RAPID SETTING CEMENT MORTARS

FOR CONCRETE REPAIR

by

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FOREWORD

During the latter part of 1966, several Districts of the Texas Highway Department were approached by firms offering a rapid setting cement patching mortar. These materials were designed to be mixed with water and placed. They had usable working times of 5 to 10 minutes and attained sufficient strength to carry traffic in 1 to 1½ hours. Because of the problems associated with repairing concrete bridge deck and roadway in heavy traffic areas, maintenance personnel were quite interested in these materials and began to use them in fairly sizable quantities. Because of the high cost of these proprietary materials and because of problems in obtaining consistent results, the Materials and Tests Division was asked to develop an economical rapid setting cement formulation which would be equivalent in performance to the better proprietary materials.

This report deals with the development of such a formulation and also with the characteristics of some proprietary rapid setting materials of various types.

I. SUBJECT

Rapid setting cement mortars for concrete repair.

II. PURPOSE

The purpose of this project was to develop an economical rapid setting cement mortar for the repair of concrete bridge decks and roadway which could be mixed and placed in a manner similar to ordinary portland cement concrete.

III. CONCLUSIONS

As a result of this investigation, a formulation was developed which is equivalent in performance and cost to the better rapid setting mortars of this same general type. The formulation is based on a combination of Type II portland cement, molding plaster, fine sand, powdered saponified vinsol resin air entraining agent, and plaster retarder.

It is believed that performance can be improved by the use of pressure calcined (high strength) gypsums in place of the molding plaster and by the addition of a water reducer to the formulation.

The durability of rapid setting mortars based on a combination of portland cement and gypsum materials is limited. A good mortar of this type, properly mixed and placed, could be expected to last three to five years under traffic. This fact should be considered if repairs with this type of material are planned.

Specific conclusions regarding the formulation of rapid setting mortars based on a combination of portland cement and gypsum

materials are as follows:

1) In order to obtain the best durability, a sulfate resistant cement must be used.

2) Set times vary considerably with different brands and different batches of the same brand of cement. Some portland cements are not suitable for use in a formulation of this type because a very rapid initial set is obtained which is not practical to retard.

3) Anhydrous calcium sulfate and calcium sulfate hemi-hydrate can both be used to accelerate the set of portland cement. The hemi-hydrate (gypsum plaster) was chosen because it is more readily available.

4) Use of high strength gypsum plaster rather than ordinary molding plaster appears to offer some improvement in durability of the rapid setting mortar.

5) In order to have sufficient time for mixing and placing, a rapid setting mortar should have a minimum initial set of 15 minutes by laboratory test. In order to achieve this, a retarder may have to be used. There are a number of retarders which will perform successfully. Of those evaluated, Commercial protein type plaster retarders were the most desirable. U. S. Gypsum Red Top Retarder was used in amounts up to 0.05% by weight with no adverse effects.

6) Addition of air entraining agent to the mix improves workability and gives the cured mortar good freeze-thaw resistance. A saponified vinsol resin air entraining agent can

be incorporated in the mix in dry form. An amount sufficient to give approximately 9% total air is used.

7) Conventional concrete water reducers are not suitable for use in this type of rapid setting mortar. Several effective agents were found which can be added to the mix in powdered form. These are naphthalene sulfonated derivatives. Use of a water reducer results in better handling characteristics and higher strengths. Since use of a minimum amount of water to obtain a workable mix is a critical point in obtaining durability, addition of an effective water reducer will help considerably.

8) Good concreting practices should be followed as closely as possible in placing and curing rapid setting cement mortars. Since areas patched with this type of material are usually released to traffic in two to three hours, damp curing is not possible. Such areas should receive an application of curing membrane as soon as the surface attains a dry appearance.

The following conclusions were reached with regard to physical properties of the rapid setting cement mortars.

1) Mortars suitable for use develop compressive strengths of 300 psi or more in two hours and reach a compressive strength on the order of 5000 psi in 14 days.

2) Freeze-thaw durability of properly formulated mortars is good.

3) Determination of mortar bar expansion in water storage indicates that these materials, even when properly formulated, expand at a greater rate than a portland cement-sand mortar.

4) Wear resistance of the rapid setting mortars is not as good as the wear resistance of portland cement-sand mortars.

Additional field tests are planned to better evaluate the effect of high strength gypsums and water reducers on performance of the rapid setting mortar formulation.

A suggested performance specification for proprietary rapid setting mortars of the type developed is included in the appendix of this report.

IV. MATERIALS

The specific materials obtained for possible use in a rapid setting cement formulation are listed in groups according to the various types of materials.

Cements

All of the cements used were standard portland cements with one exception. Although many different brands were experimented with, the bulk of the work was done with Longhorn Type III and Lone Star (Maryneal) Type II. The various cements used are listed in Table 1 on pages 5 and 6.

Table 1

Identification of Cements

Cement	Type	Manufacturer
Lumnite	High-alumina	Universal Atlas Cement
Atlas	Portland Type II	Universal Atlas Cement
Alamo	Portland Type II	San Antonio Portland Cement Co.
Capitol	Portland Type II	Capitol Cement
Capitol	Portland Type III	Capitol Cement
El Toro (Amarillo)	Portland Type I	Southwestern Portland Cement Co.
El Toro (Amarillo)	Portland Type II	Southwestern Portland Cement Co.
El Toro (El Paso)	Portland Type I	Southwestern Portland Cement Co.
El Toro (El Paso)	Portland Type II	Southwestern Portland Cement Co.
El Toro (El Paso)	Portland Type III	Southwestern Portland Cement Co.
El Toro (Odessa)	Portland Type II	Southwestern Portland Cement Co.
El Toro (Odessa)	Portland Type III	Southwestern Portland Cement Co.
Gifford-Hill	Portland Type II	Gifford-Hill Portland Cement Co.
Gulf Coast	Portland Type I	Gulf Coast Portland Cement Co.
Ideal	Portland Type III	Ideal Cement Co.
Lone Star (Houston)	Portland Type II	Lone Star Cement Corp.
Lone Star (Maryneal)	Portland Type I	Lone Star Cement Corp.
Lone Star (Maryneal)	Portland Type II	Lone Star Cement Corp.
Lone Star (Maryneal)	Portland Type III	Lone Star Cement Corp.
Longhorn	Portland Type I	Longhorn Cement, Div. of Kaiser Cement & Gypsum Corp.
Longhorn	Portland Type III	Longhorn Cement, Div. of Kaiser Cement & Gypsum Corp.
TXI	Portland Type I	Texas Industries, Inc.

Table 1

Identification of Cements (continued)

Cement	Type	Manufacturer
TXI	Portland Type II	Texas Industries, Inc.
Trinity (Dallas)	Portland Type I	Trinity Portland Cement Div., General Portland Cement Co.
Trinity (Ft. Worth)	Portland Type I	Trinity Portland Cement Div., General Portland Cement Co.
Trinity (Ft. Worth)	Portland Type II	Trinity Portland Cement Div., General Portland Cement Co.
Trinity (Ft. Worth)	Portland Type III	Trinity Portland Cement Div., General Portland Cement Co.
Trinity (Houston)	Portland Type I	Trinity Portland Cement Div., General Portland Cement Co.
Trinity (Houston)	Portland Type III	Trinity Portland Cement Div., General Portland Cement Co.

Accelerators

Work was done with two basic chemicals which in comparatively small quantities accelerate the set of portland cement. These were sodium fluosilicate, reagent grade, which was obtained from Fisher Scientific, and triethanolamine, technical grade, obtained from Centex Chemical Co.

Additives

Additives used were hydrated lime (90% minimum calcium hydroxide content), manufactured by Round Rock White Lime Co., and air-floated kaolin clay, manufactured by Georgia Kaolin Co.

Gypsums

The various gypsum materials used in this work are listed in Table 2 on the following page.

Table 2

Identification of Gypsums

Material	Type	Supplier
Anhydrous gypsum	$CaSO_4$	U. S. Gypsum
Molding Plaster	$CaSO_4 \cdot \frac{1}{2}H_2O$ + additives	Consumers Glue Co.
White Art Plaster	$CaSO_4 \cdot \frac{1}{2}H_2O$ + additives	U. S. Gypsum
No. 1 Molding Plaster	$CaSO_4 \cdot \frac{1}{2}H_2O$	U. S. Gypsum
Sunflower Molding Plaster	$CaSO_4 \cdot \frac{1}{2}H_2O$	Georgia-Pacific Co.
Hydrocal White	High strength pressure calcined gypsum ($CaSO_4 \cdot xH_2O$)	U. S. Gypsum
Hydrostone	High strength pressure calcined gypsum ($CaSO_4 \cdot xH_2O$)	U. S. Gypsum

Aggregate

The aggregates used in this work consisted of graded standard sand, as specified in ASTM Designation: C 109, and No. 4 sandblast sand obtained from Capitol Aggregates, Austin, Texas and from Clemtex, Houston. The Clemtex sand was used only in Formulation III. The gradations of the No. 4 sandblast sand were as follows:

	Percent Retained	
U. S. Std. Sieve No.	Capitol Aggregates	Clemtex
30	1	1
60	83	78
120	98	99

Retarders

The various retarders used to adjust the set time of the rapid setting mortar formulations containing gypsum materials are listed in Table 3.

Table 3

Identification of Retarders

Material	Supplier
Casein, Purified	E. H. Sargent
Dextrin, White Purified	E. H. Sargent
Gelatin, U. S. P.	J. T. Baker
Gold Bond Retarder	National Gypsum
Red Top Retarder	U. S. Gypsum
Sodate Retarder	U. S. Gypsum

Air Entraining Agents

The air entraining agents used in this work were En-Train-Air, a solution of saponified vinsol resin supplied by American Soap and Chemicals, Inc., and Vinsol NVX, a powdered saponified vinsol resin supplied by Hercules Powder Co.

