THE EFFECT OF ADMIXTURES ON THE THERMAL EXPANSION OF CONCRETE

THESIS FOR THE DEGREE OF B. S.

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The Effect of Admixtures on the
Thermal Expansion of
Concrete

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To the Civil Engineering Faculty
at Michigan State College, who have
ably assisted me in gaining my
education in Engineering, I do
hereby dedicate this thesis on
thermal expansion of concrete--J.C.L.

Preface

Acknowledgement is made to the Mr. Rothgery of the Civil Engineering department and to Mr. Finney of the Michigan Highway department for their advice and kind criticism offered in the developing of this problem

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Introduction

There is a keen interest in the engineering circles at the present time in the effect of powdered admixtures in Portland Cement concrete. Many types of inert admixtures have been used designedly or due to their presence in the aggregate. Admixtures have various effects on the properties of concrete some of which may be more or less benefical. An admixture should be considered only as one way to secure desired results and its use should be compared with other methods of obtaining similar results.

An increase in water content or in the proportion of paste, which commonly attends use of admixtures, may be expected to increase shrinkage. That a reduction in water-cement ratio reduces volume change, i.e., shrinkage both during hardening and setting is less.

The earliest work recorded concerning the linear thermic expansion of concrete is due to Bounicea, who published his results in the "Annales des Ponts et Chausses," in 1863. His work was performed on rectangular prisms 65 to 94 inches long and about 7 inches on each side, the blocks being placed in water whose temperature varied from 10 to 95 degrees C. The apparatus used was checked by measuring the determined coefficient of expansion for other materials. His result for concrete (proportion not given) was .00000795 inches / degree F.

Professor W. D. Pence of Purdue University has made a series of investigations with Portland Cement concretes. The values obtained with 1 cement to 5 gravel was . 0000053*/ degrees Fahrenheit. Other mixes are:

1-1½-3 = .00000677

1-2-4 = .0000066

1-2½-5 =.00000558

1-3-6 =.00000537

The resistance of concrete to frost is of much importance. Water expands about 9 percent in volume during freezing and when it is trapped in cavities the pressures that may be exerted are very large. In a wet concrete the water enclosed in the pores of the material tends on freezing to force the particles of Mortar apart or to set up severe internal stresses.

The resistance of concrete to freezing depends on the density and impermeability of the material, for if water can not penetrate into it no damage can be produced.

A neat Portland Cement on heating first expands owing to the normal thermal expansion. This expansion is opposed, however, by a contraction due to the shrinkage of the material as water is driven off from it. The contraction due to drying eventually becomes much larger than the normal thermal expansion and the material then commences to shrink. The actual temperature at which the maximum expansion is reached varies with the size of the specimen and the conditions of heating.

The foregoing considerations have led to an investigation of the subject. First a method of making such measurements was developed, then, experiments were made to determine the effect of admixtures on the coefficient of expansion.

Materials

The materials used consisted of Aetna Portland Cement, sand, coarse aggregates, water, and nine admixtures.

The fineness of grinding of Portland Cement was determined. This is in terms of the percentage of cement retained on a standard No. 200 sieve. A 50 gram sample of cement was placed on a NO. 20 sieve and then placed in a NO. 200 sieve. Hold the sieve in an inclined direction and move back and forth, tapping the sides of the sieve about 150 times a minute. Every twenty-five strokes rotate the sieve one sixth of a revolution. After several minutes of shaking, remove the cement. Brush the pan to make sure of getting all the particles. The percentage of residue on the sieve with a correction factor for the sieve applied, expresses the fineness of cement.

