day tests where the increases caused by the use of pellet chloride are greater than those caused by flake chloride.

Modulus of Rupture. As indicated in Figure 25, the changes (caused by the use of calcium chloride) in the moduli of rupture at the ages of 7, 28, and 90 days fell

## CONCLUSIONS

### Compressive Strength

1. In general the use of flake or pellet chloride, in amounts up to 2 percent by weight of cement, resulted in an increase in the strength of portland-cement concrete at all ages up to 90 days. Two percent commercial chloride was the optimum amount of admixture used, as far as compressive strength was concerned.

2. In non-air-entrained concrete the amount of pure anhydrous calcium chloride, whether added in the flake or pellet forms, was the factor responsible for changes in compressive strength.

3. In air-entrained concrete the use of pellet chloride caused greater increases in strength than the use of flake form.

### Modulus of Rupture

4. Even though beneficial effects were produced at early ages (1 and 3 days), the use of more than 1 percent commercial flake chloride in ordinary concrete, or

more than 2 percent in air-entrained concrete, resulted in significant reductions in the moduli of rupture.

5. The beneficial effect of pellet chloride on modulus of rupture also diminished with age. In ordinary concrete the use of more than 2 percent commercial pellet chloride caused a significant decrease in the modulus of rupture of concrete when tested at 90 days. In air-entrained concrete the addition of pellet chloride, in the amounts used, did not cause any significant differences in the moduli of rupture at 90 days of age.

6. Generally the decreases caused by the use of flake chloride were greater than those caused by the use of pellet chloride. This is shown in Figures 23 and 25.

#### Modulus of Elasticity (Sonic)

7. The sonic moduli at early ages of all concretes tested were increased by the addition of either flake or pellet chloride to the mix. At 90 days of age, however, there were no significant differences among the moduli of elasticity of the various concretes tested.

#### Entrained Air Content

8. The air content of non-air-entrained concrete was increased as greater amounts of flake and pellet chloride were added to the mix.

9. There was not much correlation between the air content of air-entrained concretes, but the addition of 2 percent flake or 1 percent pellet chloride caused significant increases in the air content of some mixes.

#### Slump

10. Generally the slumps of the concretes were increased by adding either flake or pellet chloride in amounts up to 2 percent commercial chloride. Greater amounts tended to decrease the slump.

#### Relative Effects of Flake and Pellet Chloride

11. Not only the amount of pure anhydrous calcium chloride, but the physical characteristics of the chloride added seemed to have an effect on the properties mentioned in this study. In general, pel-

let chloride seemed to impart to a concrete mix the desirable characteristic of increased compressive strength but, when used in the amount of 2 percent, did not cause significant decreases in the modulus of rupture, as did flake chloride in certain cases.

#### REFERENCES

1. Clemmer, H. F. and Burggraf, F., An Investigation in the Use of Calcium Chloride as a Curing Agent and Accelerator of Concrete, "Proceedings," ASTM, Vol. 23, Part II, p. 296 (1923).

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variation in compressive strength of non-air-entrained concrete. The form (flake or pellet) seems to have relatively little effect.

Modulus of Rupture. As indicated in Figure 23 the physical characteristics of the chloride, rather than the chloride content, seemed to be the major factor in causing variations in modulus of rupture.

within a narrow range. Because of this, it was more difficult to infer whether the chloride content or the physical characteristics of the admixture were responsible for the change in the modulus of rupture. It appears in general, however, that the use of pellet chloride as an admixture was more efficient and that the physical characteristics had the greater effect.

