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PROPORTIONING NORMAL WEIGHT AND LIGHTWEIGHT STRUCTURAL CONCRETE MIXTURES USING SHRINKAGE COMPENSATING EXPANSIVE CEMENTS

By
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Synopsis: Presents basic principles of proportioning shrinkage compensating concrete mixtures using currently available expansive cements and relates them to proportioning mixtures using Type I cement. Properties which are common to all expansive cements and their differences are discussed. Conditions under which slump loss may occur when using some expansive cements are reviewed and methods for adjusting mixing water to compensate are given. Recommendations for the use of admixtures are made and the importance of proper curing and adequate internal restraint are discussed briefly.

Keywords: admixtures; cement content; compressive strength; concretes; curing; expansive cement, type K; expansive cement, type M; expansive cement type S; expansive cements; hydration; mix proportioning; portland cement, type I; shrinkage compensating cements; slump tests; temperature.

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INTRODUCTION

In considering the selection of proportions for structural concrete mixtures using shrinkage compensating expansive cements it is desirable to first establish two pertinent definitions in order to make clear the type of concrete with which we are dealing.

> Expansive cement - a cement which, when mixed with water, forms a paste that during the early hardening period increases significantly in volume. This cement also contains calcium silicate, alumina and iron compounds such as those characteristic of the standard types of portland cement.

> Shrinkage compensating concrete - a concrete made with expansive cement in which expansion, if properly restrained, will induce compressive stresses that approximately offset tensile stresses in the concrete induced by drying shrinkage.

It should be emphasized that the principal purpose for using this concrete is to eliminate or greatly minimize drying shrinkage cracks. Cracks formed by action other than drying shrinkage are not effected.

Three types of shrinkage compensating expansive cements are presently available in the United States. They are Type K, also known as ChemComp, Type M and Type S. Their compositions and methods of production are somewhat different but they have a number of common properties which should be recognized in proportioning structural concrete mixtures. The most important are:

1. Each of these cements will produce structural concrete having approximately the same compressive strength as an average Type I cement concrete when used pound for pound in a mixture using the same aggregates and having the same slump or consistency.

2. When used in a concrete mixture pound for pound, each will result in the development of expansion within the same range of values.

3. In order to eliminate or minimize drying shrinkage cracks, the expansive force in these concretes must have adequate restraint which is usually accomplished by reinforcement.

4. Complete development of the potential expansion for each type, K, M and S, requires adequate curing and there is a relationship between mixing water requirements and proper curing which differs somewhat for each type. In designing concrete mixtures this should be taken into account and will be discussed in the sections on Mixing Water and The Trial Batch.

5. Each of the three available expansive cements contain only about 10% of the compounds which develop expansion during hydration. Approximately 90% are the familiar compounds which are characteristic of all types of standard portland cement. It follows that the basic principles and methods for proportioning structural concrete mixtures using these cements are the same as those generally used for proportioning mixtures using Type I and Type II portland cements. The only exception is in handling the mixing water due to the characteristics of the particular cement used.

AGGREGATE PROPORTIONING

We have established that the same methods used for designing structural concrete mixtures using Type I and Type II portland cements are equally satisfactory for expansive cement concretes.

Therefore, sections 5.2.6, 5.2.7 and 5.2.8 in ACI 211.1-70 are recommended for selecting aggregate proportions for normal weight or heavy weight concretes. When the aggregates to be used are from a known source and satisfactory proportions of fine and coarse have previously been established, they may be used.

For lightweight concrete, the aggregate producer can usually provide reliable information on proportions of fine and coarse aggregates and the total uncombined volumes (dry-loose basis) required to produce 1 cu.yd. of concrete. When information from this source is not available, section 3.2 of ACI 211.2-69 is a recommended guide.

The PCA "Design and Control of Concrete Mixtures, 11th Edition" is also an excellent reference and guide for both normal and lightweight concrete aggregate proportioning.

CEMENT CONTENT

The same as for Type I and Type II portland cements, the selection of an appropriate expansive cement content to meet specified concrete strength requirements should be based upon tests made on concrete mixtures

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containing the materials which will be used in the construction. The required strength may then be interpolated from a cement content vs. compressive strength curve. If data on past performance of the expansive cement to be used is not available, the following table may be used as a guide for setting up the test program. (Refer to section 4.2 of ACI 318-71.)

Guide for the Relationship Between Water-Cement Ratio and Compressive Strength of Shrinkage Compensating Concrete using Expansive Cements

Compressive Strength at 28 Days,psi	Water-Cement Ratio by Weight: Non-Air Entrained Concrete	Water-Cement Ratio by Weight: Air-Entrained Concrete
6000	0.42 - 0.45	---
5000	0.51 - 0.53	0.42 - 0.44
4000	0.60 - 0.63	0.50 - 0.53
3000	0.71 - 0.75	0.62 - 0.65

Most producers of expansive cement recommend a minimum cement factor in the range of 510 lbs. per cu.yd. with approximately 0.15% reinforcement in order to assure adequate restrained expansion. Expansion increases as the cement factor is increased and, under normal conditions of reinforced concrete design, additional reinforcement is recommended to provide a corresponding greater internal restraint. This should be kept in mind when determining the water-cement ratio.