Water Reducers

The various water reducers or flow agents experimented with are listed in Table 4.

Table 4

Identification of Water Reducers

Material	Description	Supplier
Pozzolith 100 XR	Primarily a water solution of glucosaccharide polymers	Master Builders
Pozzolith 200N	Liquid	Master Builders
Placewel, air entraining type	Liquid	Union Carbide
Placewel, non-air entraining type	Liquid	Union Carbide
Q-Broxin	Powder	Baroid Div., National Lead
Carbonox	Powder	Baroid Div., National Lead
Blancol	Granular solid - sodium salt of sulfonated napthalene condensate - used as a water solution	General Aniline and Film
Polyox FRA	Powder - long chain polymer of ethylene oxide - used as water solution	Union Carbide
Lomar LS	Powder - sulfonated napthalene condensate	Nopco Chemical Div. of Diamond-Shamrock
Lomar PW	Powder - sulfonated napthalene condensate	Nopco Chemical Div. of Diamond-Shamrock
Lomar D	Powder - sulfonated napthalene condensate	Nopco Chemical Div. of Diamond-Shamrock

V. TEST METHODS

The tests used in evaluating various rapid setting cements and mortars were standard ASTM tests or modifications thereof. These tests were as follows:

1) Time of Setting of Hydraulic Cement by Gillmore Needles (ASTM Designation: C 266).
2) Compressive Strength of Hydraulic Cement Mortars (Using 2 Inch Cube Specimens) (ASTM Designation: C 109).
3) Autoclave Expansion of Portland Cement (ASTM Designation: C 151).
4) Length Change of Cement Mortar and Concrete (ASTM Designation: C 157).
5) Resistance of Concrete Specimens to Rapid Freezing in Air and Thawing Water (ASTM Designation: C 291).
6) Air Content of Hydraulic Cement Mortars (ASTM Designation: C 185).
7) Abrasion Resistance of Concrete (ASTM Designation: C 418).

Because of the very short working time of the materials being tested, the amount of mixing water was determined on a trial and error basis until a workable low slump mix was obtained. The actual composition of each mix tested is presented in this report. In the length change tests, the air stored specimens were kept in an area where the humidity varied from 48 to 60 percent rather than the 50 $\pm$ 4 percent specified in ASTM Designation: C 157. For the determination of resistance to freezing and thawing, the specimens used were 3" x 3" x 11¼" (10 inch effective gage length). One freeze-thaw cycle consisted of 9 hours in a freezer maintained at 0°F followed by 3 hours in a water reservoir initially at room temperature. The final thawed temperature of the specimens ranged from 60 to 65°F. For the initial evaluation, the thawing was car-

ried out in tap water. Those specimens which were still in good condition after 300 cycles were then subjected to freezing in air and thawing in 4 percent sodium chloride solution. Each time the dynamic modulus of elasticity was determined, the weight and length of the specimens were also determined.

After initial freeze-thaw tests were performed, the laboratory obtained equipment with which the test could be performed exactly as outlined in ASTM Designation: C 291. Some additional tests were performed with this equipment using specimens 3" x 4" x 16" in size.

It was discovered that some of the formulations exhibited considerable expansion after 3 to 6 months of storage in water. It was believed that this was due in large part to the effect of the high sulfate content of these mortars on the portland cement present. The procedure in ASTM Designation: C 157 was modified in that bars were stored in water maintained at various elevated temperatures in an attempt to develop an accelerated expansion test. These tests were performed using bars of both 5 and 10 inch gage length. Bars of 10 inch gage length were used unless otherwise stated.

The abrasion resistance test was performed on specimens 6" x 6" x 1". Four spots on the surface of each specimen were subjected to abrasion. Two specimens were tested for each mix.

VI. TEST RESULTS AND DISCUSSION

The first step in developing a rapid setting mortar formulation was to survey the literature available on this subject. Numerous references were found on the subject of acceleration of the setting time of portland cement or on special rapid setting mixes. However, almost all of these references pertain to methods of shortening the setting time of portland cement 10 to 20 percent.

Various sources of information indicated that the following systems might give set times of the magnitude desired.

1) Combinations of portland and high-alumina cements. [1,2]
2) Use of triethanolamine in conjunction with portland cement.
3) Use of sodium fluosilicate in conjunction with portland cement.[3]
4) Combinations of portland cement, anhydrous calcium sulfate and kaolin clay.

Suggested starting formulations on portland and high-alumina cement combinations were obtained from Universal Atlas Cement. Initial tests were performed on the following combinations:

Formulation No. 1	Formulation No. 2
100 g Longhorn Type I portland cement	Same as Formulation No. 1 except that Longhorn Type III portland cement was used along with 30 ml mixing water.
91 g Lumnite high-alumina cement	
4 g anhydrous $CaSO_4$	
2 g hydrated lime	
27.5 ml mixing water per 100 g dry mix	

Set time determinations indicated that Formulation No. 2 was too slow setting for our use. Another blend of high-alumina and Type III portland cement was prepared as follows:

Formulation No. 3

100 g Longhorn Type III cement

150 g Lumnite

4 g anhydrous $CaSO_4$

2 g hydrated lime

29 ml mixing water per 100 g dry mix

Set times for Formulations 1 and 3 were as follows:

	No. 1	No. 3
Initial, Minutes	25	10
Final, Minutes	38	17

Compressive Strengths of Formulations 1 and 3 were then determined by ASTM Designation: C 109. Actual mixes were as follows:

	No. 1	No. 3
Cement Mixture, g	100	100
Graded Ottawa sand, g	250	250
Mixing water per 100 g dry material, ml	13.5	13.2

Data on these mixes is presented in Table 5 on the following page.

In view of the low strengths of the alumina-portland blends and the high cost of high-alumina cement, no further work was done with this combination.

Table 5

Properties of Rapid Setting Cements Based on High-Alumina - Portland Blends

	*Form. 1	Form. 2
Initial Set, Minutes	25	16
Final Set, Minutes	40	26
Compressive Strength, psi		
At 2 hours	525	973
At 6 hours	738	1078
At 24 hours	730	1028
At 7 days	1260	1163
At 14 days	1808	1776

*Throughout this report, the abbreviations "Form." for Formulation and "Prop." for Proprietary are used in several of the tables.

The use of triethanolamine as an accelerator was then investigated. Its effect on the set time of Longhorn Type III cement was determined. The triethanolamine was added to the mixing water. Initial tests indicated the following:

Percent Triethanolamine, Based on Weight of Cement	Effect
1	Little effect on set times
2	Shortened initial set to 50 minutes
5	Initial set - 9 minutes Final set - 18 minutes

The use of 5 percent triethanolamine produced set times similar to those of the proprietary patching mortars being used. However, the reaction involved generates a tremendous amount of heat. Addi-

tion of aggregate to the cement slowed the set time somewhat. A small batch of the following formulation had an initial set of 20 minutes and a final set of 32 minutes:

100 g Type III cement

50 g No. 4 sandblast sand

5.5 g triethanolamine

32 ml mixing water + 0.075 ml En-Train-Air

When a batch of the above formulation sufficiently large to prepare compressive strength specimens was mixed, it set up almost immediately after mixing. The amount of triethanolamine was reduced to 4 g and the amount of water increased to 34 ml. Test results on this mix are presented in Table 6.

Table 6

Properties of Rapid Setting Mortar Based on Triethanolamine as Set Accelerator

Set Times, Minutes - Initial - 10
Final - 19

Compressive Strength

Cure Time	Stress, Psi
2 Hours	342
1 Day	725
7 Days	1330

Mortar prepared using triethanolamine as a set accelerator is rather soft and crumbly. Because of the tremendous exotherm, wide variation in set times with mass and low strengths of the cured mortar,

it was decided that use of triethanolamine as a set accelerator would not be desirable.

The use of sodium fluosilicate as an accelerator for the set of portland cement was investigated. The basic formulation used to evaluate this chemical was as follows:

100 g Longhorn Type III cement

50 g No. 4 sandblast sand

40 ml water + 0.075 ml En-Train-Air

Sodium fluosilicate was used in the above mix in amounts of 0.5 and 2.0 grams by adding it to the mixing water. These amounts exceed the solubility of sodium fluosilicate in water and precipitated the vinsol resin air entraining agent present in the water. Set times obtained were as follows:

	0.5 gram	2.0 grams
Initial set, minutes	35	20
Final set, minutes	60+	60+

Both mixtures became almost unworkable within two minutes after completion of mixing. Because of the poor handling characteristics and slow final set of mortars containing sodium fluosilicate, no further work was done with this agent.

Work was then done with combinations of portland cement, anhydrous calcium sulfate and kaolin clay. A number of mixes were prepared, varying the amount of calcium sulfate from 11 to 50 grams and the kaolin clay from 13 to 25 grams per 100 grams of cement. Longhorn and Gulf Coast Type I and Atlas Type II cements were used. With

11 grams of calcium sulfate, initial set times on the order of 7 minutes were obtained, but three to four hours were required to attain final set. Increasing the amount of calcium sulfate until a desirable final set could be obtained resulted in an almost immediate initial set. The use of different brands and types of portland cement did not seem to make any difference. The basic formulation experimented with had originally been designed for patching under water. The kaolin clay was apparently added simply to give a stiff mix which would not be broken up by the water before it developed a set. It was decided that addition of the kaolin clay served no useful purpose in a patching mortar for highway use and was probably detrimental in that it was requiring addition of extra water to obtain a workable mix.