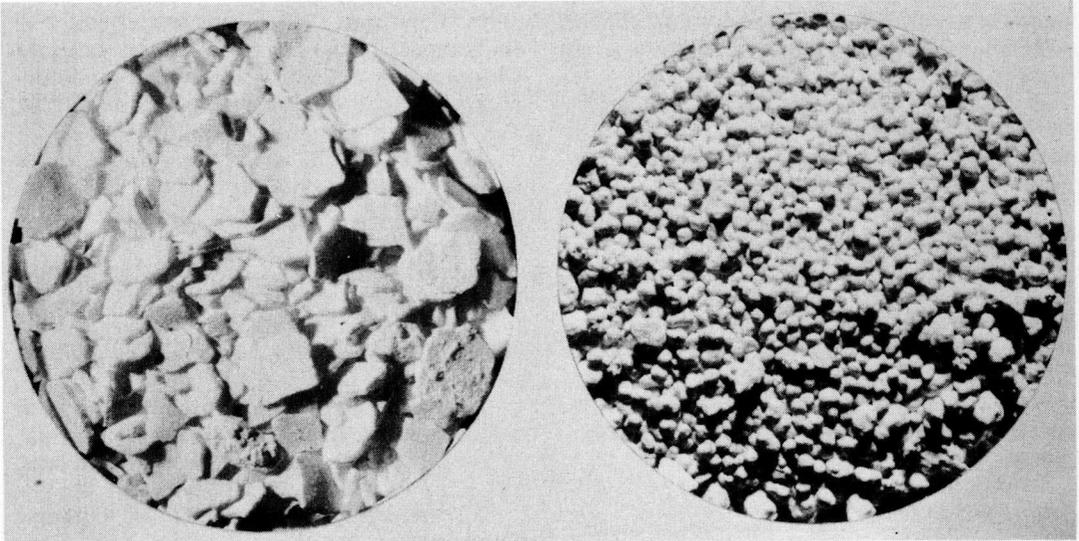


Figure 26. Flake calcium chloride (left) and pellet calcium chloride (right).

Although the flake and pellet forms of chloride had essentially the same effect at ages of 1 and 3 days, the results obtained at 7, 28, and 90 days indicate that the decreases in modulus of rupture caused by the addition of flake chloride are much greater than those caused by the use of pellet chloride containing an equal amount of pure anhydrous calcium chloride.

Type I Cement Plus Vinsol Resin Air-Entraining Agent - Compressive Strength. The results shown in Figure 24 indicate that the effect of calcium chloride on the compressive strength of air-entrained concrete is determined, to a large degree, by the physical characteristics of the chloride. This is especially true of results obtained on the 28- and 90-day tests where the increases caused by the use of pellet chloride are greater than those caused by flake chloride.

Modulus of Rupture. As indicated in Figure 25, the changes (caused by the use of calcium chloride) in the moduli of rupture at the ages of 7, 28, and 90 days fell

## CONCLUSIONS

### Compressive Strength

1. In general the use of flake or pellet chloride, in amounts up to 2 percent by weight of cement, resulted in an increase in the strength of portland-cement concrete at all ages up to 90 days. Two percent commercial chloride was the optimum amount of admixture used, as far as compressive strength was concerned.

2. In non-air-entrained concrete the amount of pure anhydrous calcium chloride, whether added in the flake or pellet forms, was the factor responsible for changes in compressive strength.

3. In air-entrained concrete the use of pellet chloride caused greater increases in strength than the use of flake form.

### Modulus of Rupture

4. Even though beneficial effects were produced at early ages (1 and 3 days), the use of more than 1 percent commercial flake chloride in ordinary concrete, or

more than 2 percent in air-entrained concrete, resulted in significant reductions in the moduli of rupture.

5. The beneficial effect of pellet chloride on modulus of rupture also diminished with age. In ordinary concrete the use of more than 2 percent commercial pellet chloride caused a significant decrease in the modulus of rupture of concrete when tested at 90 days. In air-entrained concrete the addition of pellet chloride, in the amounts used, did not cause any significant differences in the moduli of rupture at 90 days of age.

6. Generally the decreases caused by the use of flake chloride were greater than those caused by the use of pellet chloride. This is shown in Figures 23 and 25.

#### Modulus of Elasticity (Sonic)

7. The sonic moduli at early ages of all concretes tested were increased by the addition of either flake or pellet chloride to the mix. At 90 days of age, however, there were no significant differences among the moduli of elasticity of the various concretes tested.

#### Entrained Air Content

8. The air content of non-air-entrained concrete was increased as greater amounts of flake and pellet chloride were added to the mix.

9. There was not much correlation between the air content of air-entrained concretes, but the addition of 2 percent flake or 1 percent pellet chloride caused significant increases in the air content of some mixes.

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10. Generally the slumps of the concretes were increased by adding either flake or pellet chloride in amounts up to 2 percent commercial chloride. Greater amounts tended to decrease the slump.

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