ADMIXTURES

When the durability of exposed concrete must be considered, it has been found that air entraining admixtures which comply with ASTM C 260 may be used for the same purpose and with the same beneficial effects with shrinkage compensating concretes as with Type I or Type II cement concretes. Generally, the same amount of a given admixture will produce the same percentage of air in both types of concrete, all other conditions being the same.

Water reducing and water reducing-retarding admixtures of all types which comply with ASTM C 494 have been used in shrinkage compensating cement concrete. It has been found that some of these admixtures are not compatible with certain shrinkage compensating cements. If definite knowledge of a satisfactory performance record is not available, it is urged that such admixtures be tested before acceptance using the shrinkage compensating cement and other materials selected for the job. Special attention should be given to their effect on slump loss and restrained expansion since it has been found that the use of certain Type A and Type D admixtures with some expansive cements have resulted in excessive slump loss and/or a substantial loss of expansion. Generally, admixtures which are acceptable may be used in the normal dosage recommended for Type I cement concrete under moderate temperature conditions. During extreme hot weather (concrete temperatures of 85 F and higher) accompanied by conditions which contribute to high water loss from evaporation, larger than normal dosages of acceptable water reducing-retarding types have been successfully used to delay initial setting time.

Calcium chloride to accelerate setting time in cold weather should be used with caution due to its effect on expansion and/or subsequent drying shrinkage. It should be used only under extreme conditions and then limited to a maximum of 1% by weight of cement. It is recommended that the effect of calcium chloride be reviewed with the producer of the expansive cement being used before it is incorporated in the mixture. If used, calcium chloride should be added in solution in accordance with accepted good practice for Types I and II cement concretes.

MIXING WATER

It has been found that additional water is required to satisfy the chemical reactions which result in formation of the expansive compound ettringite and this creates a demand for more water to achieve complete hydration of expansive cements than is required for the hydration of Type I or II portland cements. The formation of ettringite begins soon after mixing water is added for all expansive cements. However, the rate of hydration varies for each of the three types and this must be considered in dealing with mixing water requirements, particularly for ready mix concrete.

Total time from batch plant to placement including delivery and possible unloading delays on the job may require from 30 minutes to 1 hour or even 1.5 hours. In some Type K and S cements, ettringite commences to form during this period resulting in a significant loss in slump. In this case additional initial mixing water should be added at the batch plant to assure that the specified or desired slump is obtained when concrete is placed at the job. This generally increases the water-cement ratio about 0.05 to 0.10 over a similar mixture using Type I or Type II cement. This slump loss is usually somewhat greater for Type K than for Type S but with both cements, this factor should be taken into account when developing the mix design.

During hot weather (concrete temperature above 85 F), when all hydration reactions are accelerated, a determination of the proper initial water demand is even more important and cannot be over-emphasized. Methods for accomplishing this are suggested in The Trial Batch section which follows.

Type M cement concrete does not have the slump loss associated with Types K and S while in the plastic stage due to a slower rate of ettringite formation. Concrete mixtures using Type M should be designed in the same manner as Type I or Type II cements without increasing the water-cement ratio.

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It should be remembered that additional initial mixing water, when required to offset slump loss, combines chemically with compounds in the expansive cement to form ettringite and has little or no effect on concrete properties because the free "water of convenience" is not increased. Job tests have shown that shrinkage compensating concrete develops compressive strength and other engineering properties which are comparable to Type I cement concrete at the same cement content and using the same aggregates when placed at the same slump although the slump may have been greater when it left the batching plant. Slump recommendations for placing shrinkage compensating concretes are 4" to 6" for normal weight and 3" to 4" for lightweight. Under hot weather conditions and where slump loss may be involved, greater expansion and better finishing properties may be expected if concrete is placed at the high end of each range.

THE TRIAL BATCH

The importance of determining initial mixing water requirements for shrinkage compensating concrete has been discussed in general terms in the Mixing Water section. We have learned this very important factor varies for some expansive cements depending on expected job conditions. Therefore it is appropriate to review mixing water requirements with specific recommendations for each cement.

When concrete temperatures will not exceed approximately 75 F and total time from mixing to final placement does not exceed 30 to 45 minutes, the total mixing water requirements for all three types, K, M and S will be comparable to Type I for the same placement slump. Examples are dry batching to a paver with machine screeding and finishing; dry batch ready mix truck delivery with job site mixing; or short travel time to the job with immediate truck mixer unloading.