A chemical analysis was performed on a sample of one of the proprietary patching materials which appeared to be giving good performance in the field. The probable composition, based on this analysis was as follows:

53 percent by weight portland cement

14 percent by weight $CaSO_4 \cdot \frac{1}{2}H_2O$ (plaster of Paris)

33 percent by weight fine sand

This material also contained a powdered vinsol resin air entraining agent. Additional trial mixes were prepared with portland cement, anhydrous calcium sulfate and sand. Vinsol resin air entraining agent in solution was added to the mixing water. Addition of the air entraining agent helped considerably in obtaining a workable mix with less water. This in turn improved the initial and

final set time relationships. The use of excessive mixing water "kills" the quick set obtained by the use of anhydrous $CaSO_4$ or $CaSO_4 \cdot \frac{1}{2}H_2O$. Although the results were better, addition of sufficient anhydrous $CaSO_4$ (about 20 grams per 100 grams of cement) to obtain early strength development resulted in initial set times on the order of five to six minutes, which would not allow sufficient working time for placement of the mortar. Since the proprietary patching materials appeared to contain $CaSO_4 \cdot \frac{1}{2}H_2O$ rather than anhydrous calcium sulfate and finely ground anhydrous sulfate is not readily available, the decision was made to work with portland cement - plaster of Paris combinations. Set times and strength development on initial trial formulations looked quite promising. Trial formulations were as follows:

Form. 1	Form. 2
78 g Longhorn Type I portland cement	79 g Longhorn Type III portland cement
22 g Molding plaster (Consumer's Glue Co.)	21 g Molding plaster (Consumer's Glue Co.)
50 g No. 4 sandblast sand	50 g No. 4 sandblast sand
37 ml water + 0.075 ml En-Train-Air	37 ml water + 0.075 ml En-Train-Air

Set times were as follows:

	No. 1	No. 2
Initial, Minutes	11	12
Final, Minutes	26	25

It was believed that the most rapid strength development using the least amount of plaster could be obtained with a Type III cement. Preliminary mixes with several different cements indicated

that Longhorn Type III gave the best working characteristics, so Formulation No. 2 above was selected for a more complete evaluation and designated as Formulation I. Compressive strength, autoclave expansion, freeze-thaw and length change tests were performed. The results of the compressive strength and autoclave expansion tests are presented in Table 7. Since the freeze-thaw and length change determinations are long term tests and data was not available at this point in the investigation, the results from these tests for Formulation I as well as Formulations II, III, and IX and Proprietary Mortars A, B, C and D are tabulated in the appendix.

Table 7

Properties of Formulation I

Autoclave Expansion Avg. - 0.087%

Compressive Strengths

Cure Time	Stress, Psi
2 Hours	283
6 Hours	342
1 Day	3375
3 Days	5588
7 Days	5100
14 Days	6482

Since tests to this point indicated that $CaSO_4 \cdot \frac{1}{2}H_2O$ was a suitable set accelerator for portland cement, several producers of gypsum

materials were contacted to obtain samples of the hemi-hydrate for further testing. Samples were received from U. S. Gypsum and Georgia-Pacific. Trial batches of Formulation I using these materials did not perform well at all with regard to set time. The initial set occurred in approximately six minutes. The manufacturer of the molding plaster used originally (Consumer's Glue Co.) was contacted regarding its composition. They stated that their material was mainly $CaSO_4 \cdot \frac{1}{2}H_2O$, but contained some additives to give a dense smooth surface on molded items. Literature research indicated that these additives could possibly be dextrin or casein which might be acting as a retarder in the rapid setting cement formulation.

A sample of U. S. Gypsum White Art Plaster, which contains dextrin, was obtained and preliminary mixes prepared with this material. Typical set times were as follows:

Initial, Minutes - 19

Final, Minutes - 42

These set times were sufficiently long - perhaps longer, than needed. Initial set times on the order of 10 minutes could be obtained by using approximately equal amounts of U. S. Gypsum No. 1 Molding Plaster, which contains no additives, and White Art Plaster. However, it was believed that it would be better to base the rapid setting cement mortar on pure $CaSO_4 \cdot \frac{1}{2}H_2O$ and add any necessary retarders separately. Several possible retarders were evaluated. Sodate, described as a chemical type retarder, and Red Top, described as a colloidal type retarder, were obtained from U. S. Gypsum. A

sample of Gold Bond Retarder (a material similar to the Red Top Retarder), manufactured by National Gypsum Co., was also obtained. In addition, casein, dextrin and gelatin, all of which act as colloidal retarders, were evaluated in the following basic formulation:

79 g Longhorn Type III cement

21 g U. S. Gypsum No. 1 Molding Plaster

50 g No. 4 sandblast sand

37 ml water + 0.075 ml En-Train-Air

The Sodate Retarder did not seem to have any effect whatsoever on set times, even when added in amounts as high as 0.5 gram. All of the other agents did retard the set time. The Red Top and Gold Bond Retarders seemed to be more effective and consistent than the casein and dextrin. The gelatin produced good results provided it was dissolved in the mixing water. Set times and compressive strength data on mixes incorporating Red Top and Gold Bond Retarders and Gelatin are presented in Table 8.

The use of a retarder in small amounts did not adversely affect the strength development of the mortar. The decision was made to use the Red Top Retarder in the experimental work whenever a retarder would be needed.

Table 8

Effect of Retarders on Rapid Setting Mortars

	No Retarder	0.047 g Red Top	0.07 g Red Top	0.06 g Gold Bond	0.075 g Gelatin
Initial Set, Minutes	6	13	16	15	20
Final Set, Minutes	11	25	25	25	29
Compressive Strength, psi					
2 Hours	340	358	463	335	367
6 Hours	582	596			
1 Day	2805	2820	2048	2113	2413
3 Days	3970	4075			
7 Days	4962	5050	4290	4550	4778

Freeze-thaw and length change tests were initiated on the rapid setting formulation containing retarder. The exact mix tested, designated as Formulation II, was a follows:

79 g Longhorn Type III portland cement

21 g U. S. G. No. 1 Molding Plaster

50 g Capitol Aggregates No. 4 Sandblast Sand

0.07 g U. S. G. Red Top Retarder

39 ml water + 0.075 ml En-Train-Air

Set time and compressive strength data are presented in Table 9.

Table 9

Properties of Formulation II

Set Times, Minutes - Initial - 16
Final - 25

Compressive Strength

Cure Time	Avg. Stress, Psi
2 Hours	463
1 Day	2048
7 Days	4290

Development of a rapid setting patching material had progressed to the stage where field trials would be desirable. Districts 12 and 18 agreed to place rapid setting material prepared by the laboratory. A discussion of the field trials is presented later in this report. In preparing the dry mixes for the field trials, it became quite obvious that there is a difference in characteristics, mainly speed of set of the mortar, even with different batches of the same brand and type of cement. As in our previous tests, Longhorn Type III cement was used to make up the dry mixes. It was found that with this particular batch of cement, the initial and final set times were 12 and 25 minutes, respectively, with no retarder added. In order to determine what set times would be most desirable in the field, retarder was added to some of the mix. It was found that initial and final sets of 25 and 40 minutes respectively could be obtained by addition of only 0.05 gram of Red Top Retarder per 150 grams of dry mix prepared with this cement.

Based on satisfactory initial performance of the field trial material which was placed in July of 1968, District 12 desired to do additional repair of concrete pavement with rapid setting mortar. It was decided that their maintenance personnel could prepare the dry mix from the raw materials. In September of 1968, preliminary evaluation was made of rapid setting mortar based on the raw materials which they proposed to use. The portland cement was Capitol Aggregates Type III. The initial set with this cement occurred in three to four minutes. Addition of retarder in amounts as high as 0.2 gram per 150 grams dry mix had no effect on the set times. The only other cement which they had available for use at that time was Texas Industries Type I, which seemed to perform quite well. The formulation designed for District 12, designated in this report as Formulation III, was as follows:

79 g TXI Type I portland cement

21 g U. S. G. No. 1 Molding Plaster

50 g Clemtex No. 4 Sandblast sand

0.05 g U. S. G. Red Top Retarder

31.5 ml water + 0.075 ml En-Train-Air

Set times and compressive strength data on this formulation are presented in Table 10.

Table 10

Properties of Formulation III

Set Times, Minutes - Initial - 20
Final - 28

Compressive Strength

Cure Time	Avg. Stress, Psi
2 Hours	368
6 Hours	634
1 Day	3161
3 Days	4262
7 Days	5275
14 Days	6083

In view of the problem encountered in using different cements, the decision was made to evaluate a large number of different brands and types of cement in the basic formulation which had been established with regard to set time characteristics. A tabulation of the results obtained is presented in Table 11.