Data Sheet

Trial	I	II
Material	Portland	Cement
Date	11/ 16/ 40	11/ 16/ 40
Air Temperature	74^{o}	74^{o}
Method of Shaking	Hand	Hand
Weight of Sample	50	50
Weight Retained on 200 #	88.09	8.01
Weight Passing 200 #	41.91	41.96
Weight Lost	0.00	0.03
% Lost	0.00	0.06
% Retained	16.18	16.02
Fineness	16.18	16.02

Sample Calculations

Wt. lost = wt. passed + wt. retained – wt. of sample

= 41.91 + 8.09 - 50 = 0.00 grams

% lost = Wt. lost X 2 = 0.00 X 2 = 0.00

% Retained = Wt. retained X 2

= 8.09 X 2 = 16.18

Determination of Sieve Analysis of the Aggregates

Select a representative sample of the fine or coarse aggregate by quartering a larger sample. Dry the sample so as to have not less than 500 grams of fine or sand and about 3000 times the size of the largest sieve required for the coarse aggregate.

Than arrange the sieves in order and placing in sample of sand in the sieve. It was than placed in the shaker for fifteen minutes and the amount retained on each sieve was weight.

It was not possible to use the shaker on the coarse aggregate so they were shaken by hand and the retained amount was weight.

The percentage retained on each sieve for the sand and coarse aggregate was than calculated. From this data the fineness modulus for the sand and coarse aggregate was found.

Data Sheet

Materials	Sand
Date	11/ 9/40
Method of Shaking	Machine
Weight of Sample Used	510 grams

Sieve Number	Diameter Of Opening	Total Wt. Retained	Total per cent Retained	Total per cent passing
	1.5	0	0	100
	.742	0	0	100
	.371	0	0	100
4	.185	7	7.3	92.6
8	.093	105	20.6	79.4
14	.046	267	52.4	47.6
28	.0232	390	76.5	23.5
48	.0116	502	98.5	1.5
100	.005	508	99.4	0.6
Totals		510	354.7	
Fineness Modulus			3.547	

Data Sheet

Materials	Fine Aggregates
Date	11/ 9/ 40
Method of Shaking	Hand
Time of Shaking	
Weight of sample used	2990 grams

Sieve Number	Diameter of Opening	Total Wt. Retained	Total Percent Retained	Total percent passing
	1.5	0	0	100
	.742	425	14.2	85.8
	.371	2668	89.0	11.0
4	.185	2988	99.5	0.5
8		2990	100	0.0
14				
28				
48				
100				
Totals		2990	702.7	
Fineness Modulus			7.027	

Data Sheet

Materials	Coarse Aggregates
Date	11/9/ 40
Method of Shaking	Hand
Time of Shaking	
Weight of sample	4420

Sieve Number	Diameter of Opening	Total Wt. Retained	Total per-cent Retained	Total per-cent Passing
	1.5	2277	6.3	93.7
	.742	4312	97.5	2.5
	.371	4418	99.9	0.1
4	.185	4420	100	0.0
8	.093			
14	.046			
28	.0232			
48	.0116			
100	.005			
Totals		4420	803.7	
Fineness Modulus			8.037	

Data Sheet

Materials 50% Fine and 50% Coarse Aggregate

Method of Shaking Hand

Date 11/ 9/ 40

Time of Shaking

Weight of sample

Sieve Number	Diameter of Opening	Total Wt. Retained	Total per-cent Retained	Total per-cent Passing
	1.5	138	3.15	96.85
	.742	2448	55.85	44.15
	.371	4140	94.75	5.45
4		4280	100	2.25
8		4380		0.0
14				
28				
48				
100				
Totals		3705	753.2	
Fineness Modulus			7.532	

Note: The aggregate used in experimenting was made up of 50% fine and 50% coarse aggregate.

To determine the unit weight of the aggregate
for concrete.

For aggregate whose maximum diameter is $\frac{1}{2}$ inch or less, use the 1/10 cubic foot measure. For aggregate whose maximum diameter is over $1\frac{1}{2}$ inches in diameter use the 1 cubic foot measure. The sample of aggregate should be room dry and thoroughly mixed. Room-drying of aggregate should be done only until the surface moisture has disappeared, inasmuch as these values are used on that basis. Fill the measure one-third full of aggregate and level off with the fingers. Tamp the aggregate with the pointed end of the tamper 25 times. Fill two-thirds full, now, level off and tamp. Fill the measure full to overflowing and tamp, strike off the surplus with the tamping rod. Determine the net weight of aggregate in the container. From this you can determine the weight of the material per cubic foot.