When concrete temperatures are above 75 F or when total elapsed time from mixing to unloading is from 45 minutes to 1.5 hours or there is a combination of these conditions, special test methods are recommended for Types K and S expansive cements to determine the proper initial mixing water in the trial batch in order to obtain the specified placement slump. Both of the following trial batch procedures have been used with success:

First Method

Step 1. Follow accepted methods as for Type I portland cement concrete except add 10% additional water for Type K or 5% for Type S.

Step 2. The initial mixing should follow 5.1.2 of ASTM C 192.

Step 3. Immediately at end of the 2 minute mixing period following 3 minute rest, determine slump and record as initial slump.

Step 4. As quickly as possible, return concrete used for slump test to mixer and continue mixing for 15 minutes.

Step 5. Determine slump and record as placement slump. If this slump does not meet specification requirements, repeat batch with appropriate mixing water adjustment.

Step 6. Mold strength and restrained expansion specimens. Determine yield and the air content if required.

Second Method

Step 1. Follow ASTM C 192 methods using mixing water required to develop the specified placement slump.

Step 2. Confirm slump after mixing in accordance with 5.1.2 of ASTM C 192.

Step 3. Without further mixing, cover batch with wet burlap for 20 minutes.

Step 4. Remix for 2 minutes adding water to produce the specified placement slump. Add initial water to remix water to determine the initial mixing water required at batch plant to provide the specified placement slump after 30 to 45 minutes total delivery time.

Step 5. Mold strength and restrained expansion specimens. Determine yield and air content if required.

If trial batch data are lacking, these approximations have provided satisfactory results when Type K or Type S are used:

1. Use an acceptable ASTM C 494 water reducing admixture and maintain the same amount of mixing water as for a similar Type I cement mixture without the admixture.

2. Add 10% for Type K or 5% for Type S to the mixing water required for similar mix if Type I cement was used.

When Type M expansive cement is used, the total mixing water required for shrinkage compensating concrete is comparable to a similar mixture using Type I cement including delivery and placement under hot weather conditions. When the requirements of ASTM C 94 are followed, the slump loss from batch plant to placement at the job, if any, is approximately the same as Type I cement concrete under the same conditions.

Compressive strength specimens may be made with single-use molds in accordance with Section 2.2.2 of ASTM C 192. Steel cylinder molds provide early restraint which usually increase strength values from 5% to 10% over single-use molds. However, the normal factor of safety in concrete mixture design generally compensates for this strength loss.

Special 3"x3"x10" prism molds which restrain the concrete are used to cast specimens for determining restrained expansion. Producers of expansive cement can furnish information on prism mold construction and complete details of the test method.

GENERAL NOTES

While the selection of proportions for shrinkage compensating concrete mixtures using expansive cements is not specifically concerned with reinforcement, job placement or curing, I would like to add these precautionary notes:

In order for this type of concrete to provide satisfactory performance, it is desirable that reinforcement for developing restraint in floors or slabs-on-grade be placed in the upper half approximately one-third of its' thickness from the top surface. To be certain of adequate restraint, the percentage of such reinforcement should not be less than 0.15%.

I wish to stress the importance of following the hot and cold weather concrete temperature and protection recommendations in ACI 304 on Measuring, Mixing and Placing Concrete, Chapter 18; ACI 305 on Hot Weather Concreting; ACI 306 on Cold Weather Concreting and Section 804 in ACI 301, Standard Specifications for Structural Concrete for Buildings. Shrinkage compensating concrete should be placed at temperatures between 50 F and 90 F, the same as recommended for all types of portland cement concrete in these excellent publications.

As has been pointed out, the hydration and expansion of concrete containing compounds which form ettringite requires additional mixing water when compared to similar Type I portland cement concrete regardless of the rate at which ettringite forms. When the rate of ettringite formation is such that it is not necessary to add additional water to compensate for slump loss, it is highly desirable to provide the additional water requirement during the first 3 to 7 days after placement by wet curing. If slump loss during delivery makes it desirable to add additional water when the concrete is first mixed, the application of a curing compound complying with ASTM C 309 or curing by covering the concrete with polyethylene sheets or similar covering is generally adequate although wet curing is preferred.

This calls attention again to the importance of using the placement slump rather than initial slump at the batch plant as the proper criterion for determining concrete consistency. It should also be noted that a total time limit of 1 hour from batching to placement will provide better utilization of the expansive potential in shrinkage compensating concretes using all types of expansive cement.

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FACTORS INFLUENCING PROPORTIONING OF AIR-ENTRAINED CONCRETE

By
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Synopsis: A discussion of the effect of purposefully entrained air on the properties of concrete. Factors which affect the entrainment of air in concrete such as cement, sand, and mix temperature are discussed. Strength reductions to be expected and suggested air contents as related to maximum size aggregate are shown.

Keywords: admixtures; aggregate size; aggregates; air entrained concretes; air entrainment; cement content; compressive strength; mix proportioning; pozzolans; temperature.