Table 11

Set Times of Rapid Setting Cement
Mortar Containing Different Portland Cements

Cement	Retarder Added, Gram	Initial Set, Minutes	Final Set, Minutes
Alamo Type II	0	4	8
Alamo Type II	0.05	7	11
Capitol Type II	0	6	11
Capitol Type II	0.05	11	18

Table 11 (Continued)

Cement	Retarder Added, Gram	Initial Set, Minutes	Final Set, Minutes
El Toro (Amarillo) Type I	0	17	29
El Toro (Amarillo) Type II	0	8	15
El Toro (Amarillo) Type II	0.05	16	26
El Toro (Amarillo) Type II	0.10	27	39
El Toro (El Paso) Type I	0	5	9
El Toro (El Paso) Type I	0.05	6	11
El Toro (El Paso) Type I	0.10	11	15
El Toro (El Paso) Type II, Sample 1	0	7	11
El Toro (El Paso) Type II	0.10	21	31
El Toro (El Paso) Type II, Sample 2	0	4	7
El Toro (El Paso) Type II, Sample 2	0.05	6	9
El Toro (El Paso) Type III	0	5	9
El Toro (El Paso) Type III	0.10	14	20
El Toro (Odessa) Type II	0	3	9
El Toro (Odessa) Type II	0.05	4	11
El Toro (Odessa) Type II	0.10	4	11
El Toro (Odessa) Type III	0	3	10
El Toro (Odessa) Type III	0.10	4	9
Gifford-Hill Type II	0	4	7
Gifford-Hill Type II	0.05	4	8
Ideal Type III	0	8	16
Ideal Type III	0.05	15	27

Table 11 (Continued)

Cement	Retarder Added, Gram	Initial Set, Minutes	Final Set, Minutes
Ideal Type III	0.06	18	30
Lone Star (Houston) Type II	0	10	19
Lone Star (Maryneal) Type I	0	12	20
Lone Star (Maryneal) Type I	0.05	29	44
Lone Star (Maryneal) Type II, Sample 1	0	14	23
Lone Star (Maryneal) Type II, Sample 1	0.05	29	41
Lone Star (Maryneal) Type II, Sample 2	0	9	16
Lone Star (Maryneal) Type II, Sample 2	0.03	11	19
Lone Star (Maryneal) Type II, Sample 3	0	8	15
Lone Star (Maryneal), Type II, Sample 3	0.03	13	19
Lone Star (Maryneal) Type II, Sample 3	0.04	17	25
Lone Star (Maryneal) Type III*	0	27	43
Lone Star (Maryneal) Type III*	0.05	46	65
TXI Type II	0	11	16
TXI Type II	0.02	15	21
Trinity (Dallas) Type I	0	14	27
Trinity (Dallas) Type I	0.05	31	44
Trinity (Ft. Worth) Type I	0	5	14

*Although this cement resulted in long set times, the mix develops a structure quite rapidly which causes poor handling characteristics.

Table 11 (Continued)

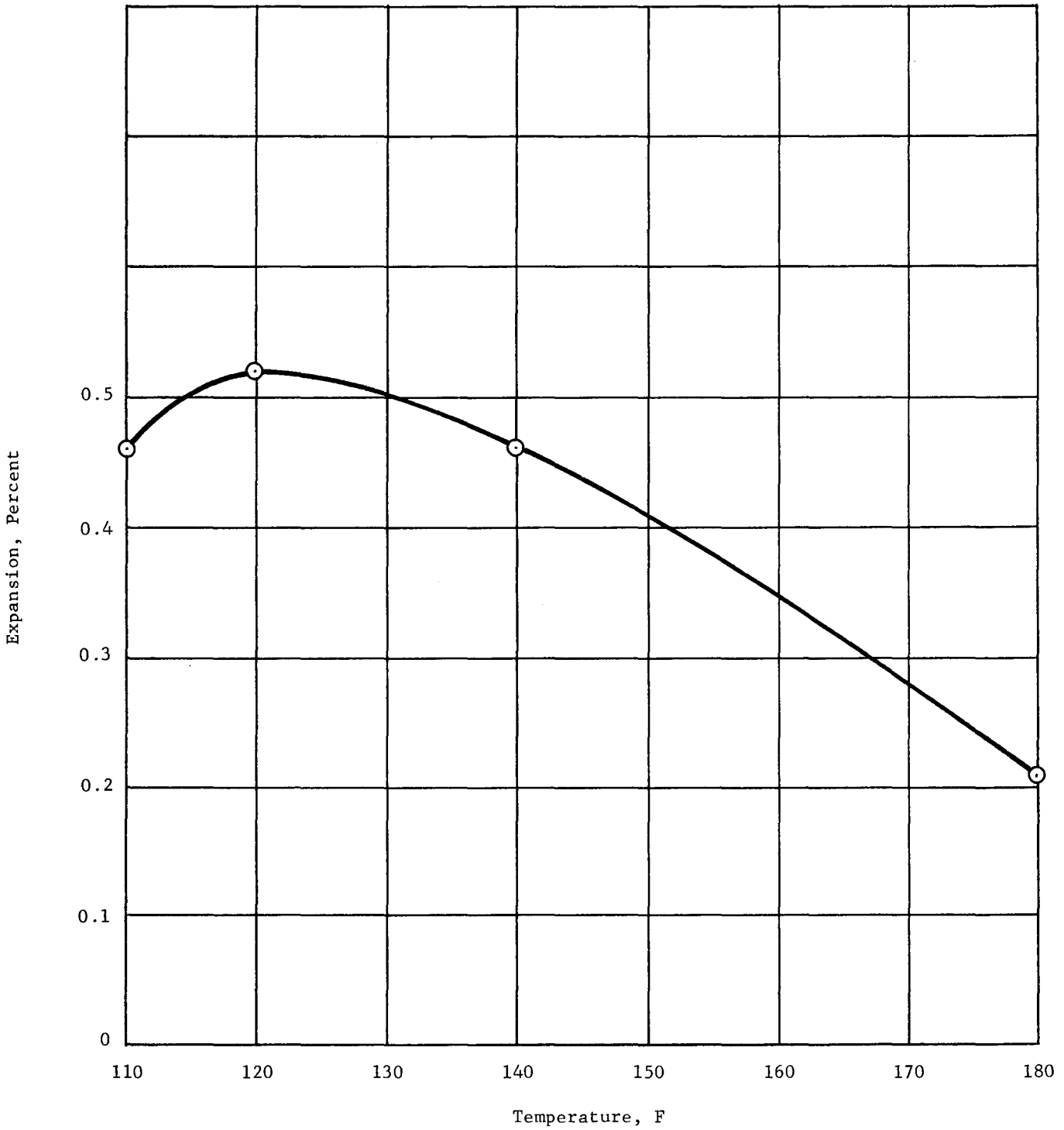
Cement	Retarder Added, Gram	Initial Set, Minutes	Final Set, Minutes
Trinity (Ft. Worth) Type I	0.05	7	15
Trinity (Ft. Worth) Type I	0.10	8	15
Trinity (Ft. Worth) Type II	0	5	10
Trinity (Ft. Worth) Type II	0.05	7	11
Trinity (Ft. Worth) Type II	0.10	9	15
Trinity (Ft. Worth) Type III	0	7	15
Trinity (Ft. Worth) Type III	0.05	13	22
Trinity (Ft. Worth) Type III	0.10	23	31
Trinity (Houston) Type I	0	10	19
Trinity (Houston) Type I	0.05	16	27
Trinity (Houston) Type III	0	21	34
Trinity (Houston) Type III	0.02	34	53

It was found that some cements were completely unsuitable for use in the rapid setting formulation because of very rapid initial sets which could not be retarded. As already noted, there was also quite a variation between batches of the same cement. Investigation of chemical composition and other characteristics of the cement has not revealed why this phenomenon occurs. It became apparent that laboratory trial mixes should be prepared for each batch of cement to be used in making up the rapid setting mortar to determine its suitability for use and the amount of retarder, if any, necessary to obtain the desired working time.

Results of length change tests being performed on Formulation II pointed out a characteristic which could be detrimental to the performance of the rapid setting mortar formulation. After 16 weeks in water storage, the bars had expanded much more than specimens of the proprietary materials being tested. The same characteristic was being evidenced by Formulations I and III although it was not as pronounced. After 32 weeks in water, Formulation II had expanded so much that the bars could not be measured. Warping and surface cracking was evident Formulation I reached this condition after 96 weeks in water In approximately 64 weeks, Formulation III evidenced extreme expansion and deterioration. After reviewing the situation, it was believed that the most likely cause of this expansion and deterioration in water was due to sulfate reaction with the Type I or Type III cement being used in the formulation If this was the case, use of a Type II cement should help considerably Other factors which might be involved included the retarder and the type of plaster being used. Because of economic considerations, an ordinary plaster had been used. Pressure calcined plasters are available which, although considerably more expensive, were reported by the manufacturer to have better water resistance. A more rapid method than ASTM Designation: C 157 to determine tendency to expand excessively was needed. It was thought that immersion of the test bars in water at elevated temperature might be a possibility. Length change in water maintained at 110 $\pm$ 3, 120 $\pm$ 3, 140 $\pm$ 5 and 180 $\pm$ 5 F was determined for Formulation II The average expansion after 28 days at these temperatures is presented in Graph 1. The maximum expansion occurred at 120 F.