Data Sheet

Material	Sand	Coarse (50-50)
Date	11/ 2/ 40	11/2/40
Size of container	1/10 cu ft.	1 cu ft.
Weight of Container	2.62 #	12.05 #
Weight of material and container	13.80 #	123.07 #
Weight of material	11.18 #	111.02 #
Weight per cubic foot	111.8 #	111.02 #

Sand: Weight/ cu. ft. = Wt. material X 10 = 11.18 X 10 = 111.8 #

Coarse: Weight/ cu. ft. = Wt. material X 1 = 111.02 X 1 = 111.02 #

Method of Proportioning

a) Estimate a mix that will give a given strength. Try a 1.5 mix (combine fine and coarse)

b) Figure 5-4 page 89 Plain Concrete -- Bauer. Maximum permissible fineness moduli is 5.75

c) Check in figure 5-3 Strength is low 2350 p.s.i try mix 1:4.7 Strength is 2550 p.s.i. which is all right.

P = percentage fine aggregate

A = fineness modulus of coarse

B = fineness modulus of combined

C = fineness modulus of sand.

Percentage of coarse aggregate is equal to 100 minus the percentage of fine aggregate

$$P = \frac{7.532 - 5.80}{7.532 - 3.547} \times 100 = \frac{1.732 \times 100}{3.985} = 43.7$$

percentage of coarse is 56.3%

d) Find weight per cubic foot of sand and aggregates.

Sand	=	111.8 #
Gravel	=	111.02#
Combination	=	121.6 #

Calculations of Weight

111.8 X 43.7 = 48.6 #
111.0 X 56.3 = 62.4 #

Total = 111.0

$$\text{Shrinkage factor} = \frac{111.0}{121.6} = 91.5$$

$$\frac{4.7}{91.5} = 5.15$$

New proportion 1:5.15

Cubic feet sand 5.15 X 43.7 = 2.25 cubic feet

Weight sand = 2.25 X 111.8 = 252# / cubic feet

Cubic feet coarse aggregate 5.15 X 56.3 = 2.80 cubic feet

Weight coarse aggregate 2.8 X 111.0 = 311 # / cu. ft.

		Absolute Vol.
Water one cubic foot cement	=	.49
2.25 cu. ft. sand $\frac{2.25 \times 111.8}{62.4 \times 2.65}$	=	1.52
2.80 cu ft. coarse aggregate $\frac{2.80 \times 111.0}{62.4 \times 2.65}$	=	1.88
Total		4.79