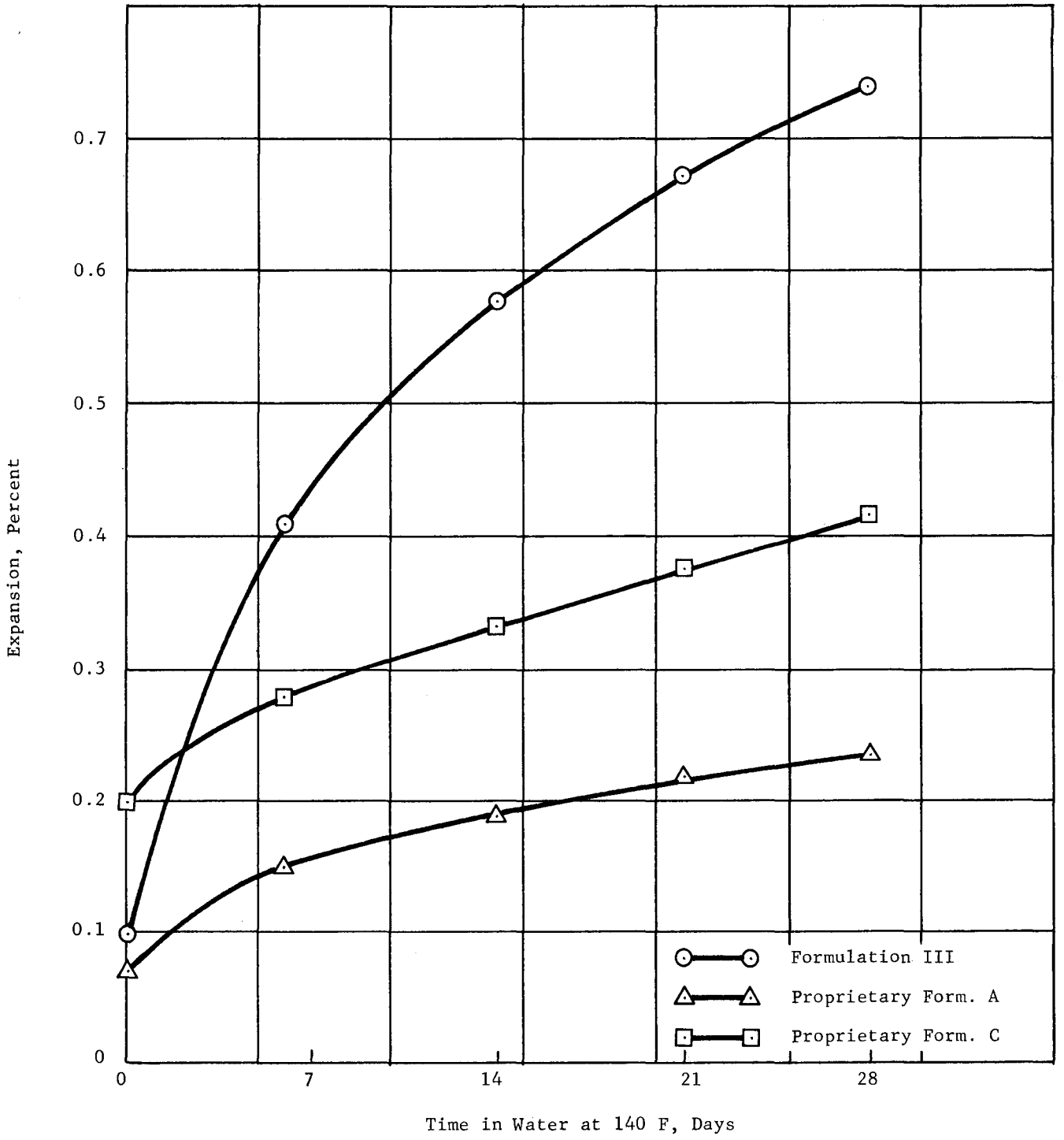
Graph 1

Expansion of Formulation II After 28 Days
in Water at Various Temperatures



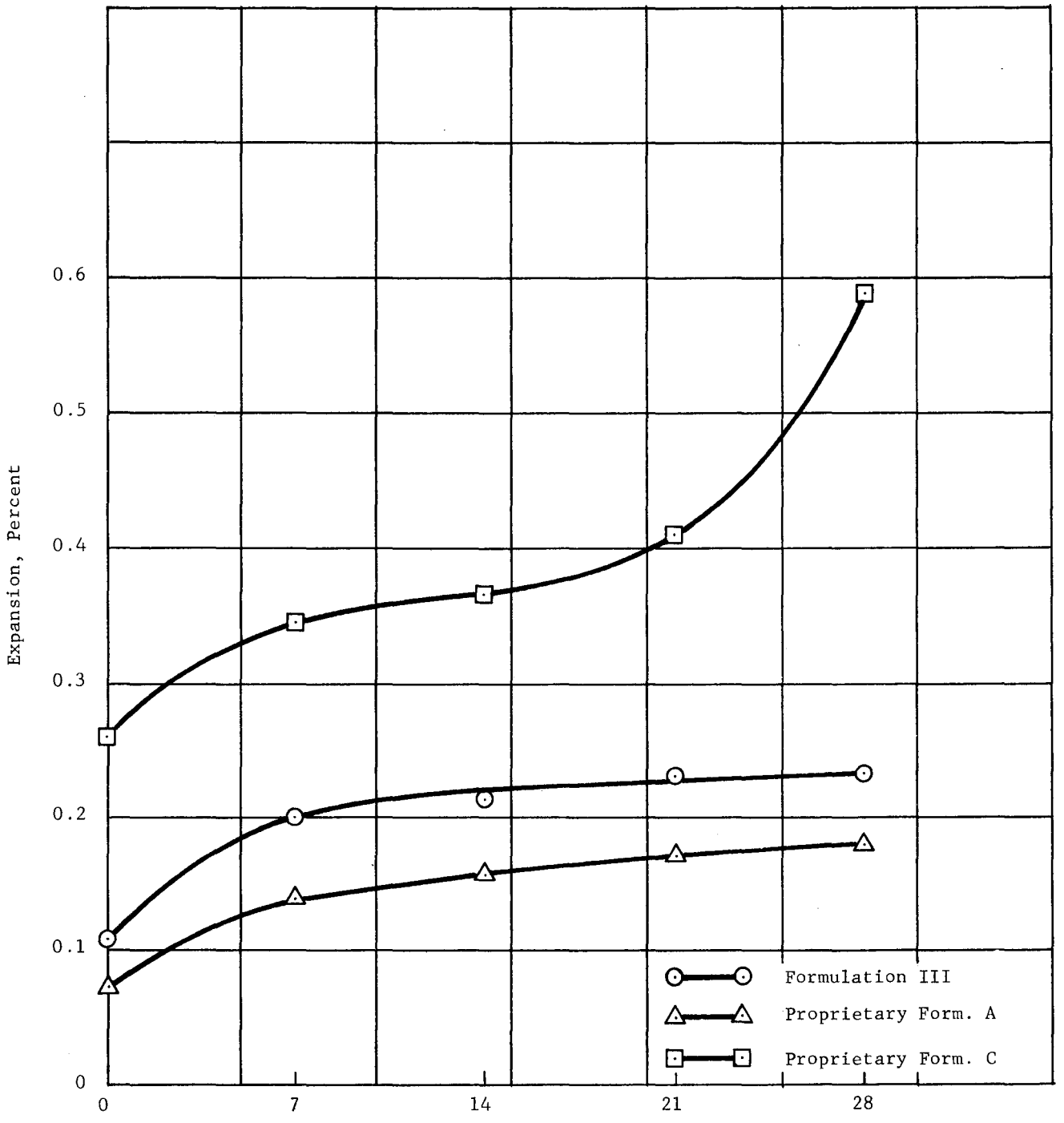
Graph 2

Expansion of Rapid Setting Cement Mortars
After 28 Days in Water at 140 F



Graph 3

Expansion of Rapid Setting Cement Mortars
After 28 Days in Water at 180 F



Expansion at 140 and 180 F was also determined on Proprietary Formulations A and C and Formulation III. The results obtained are depicted in Graphs 2 and 3. An examination of the results indicates that for Proprietary Formulation A and Formulations II and III, maximum expansion rate occurs in the vicinity of 120 to 140 F. The rate at 140 F was about four times as great as the rate at 73.4 $\pm$ 3.0 F. The most important point was that Formulations II and III showed considerably more expansion than Proprietary Formulation A, which indicated good correlation with the test performed at 73.4 $\pm$ 3.0 F. Formulation C did not follow the same pattern as the other materials. It should be noted that it was an experimental material of considerably different composition than the proprietary materials being used by the Department and the equivalent formulations developed by the laboratory.

In evaluating the effect of various constituents on expansion of the mortar, bath temperatures of 110, 120 and 140 F were used. The effect of a Type II rather than a Type I or Type III cement on resistance to expansion was first evaluated. Very few Type II cements were suitable for use in the basic formulation. Most of them tend to produce very rapid, uncontrollable set times. Lone Star (Maryneal) and Texas Industries Type II were both suitable for use in the formulation. Mixes were prepared with these cements and Longhorn Type III. Actual compositions were as follows:

	Form. IV	Form. V	Form. VI
Cement, g	79 (Longhorn Type III)	79 (Lone Star (M) Type II)	79 (TXI Type II)
U.S.G. No. 1 Molding Plaster, g	21	21	21
C.A. No. 4 Sandblast Sand, g	50	50	50
Water, ml	37.5	36.0	34.5
En-Train-Air, ml	0.05	0.05	0.05
Tricalcium aluminate content of cement, %	11.5	6.8	2.5

Test results on these mixes is presented in Table 12.

Table 12

Effect of Different Cements on Rapid Setting Mortar Properties

Property	Form. IV	Form. V	Form. VI
Initial set, Minutes	5	11	5
Final set, Minutes	11	20	10
Compressive Strength, psi			
2 Hours	378	320	235
1 Day	2208	2595	2480
Percent Expansion at 140 F (5 inch bars)			
7 Days	0.072	0.050	0.034
14 Days	0.308	0.140	0.070
21 Days	0.432	0.178	0.086

The use of Type II cement definitely reduced the amount of expansion.

The effect of using a pressure calcined plaster was then evaluated. Hydrocal White and Hydrostone, pressure calcined plaster materials produced by U. S. Gypsum, were substituted for the No. 1 Molding Plaster in Formulation IV. The amount of water required was reduced to 36 ml. The mix containing Hydrocal White was designated Formulation VII and the one containing Hydrostone, Formulation VIII. The properties of these formulations are presented in Table 13.

Table 13

Effect of High Strength (Pressure Calcined) Plasters on Rapid Setting Mortar Properties

Property	Form. VII	Form. VIII
Initial Set, Minutes	6	6
Final Set, Minutes	15	20
Compressive Strength, psi		
2 Hours	508	375
1 Day	2172	1975
Percent Expansion in Water at 140 F (5 inch bars)		
7 Days	0.062	0.072
14 Days	0.232	0.244
21 Days	0.308	0.324
28 Days	0.356	0.374

The use of high strength plaster also reduces the rate of expansion of the mortar, although the reduction is not as pronounced as that obtained with low tricalcium aluminate content cement.

The relative expansion of the mortar with and without retarder was then evaluated. Red Top Retarder in the amount of 0.03 gram per 150 grams dry mix was added to Formulations V and VI. Test results on these mixes are presented in Table 14.

Table 14

Effect of Retarder on Rapid Setting Cement Mortar Properties

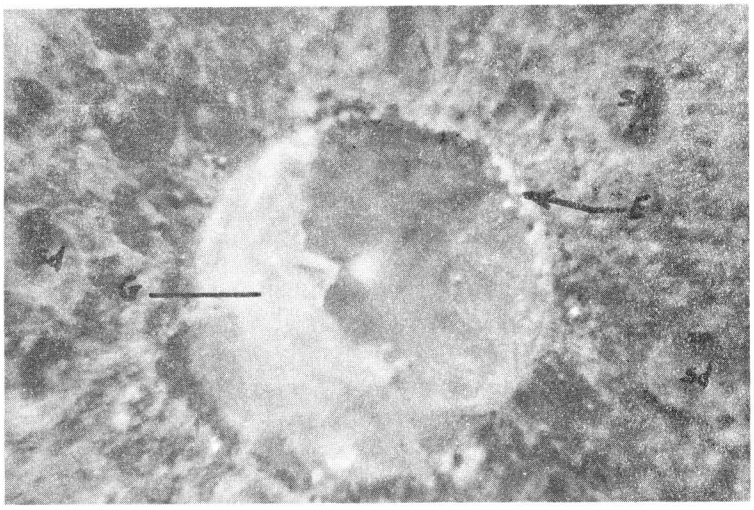
Property	Form. V + Retarder	Form. VI + Retarder
Initial Set, Minutes	29	9
Final Set, Minutes	37	15
Compressive Strength, psi		
2 Hours	343	210
1 Day	3518	2225
Percent Expansion in Water at 140 F (5 inch bars)		
7 Days	0.042	0.030
14 Days	0.108	0.064
21 Days	0.148	0.078
28 Days	0.172	0.090

The use of retarder appears to improve resistance to expansion.

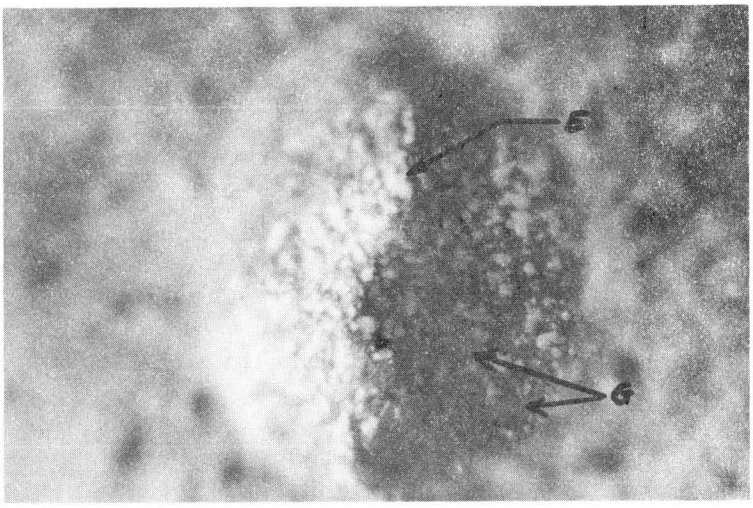
The results of long-term length change tests are tabulated in Tables 1-A and 2-A of the appendix. The most significant information obtained from all the length change tests was the rapid expansion and subsequent deterioration in water of the initial laboratory formulations and the fact that utilization of Type II cement solved the problem. The accelerated length change in water of Formulations IV through VI presented in Table 12 shows that the expansion is directly related to the amount of tricalcium aluminate present in the cement, which indicates that most of the expansion is due to sulfate attack.

After Proprietary Formulation A test specimens had expanded to the point where they could not be measured, freshly broken pieces and polished sections from them were examined utilizing reflected-light microscopy coupled with transmitted plane and polarized light on thin sections. Three secondary chemical compounds were identified in the mortar bars. The most predominant of the three, which was present in both the voids and the paste, was calcium sulfate dihydrate (Gypsum; $CaSO_4 \cdot 2H_2O$, monoclinic, n=1.52) as indicated in the photomicrographs on the following page. The presence of this compound would be expected, since the reactive portion of this type of rapid setting mortar is approximately 20% $CaSO_4 \cdot \frac{1}{2}H_2O$. It occurred as large clear blade-like and often intergrown crystals wedged in the air voids and single lath-like crystals scattered throughout the paste.

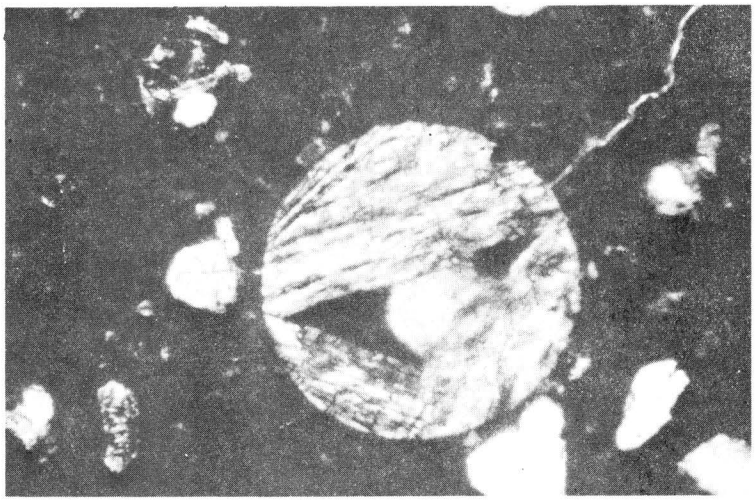
A second mineral identified common only to the voids, is calcium difluoride (fluorite; CaF_2, cubic, n=1.43). It was found associated



Photomicrograph of mortar bar sample showing air void containing gypsum crystals (G) and ettringite (E). Sand grans (Sd) in the paste matrix are indicated. (Mag. 100X)



Photomicrograph taken of same specimen above showing a different air void containing ettringite and a small amount of gypsum. (Mag. 100X)



Photomicrograph of a 30μ thin section of above sample showing air void containing gypsum crystals. Smaller gypsum crystals and sand grains can be seen in the paste matrix. (Mag. 125X)

with the gypsum crystals in air voids and was indistinguishable except under polarized light. It is possible that this compound resulted from a small amount of a fluoride salt added to the mortar as a set accelerator.

The third compound was also observed only in the voids. It appeared as minute white fibrous spherulitic growths in the voids. Based on its form and optical properties this material has been identified as high-sulfate calcium sulfoaluminate (ettringite $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$).

A review of the literature reveals that several workers conclude that secondary deposits of gypsum and ettringite are brought about through sulfate attack. The mechanism of reaction involves sulfate ions (in sufficient concentrations) combining with the hydrous calcium aluminates of the cement paste. These reactions are accompanied by expansion of the entire paste matrix with resulting progressive distension, warping, and fracturing of the concrete. Later reaction stages are characterized by a complete decomposition of the paste.

These findings indicate quite conclusively that the expansion in water of these rapid setting mortars is due to reaction of sulfate compounds with constituents of the portland cement.

The length change of rapid setting cement mortars during air storage is not appreciably different than that of ordinary portland cement.[4] However, the long-term expansion of these mortars in

water, even though they contain sulfate resistant cement, is greater than that for ordinary portland cement. It would be expected that the total expansion and contraction on wetting and drying would be greater for these materials than for ordinary portland cement.

From this point, Type II cement was used in the experimental formulations. Lone Star (Maryneal) was used because it consistently gave the longest initial set with a reasonable amount of retarder.

The only additive used in the experimental formulations up to this point other than retarder was a liquid vinsol resin air entraining agent. It was added at a rate that would theoretically produce 7 to 8% entrained air. For field use, it is desirable that the rapid setting mortar be a single component material - i.e., the only thing to be added would be the mixing water. Substitution of a powdered air entraining agent for the liquid vinsol resin agent would be desirable. Air contents were determined by ASTM Designation: C 185 on fresh mortar containing En-Train-Air liquid vinsol resin air entraining agent and Hercules Vinsol NVX, a powdered saponified vinsol resin. The basic formulation tested was as follows:

79 g Lone Star (Maryneal) Type cement

21 g U.S.G. No. 1 Molding Plaster

50 g Capitol Aggregates No. 4 sandblast sand

0.04 g U.S.G. Red Top Retarder

Data obtained by ASTM Designation: C 185 was as follows:

	No Additive	0.05 ml Liquid Agent per 150 g Dry Mix	0.01 g Vinsol NVX per 150 g Dry Mix (Form. IX)
Dry weight of mix, g	1800	1800	1800
Ml water required	378	395	387
Flow, percent	90	95	89
Weight per 400 ml of Mortar, g	840	802	790

In order to calculate the percent air, the following specific gravities were used:

Cement - 3.15

Plaster - 2.80

Sand - 2.60

The resulting air contents were as follows:

No Additive - 3.6%

Liquid Vinsol - 7.1%

Powdered Vinsol - 8.9%

Physical characteristics of the formulation containing the powdered vinsol resin were as follows:

Initial Set, Minutes - 20

Final Set, Minutes - 30

Compressive Strength, psi

2 Hours - 314

1 Day - 3705

14 Days - 6006

These results indicated that powdered saponified vinsol resin added to the dry mix would perform quite well and eliminate the need

for addition of a separate component on the job. Based on all the work up to this point, Formulation IX would be equivalent in performance to the proprietary rapid setting mortars which have given satisfactory performance. It was estimated that it could be obtained in 50 or 100 pound bags at a cost of 4 to 5 cents a pound.