Weight materials per cylinder

Weight cement $= \frac{.25}{4.79} \times 94 = 4.9$ #

Weight water $= \frac{.25}{4.79} \times 62.4 = 3.26$ #

Weight sand $= \frac{.25}{4.79} \times 252 = 13.2$ #

Weight coarse aggregate $= \frac{.25}{4.79} \times 311 = 16.3$#

Proportions

Cement $= \frac{4.9}{4.9} = 1$

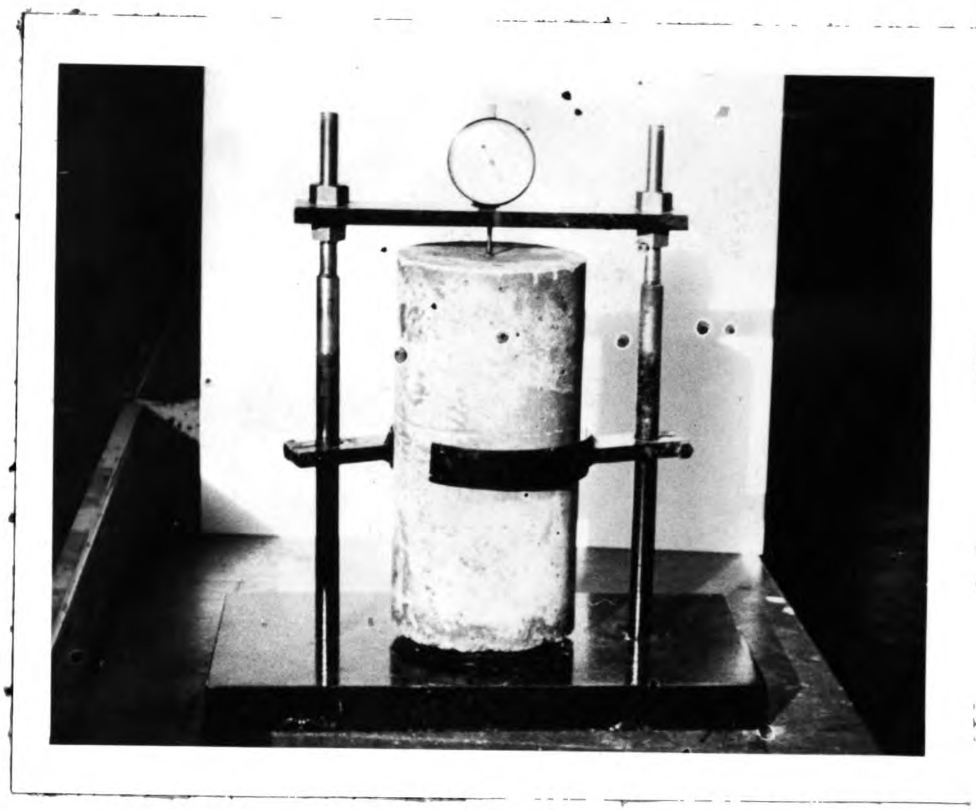
Sand $= \frac{13.2}{4.9} = 2.7$

Coarse Aggregate $= \frac{16.3}{4.9} = 3.33$

1 : 2.7 : 3.3

Apparatus

The apparatus or its shall be called a comparator was made for the experimenting. It consists of a resting point for the cylinders and a federal dial to measure the height of the cylinder at the start. The comparator is better explained by the accompaning picture.



Admixtures

The admixtures used in the experiment were the following: Silica dust, Lime stone dust, Bentonite, Plastiment, Fly Ash, Pozzolith, Orvus, Vinsol Resin, and Natural Cement.

Silica occurs in nature in all of the polymorphous forms. The form that is most used is quartz. This raw silica as brought from the quarry or mines requires to be crushed or ground. This ground material is made extremely fine and is called silica dust. Silica dust is used in the ratio of 15 #/ sack of cement. The amount of silica dust required for one cylinder is:

$$\frac{15}{94} = .16 \times 4.9 = .784 \#$$

Limestone occurs in nature in the form of rocks. These rocks brought from a mine are ground extremely fine. The dust from the grinding is used as limestone dust. Limestone dust is used in the ratio of 15 # / sack of cement. The amount of limestone dust required for one cylinder is:

$$\frac{15}{94} = .16 \times 4.9 = .784 \#$$

Bentonite, an extremely fine-grained clay formed by the weathering of wind blown Volcano ash, was originally observed in Fort Benton shales of the upper Missouri Valley. In outward appearance, bentonite resembles a grey mud, but the very colloidal types exhibit considerable swelling characteristics on additions of water. The ratio of bentonite is 5 #/ sack of cement. The amount required for one cylinder is $\frac{5}{94} = .0534$

$.0534 \times 4.9 = .262$ #

Plastiment is an extremely fine grained material and has a reddish-brown color. The ratio of Plastiment is 1# / sack of cement. The amount required for one cylinder is:

$\frac{1}{94} = .0107$

$.0107 \times 4.9 = .0524$ #

Fly Ash, an extremely fine material, made from pulverized coal ash was used in the ratio of 15 # / sack of cement. The amount required for one cylinder is:

$\frac{15}{94} = .16$

$.16 \times 4.9 = .784$ #

Puzzolith is a manufactured material which is produced by the Master Builders. It is an extremely fine grained material and is grey in color. The ratio used was 2# / sack of cement. The amount required for one cylinder is:

$\frac{2}{94} = .0203$

$.0203 \times 4.9 = .099$ #

Orvus is a type of soap which has an extremely great amount of carbon in its molecular formula. This soap will act the same in salt water as in plain water. The ratio used was .015 # / sakk of cement. The amount required for one cylinder is $\frac{.015}{94} = .00016$ #

$.00016 \times 4.9 = .00078$ #

The soap was mixed with water in the given amounts and 68 ml. was used.

Resin is either a natural or synthetic product. The resin used in this experiment was synthetic Vinsol resins. It is a light grey in color. The ratio used was full amount. The amount required to make one cylinder is 4.9 #.

Natural cement is of two types:
1) With out grinding aid and 2) with grinding aid. The trade name of the natural cement used was a Luxment and it is made without grinding aid. The ratio used was 1 sack to 6 sacks of cement. The amount required to make one cylinder is: $\frac{4.9}{6} = .827$ #.

Experimental Procedure

The mixing of the materials was done by hand. After the sand, cement, coarse aggregate and water were carefully measured; the cement and sand were mixed first dry. Then the coarse aggregate was spread over the cement-sand mixture and remixed again. A crater was formed in the center, into which the water was poured. When the water was absorbed, the mixing was proceeded until the concrete is homogeneous in color. Upon completion of the mixing, cylinders (6" x 12") were filled in three increments, rodding at each increment 25 times with a round rod and bullet-pointed at the lower end. Distribute the strokes in uniform manner over the cross section of the mold. Care is taken to place sufficient strokes in order to prevent honeycombing. After the top layer has been rodded, the excess is struck off. Steel plugs ¼" in diameter and about 1" long were inserted in the ends of the cylinders before placed in the moist room for curing. The samples were left in the molds for not longer than twelve hours.

The conditions for curing the cylinders were the same in all cases. There was a relative humidity of 100% and the temperature of the moist room varied from 68° to 69° F. They were left in the moist room for seven days before an inital reading was taken. The test cylinder was then placed in the electric oven, for twenty-four hours, at a temperature of 110° C and again measured. They were then taken to a refrigerator for twenty-four hours at a temperature of

– 10° F before another reading was taken. The cylinders were then allowed to stand at room temperature for 24 hours before a compression test was made upon them.

Experimental Data

Name of Admixture	Used	Inital Reading	Hot	Cold	Change
None (plain)	1	50/1000	61.5/1000	43.8/1000	17.6/1000
	2	51/1000	62.4/1000	44.9/1000	17.5/1000
Silica Dust	1	60/ 1000	71.5/1000	53.9/1000	17.6/1000
	2	63/1000	74.5/1000	56.9/1000	17.6/1000
Limestone Dust	1	59/1000	70.6/1000	52.8/1000	17.8/1000
	2	57/1000	68.6/1000	50.9/1000	17.7/1000
Bentonite	1	40/1000	52.5/1000	33.4/1000	19.1/1000
	2	43/1000	55.5/1000	36.3/1000	19.2/1000
Plastiment	1	48/1000	59.6/1000	41.8/1000	17.8/1000
	2	47/1000	58.6/1000	40.9/1000	17.7/1000
Fly Ash	1	52/1000	63.8/1000	45.8/1000	18.0/1000
	2	50/1000	61.5/1000	43.8/1000	17.8/1000
Pozzolith	1	43/1000	54.2/1000	37/1000	17.2/1000
	2	45/1000	56/1000	39.1/1000	16.9/1000
Orvus	1	69/1000	80.4/1000	62.9/1000	17.5/1000
	2	68/1000	79.4/1000	62/1000	17.4/1000
Resin	1	50/1000	61.2/1000	44.1/1000	17.1/1000
	2	50/1000	61.2/1000	44/1000	17.2/1000
Luxment	12	55/1000	67/1000	48.6/1000	18.4/1000
	2	52/1000	63.9/1000	45.7/1000	18.2/1000