Because the performance of rapid setting mortars based on a combination of portland cement and plaster materials can be affected quite adversely by addition of too much mixing water, the use of a water reducing agent would be desirable. Experimentation with conventional water reducers designed for use with portland cement concrete did not prove successful. These additives all retarded the set of the mortar to some degree and were not effective in reducing the water requirement when added in the recommended amounts. These additives also had the disadvantage of being in a liquid form which would necessitate making the mix a two component system. Several companies that produce flow agents or water reducers were contacted and samples of the agents shown in the materials section obtained. These agents were all in dry form and were not necessarily designed for use in concrete mixes. The basic formulation used to evaluate the agents was as follows:

79 g Lone Star (M) Type II portland cement

21 g U.S.G. No. 1 Molding Plaster

50 g No. 4 sandblast sand

0.01 g Vinsol NVX

0.02 g Red Top Retarder

Initial and final set times on the above mixed with 35 ml water were 25 and 35 minutes respectively. A tabulation of the results obtained with different water reducers or flow agents is presented in Table 15.

Table 15

Evaluation of Various Water Reducers

Agent	Grams Added to 150 Grams Dry Mix	Effect on Water Requirement*	Initial and Final Set Times, Minutes
Q-Broxin	0.1	No significant reduction	32 and 45
	0.2	No significant reduction	33 and 46
	0.5	No significant reduction	40 and 64
Carbonox	0.1	Slight improvement in consistency	25 and 37
	0.5	3% reduction	16 and 25
Blancol**	0.1	Slight improvement in consistency	23 and 33
	0.2	2 to 3% reduction	24 and 34
	0.5	10% reduction	37 and 51

*The water reduction shown is an estimate based on apparent consistency of the mixes rather than determination by ASTM.

**The Blancol is a granular material and could not be used unless it was ground to a fine powder or dissolved in water. For these tests, it was dissolved in the mixing water.

Table 15 (Continued)

Agent	Grams Added to 150 Grams Dry Mix	Effect on Water Requirement*	Initial and Final Set Times, Minutes
Polyox FRA***	0.007	3% reduction	18 and 30
	0.013	No additional change	19 and 31
	0.033	Consistency not as good as with smaller amts. - mix is sticky	17 and 29
Lomar LS	0.1	No noticeable effect	26 and 35
	0.3	6% reduction	22 and 34
	0.4	8% reduction	27 and 37
	0.5	10+% reduction	24 and 39
Lomar PW	0.1	No noticeable effect	24 and 33
	0.4	6% reduction	24 and 40
	0.5	8 to 10% reduction	22 and 39
Lomar D	0.1	No noticeable effect	27 and 39
	0.4	6% reduction	24 and 34

***The Polyox FRA goes into solution quite slowly and in order to have any effect, must be put into solution prior to use.

Of the agents evaluated, the Blancol and Lomar LS were the most effective. The Lomar LS is the most desirable for use because it is a finely powdered material which can be blended directly with the dry rapid setting mortar mix. The effect of 0.3 gram

Lomar LS on water reduction and air content was determined by ASTM Designation: C 185. The results were as follows:

Water Reduction - 7.0%

Air Content - No Lomar LS - 9.5%
0.3 g Lomar LS - 12.0%

If Lomar LS is used as an additive, the amount of air entraining agent should be reduced slightly. Additional tests were performed on the following formulation, designated as Formulation X.

79 g Lone Star (M) Type II Cement

21 g U.S.G. No. 1 Molding Plaster

50 g No. 4 Sandblast Sand

0.3 g Lomar LS

0.04 g Red Top Retarder

0.0067 g Vinsol NVS

30 ml water

The results are presented in Table 16. The compressive strengths of Formulation X at one and 14 days were significantly higher than obtained with other formulations.

Freeze-Thaw Tests on Rapid Setting Mortars

The results of freeze-thaw tests are presented in Table 3-A of the appendix.

Proprietary Formulations A and B and Formulations I and II evidenced no deterioration after a total of 300 cycles of freezing in air and thawing in tap water followed by an additional 300 cycles of freezing

Table 16

Properties of Rapid Setting Mortar Formulation X

Initial Set, Minutes - 15

Final Set, Minutes - 27

Compressive Strength, psi

2 Hours - 308

1 Day - 3800

14 Days - 6819

Percent Expansion in Water:	73.4 F	120 F
7 Days		0.043
14 Days		0.100
28 Days	0.092	0.137
8 Weeks	0.129	
16 Weeks	0.186	

Percent Shrinkage in Air

5 Days - 0.013

7 Days - 0.041

14 Days - 0.097

21 Days - 0.112

28 Days - 0.123

8 Weeks- 0.150

16 Weeks- 0.152

in air and thawing in 4% sodium chloride solution. In order to determine if thawing in salt solution immediately following curing would be more detrimental to the mortar, Formulation II was subjected to 300 cycles of freezing in air and thawing in 4% salt solution. The mortar performed equally well under these conditions. Proprietary Formulations C and D performed very porrly with respect to freeze-thaw resistance. These were both experimental materials and as mentioned earlier were of a different composition than the other proprietary and laboratory formulations discussed in this report.

Additional freeze-thaw tests were performed on Formulations II and IX using the exact procedure and equipment called for in ASTM Designation: C 291. The specimens used were 3" x 4" x 16." Neither formulation showed any significant deterioration after 300 cycles of freezing in air and thawing in tap water.

The freeze-thaw specimens for Proprietary Formulations A and B and Formulations I and II were stored dry after completion of the freeze-thaw tests. Approximately 2½ years after the specimens were cast, the relative dynamic modulus was determined on Specimen 3 from Run 1 for Formulation II and Specimen 2 for Formulation A. The results were as follows:

Formulation II, Specimen 3 - 90.9 percent

Proprietary Formulation A, Specimen 2 - 85.6 percent

Although the modulus had decreased, the decrease was mainly due to the weight change of the specimens as they lost absorbed water.

Petrographic analysis of segments cut from these specimens revealed considerable microcracking in both materials.

These tests indicate that rapid setting cement mortars of this type can be formulated to have very good resistance to freezing and thawing.

Abrasion Resistance of Rapid Setting Mortars

In conjunction with an evaluation of two proprietary rapid setting cements for District 2, the abrasion resistance of several formulations was determined. The results obtained are presented in Table 17.

Table 17

Abrasion Resistance of Rapid Setting Mortars

Material	Percent Weight Loss
Proprietary Formulation A	1.93
Proprietary Formulation E	3.01
Proprietary Formulation F	2.30
Formulation IX	2.08
Control Mix	0.82

Proprietary Formulations A and F and Formulation IX were of similar composition. Proprietary Formulation E had a considerably higher gypsum content. The control mix consisted of the following:

100 g Alamo Type III cement

50 g Capitol Aggregate No. 4 sandblast sand

32 ml water

All of the rapid setting mortars had less resistance to abrasion than the control mix. Abrasion resistance apparently decreases with increasing gypsum content, as evidenced by the high loss of Proprietary Formulation E. Field tests of rapid setting mortars confirmed that the wear or abrasion resistance of these materials is not as good as ordinary concrete.

Field Trials

Two dry mixes were prepared for field trials. The basic formulation was the same as Formulation II. Mix No. 1 contained no retarder whereas Mix No. 2 contained 0.05 gram retarder per 150 grams. Laboratory set times were as follows:

	Mix 1	Mix 2
Initial Set, Minutes	12	25
Final Set, Minutes	25	40

The field trials were conducted in Districts 12 and 18. The material was placed in District 12 on July 8, 1968, on Westbound IH-10 within the City of Houston. It was used to repair spalled pavement joints. The material was placed in District 18 on July 23, 1968, on a bridge deck on IH-35 within the City of Dallas. It was used to replace concrete which had delaminated at the top reinforcing steel. Both of these locations are in extremely high traffic areas. District 12 added pea gravel at the rate of 30 pounds per 50 pounds of dry mix to portions of both the No. 1 and No. 2

mixes that were placed in the larger patches. In September of 1968, District 12 placed about 27 tons of rapid setting mortar on IH-10. It was quite similar to the material placed experimentally except that it contained a Type I portland cement.

Examination of the District 12 patches in April of 1969 indicated that the smaller experimental patches were performing fairly well. The large patches, both with pea gravel and those without, were evidencing distress. The material containing pea gravel had checkerboard cracking on the surface and was beginning to break up. That containing no pea gravel had some cracking and spalling. Of the numerous patches placed in September of 1969 by District 12 personnel, about 20 percent evidenced distress of some type.

By March of 1970, almost all of the experimental patches placed in District 12 had failed or were evidencing distress.

The condition of the patches in District 18 nine months after placement was good. In July of 1969, the structure on which the patches had been placed was overlayed with rubberized asphaltic concrete. At that time the patches were still performing satisfactorily. The overlay prevented any further examination of the patches, although examination of the overlay does not indicate any major deterioration of the concrete beneath it is occurring.

Based on observation of work in the field with these materials, the following conclusions were reached regarding rapid setting mortars of the general composition presented in this report.

1) There is a tendency to use too much mixing water in the field which will adversely affect durability. Addition of a water reducer or dispersing agent results in workability with less water. This should help considerably although no data is available on field performance of mixes containing water reducers.

2) In order to allow sufficient time for mixing and placing, the mortar should have a usable working life of 8 to 10 minutes. This corresponds to an initial set of approximately 15 minutes in the laboratory. If a mortar sets more rapidly than this, there is the danger of its being overworked - i.e., handled while it is attempting to attain a set. This will adversely affect performance.

3) In view of the fact that areas patched with rapid setting mortars are released to traffic in two to three hours after placement, the mortar may not receive adequate curing. This is an important factor in durability. The patches should receive an application of curing membrane as soon as the surface attains a dry appearance (usually about 20 minutes after placement).

These materials, though quite useful in patching areas which must be released rapidly to traffic, cannot be considered permanent repair materials. Because of the fact that they contain a combination of portland cement and gypsum, there is a deterioration factor built into the mortar. A good mortar of this type, properly mixed and placed, could be expected to last three to five years

under traffic. Obviously the life of a patch will vary considerably depending upon conditions to which it is subjected.

Plans for Further Work

Very little work was done with aggregates for use in the patching mortar. Work needs to be done with different gradations and amounts of aggregate in the mix. It is believed that improved performance can be obtained with water reducers and the use of high strength plasters. Additional field tests are planned using formulations containing these materials in conjunction with sulfate resistant cement.

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[3]Manolesa, O., and Poenaru, G., "Sodium Fluosilicate as an Additive in Cement Mortars," Revue des Materiaux de Construction et de Travaux Publics, No. 576, pp. 276-289, 1963.

[4]Gonnerman, H. F.; Lerch, William; and Whiteside, Thomas M., "Investigations of the Hydration Expansion Characteristics of Portland Cements," PCA Bulletin 45, June 1953.

APPENDIX

Table 1-A

Summary of Length Change of Rapid Setting Cement Mortars, Air Storage

Figures shown are negative unless otherwise indicated

Time in Air	Average Percent Change							
	Form. I	Form. II, Run 1	Form. II, Run 2	Form. III	Form. IX	Prop. Form. A	Prop. Form. C	Prop. Form. D
4 Days	+0.094			+0.096		+0.037		
7 Days	+0.048		+0.027	+0.057	+0.004	0.005	+0.975	+0.098
14 Days	0.005		0.012	+0.012	0.040	0.056	+0.902	+0.059
28 Days	0.039	0.090	0.047	0.024	0.089	0.095	+0.851	+0.029
8 Weeks	0.059	0.112	0.081	0.055	0.118	0.121	+0.812	0.010
16 Weeks	0.074	0.157	0.105	0.086	0.129	0.139	+0.788	0.023
32 Weeks	0.128	0.165	0.169	0.091	0.129	0.200	+0.781	0.026
64 Weeks	0.138	0.224	0.191	0.147		0.212	+0.713	0.033
96 Weeks		0.246		0.165				
128 Weeks	0.199				0.275			

Table 2-A

Summary of Length Change of Rapid Setting Cement Mortars, Water Storage

Changes shown are positive

Time in Water	Average Percent Change							
	Form. I	Form. II, Run 1	Form. II, Run 2	Form. III	Form. IX	Prop. Form. A	Prop. Form. C	Prop. Form. D
8 Weeks	0.311	0.262	0.380	0.297	0.220	0.139	2.980	0.339
16 Weeks	0.521	1.505	0.495	0.519	0.308	0.218	**	0.433
32 Weeks	1.052	*	1.011	1.022	0.460	0.376		0.525
64 Weeks	1.089		*	*		0.659		0.611
96 Weeks	*					1.077		
128 Weeks						1.347		
160 Weeks						***		

*Expansion was so great that bars could not be measured with standard equipment. Bars were beginning to warp and show map cracking and disintegration on the surface.

**Expansion such that bars could not be measured with standard equipment. However, bars did not evidence any warping, cracking or disintegration.

***Expansion such that bars could not be measured with standard equipment. Bars were beginning to warp. Expansion was approximately 5%.

Table 3-A

Summary of Freeze-Thaw Tests on Rapid Setting Cement Mortars

After 300 cycles, thawing in tap water:

Property	Formulation I Specimens				Formulation II Specimens			
	1	2	3	4	1	2	3	4
Relative Dynamic Modulus of Elasticity, Percent	109.8	111.1	109.3	109.4	107.0	110.8	111.1	113.0
Weight Change, Percent	-1.3	-1.1	-1.1	-1.2	-1.4	-1.2	-1.2	-0.7
Length Change, Percent	+0.085	+0.086	+0.062	+0.096	+0.047	+0.053	+0.057	+0.072
Condition of Specimens	No visible deterioration other than very slight scaling and rounding of corners due to handling.							

After 300 cycles, thawing in tap water + 300 cycles, thawing in 4% salt solution.

Relative Dynamic Modulus of Elasticity, Percent	113.7	114.2	113.9	115.9	107.0	110.8	111.1	113.0
Weight Change, Percent	-1.0	-0.6	-0.8	-0.8	-1.2	-1.2	-1.2	-0.9
Length change, Percent	+0.156	+0.165	+0.142	+0.172	+0.096	+0.094	+0.100	+0.152
Condition of Specimens	Some enlarging of surface units - slight additional damage due to handling - otherwise no noticeable change in specimens.							

After 300 cycles, thawing in tap water.

Table 3-A (Continued)

Property	Proprietary Formulation A Specimens 1	2	Proprietary Formulation B Specimens 1	2	3	4
Relative Dynamic Modulus of Elasticity, Percent	109.6	108.8	110.8	113.2	112.7	113.0
Weight Change, Percent	-1.9	-1.9	-0.3	-0.1	-0.4	-0.1
Length Change, Percent	+0.040	+0.038	+0.088	+0.093	+0.092	+0.102
Condition of Specimens	No visible cracks - only minor surface scaling rounding at corners due to handling.					
After 300 cycles thawing in tap water + 300 cycles, thawing in 4% salt solution.						
Relative Dynamic Modulus of Elasticity, Percent	112.8	110.2				
Weight Change, Percent	-2.0	-2.0				
Length Change, Percent	+0.056	+0.055				
Condition of Specimens	No noticeable change in specimens other than slight additional damage to corners.					

Table 3-A (Continued)

After 21 cycles, thawing in tap water

Property	Proprietary Formulation C Specimens				Proprietary Formulation D Specimens			
	1	2	3	4	1	2	3	4
Relative Dynamic Modulus of Elasticity, Percent	81.3	77.2	94.5	32.2	83.7	93.9	93.3	92.3
Weight Change, Percent	+0.2	+0.2	0	0	0	+0.1	+0.1	+0.1
Length Change, Percent	+0.054	+0.057	+0.042	+0.044	-0.18	+0.065	+0.064	+0.020
Condition of Specimens	All Form. C specimens evidence severe transverse cracking. No. 1 has one crack almost completely through specimen.				Specimens 1 and 2 evidence considerable transverse cracking. 3 and 4 show slight cracking.			

After 30 cycles, thawing in tap water

Relative Dynamic Modulus of Elasticity, Percent	44.3	58.7	84.1		41.3	70.2	88.1	78.3
Weight Change, Percent	+0.5	+0.4	+0.1		+0.2	+0.2	+0.2	+0.3
Length Change, Percent	+0.100	+0.126	+0.067		+0.065	+0.124	+0.097	+0.168
Condition of Specimens	Specimen No. 4 was so severely cracked modulus could not be determined. Additional cracks had developed in other specimens.				Specimen No. 1 cracking severely. Cracking increasing on 2, 3 and 4.			

Table 3-A (Continued)

After 40 cycles, thawing in tap water

Property	Proprietary Formulation C Specimens 1	2	3	Proprietary Formulation D Specimens 1	3	4
Relative Dynamic Modulus of Elasticity, Percent	28.6	27.2	64.1	14.1	63.9	43.1
Weight Change, Percent	+0.7	+0.7	+0.3	+0.4	+0.3	+0.5
Length Change, Percent	+0.162	+0.195	+0.200	+0.198	+0.137	+0.189
Condition of Specimens	Transverse cracking very bad - test ended.			Specimen No. 2 broke after 35 cycles. Other specimens severely cracked. Test ended.		

A second run was made on Formulation II with all thawing done in 4% salt solution. The results after 300 cycles are presented below.

Porperty	Formulation II Specimens 1	2	4
Relative Dynamic Modulus of Elasticity, Percent	106.1	106.1	107.7
Weight Change, Percent	+0.4	+0.2	-0.2
Length Change, Percent	+0.148	+0.138	+0.107
Condition of Specimens	No visible cracking - slight scaling near the ends of the specimens. Rounding at corners due to handling.		

Table 3-A (Continued)

After 300 cycles, thawing in tap water - C 291 unmodified

Property	Formulation II Specimens			Formulation IX Specimens		
	1	2	3	1	2	3
Relative Dynamic Modulus of Elasticity, Percent	104.2	106.2	104.3	105.1	105.6	104.2
Weight Change, Percent	-0.3	-0.4	-0.4	-0.1	-0.1	-0.1
Condition of Specimens	No visible cracks - minor surface scaling, mainly on ends of specimens.					

Suggested Performance Specification for Rapid Setting Cement Mortar

1. Description

This specification covers a single package rapid setting patching material which requires only the addition of mixing water to form a mortar suitable for repairing spalled or deteriorated areas on concrete pavement or bridge decks. The mortar must be of such a nature that it can be mixed and placed in a manner similar to that used for conventional portland cement mortar. Fine aggregate included in the rapid setting material must all pass the No. 4 sieve (U. S. Standard Screen).

2. Packaging

The material shall be packaged in multi-wall moisture resistant paper bags.

3. Physical Requirements

For all of the following tests the amount of mixing water used with the dry mix shall be sufficient to obtain a flow of 80 to 95, determined as specified in ASTM Designation: C 109.

Set Times (ASTM Designation: C 266)

Initial - 15 Minutes Minimum

Final - 40 Minutes Maximum

Compressive Strength (ASTM Designation: C 109 Modified)

Cure Time	Minimum Strength, Psi
2 Hours	300
24 Hours	2500
14 Days	4500

Expansion in Water (ASTM Designation: C 157 Modified)

Percent Expansion, Maximum - 0.25

Curing time in water for the specimens shall be six days. They then shall be placed in water maintained at 120 $\pm$ 3 F for 21 days after which percent expansion shall be determined.

Freeze-Thaw Resistance (ASTM Designation: C 291)

The relative modulus of elasticity of the mortar shall be 60 percent minimum after 100 cycles of rapid freezing in air and thawing in water.