Name of Admixture Used		Compression Strength	Coefficient of Expansion
None	1	2600 p.s.i.	.00000610
	2	2605 p.s.i.	.00000603
Silica Dust	1	2595 p.s.i.	.00000611
	2	2600 p.s.i.	.00000611
Limestone	1	2585 p.s.i.	.00000618
	2	2580 p.s.i.	.00000615
Bentonite	1	2520 p.s.i.	.00000664
	2	2510 p.s.i.	.00000666
Plastiment	1	2580 p.s.i.	.00000618
	2	2585 p.s.i.	.00000615
Fly Ash	1	2570 p.s.i.	.00000626
	2	2580 p.s.i.	.00000618
Pozzolith	1	2710 p.s.i.	.00000596
	2	2705 p.s.i.	.00000591
Orvus	1	2630 p.s.i.	.00000607
	2	2625 p.s.i.	.00000605
Resin	1	2715 p.s.i.	.00000594
	2	2710 p.s.i.	.00000597
Luxment	1	2540 p.s.i.	.00000638
	2	2550 p.s.i.	.00000632
	1		

Calculation

$K = \frac{e}{l \times t}$

K = coefficient

e = elongation

l = length

t = temperature change

110° C to -10° F

110° C = 230° F

(110° X 1.8) + 32 = 230

230° to - 10° F

1) $.0000061 = \frac{e}{12 \times 240}$ $e = .0176$ "

$$K = \frac{17.6}{1000 \times 12 \times 240} = \frac{17.6}{2880000} =$$

.0000061 inches/ degree F

Conclusion

The applicability of these conclusion is limited to concretes under conditions similar to those of this investigation with regard to type and proportions of materials, fineness of cement, and the curing conditions.

For each admixture two individual molds were made up of the same mix and under the same curing and testing conditions. The slight variations in the two cylinders is probably due to the loss of heat or coldness in testing. In general concrete mortar is subject to expansion, and there are a number of admixtures on the market today which supposedly reduce this expansion. But from the experimental data none of the admixtures used gave any great effect in the coefficient of expansion. The admixture that gave the greatest expansion was Bentonite, while Pozzolith and Vinso/ Resin gave the least expansion. The experimental data also shows that with a low coefficient of expansion there is a high compression strength produced. From this it can be said that the expansion causes tension in the mortar rather than compression so that the bond is weakened.

Of the nine admixtures used only a few of these reduced the coefficient of expansion , and even then, they do not completely eliminate the expansion.

Bibliography

1. Cement and Concrete --------L.C. Sabin

2. Practical Cement Testing 6------W.P. Taylor

3. Cement- Mortor- Concrete --------M.S.Falk

4. The Chemistry of Cement and Concrete ---F.M. Lea

5. Portland Cement Association Information ---
Sheet No. St 24

6. Structural Material Research Laboratory ---- D. A. Abrams

7. Concrete Its Manufacture and Use ------ Koehring

8. Plain Concrete ---------------------- E.E. Bauer

9. Master Builders Booklet less Water yet More
placeability

10. The properties of Silica --------------- R. B. Spsman

11. Properties of Mortars and Concretes Containing
Portland Pozzolan Cements --- R.E.Davis,
J.W. Kelly, G.E.Troxell, and H.E. Davis

12. Journal of American Concrete Institute
Volume 8 May- June 1937

13. Journal of American Concrete Institute
Volume 9 July- August 1937