REVOLUTION IN SHRINKAGE COMPENSATION

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When the ACI Committee 223 Shrinkage-Compensating Concrete, issued its revised document, ACI 223R-10, "Guide for the Use of Shrinkage-Compensating Concrete" in Dec. 2010 it started a revolution in the Shrinkage-Compensating concrete industry that is growing and spreading into all uses of concrete. Two new concepts were introduced in this issue that have completely and totally changed how shrinkage-compensating concrete is manufactured and placed. These two. REVOLUTIONARY concepts are: REVOLUTION number one TYPE G Shrinkage-Compensating concrete, and REVOLUTION number two, COMPONENTS. In addition, many of the drawbacks (high cost, special handling, special construction techniques) previously associated with shrinkage-compensating concrete have been eliminated or greatly reduced (Revolution number. three?) by the introduction of these two revolutionary concept developments, Type G and Components.

Revolution Number One-Type G Shrinkage-Compensating Concrete. The revolution started in August 2002[1] with the publication in Concrete International of test results of shrinkage compensating concrete made with a component. The article was analyzed by ACI Committee 223, Shrinkage-Compensating Concrete, and the tested component was judged to be an "or equal" to Shrinkage -Compensating concrete made with Type K cement. The then current document ACI 223-98 Standard Practice for the Use of Shrinkage-Compensating Concrete, and all previous 223 documents, were based on ettringite systems, particularly Type K cement. ACI 223 decided that the component tested and reported on should therefore be incorporated into the next issue of the 223 document. It was during this process that the newly recognized calcium hydroxide expansion mechanism of the component was designated as Type G.

Revolution Number Two Shrinkage-Compensating Component. A component, that when added to a standard concrete mix produces a shrinkage-compensating concrete, has been available, and in use, for approximately four decades. But the product has never been able to establish wide acceptance since it was not included in, nor in compliance with, ACI 223 and
therefore lacked the credibility and weight of ACI recognition, acceptance, and documentation. Lacking these credentials the component could not be specified with an ACI cited reference thus eliminating its use on many projects.

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[1]Russell, H., G., Stadler, R. A., Gelhardt III H., G., "Shrinkage-Compensating Concrete Made with an Expansive Component", Concrete International, August 2002, American Concrete Institute, Farmington Hills, MI

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Type G

As a result of the issuance of ACI 223R-10, Type G components are now recognized and supported by ACI 223 and have the full credibility and weight of ACI recognition, acceptance, and documentation. In practice, components have replaced cements as the preferred method to produce shrinkage-compensating concrete.

Type G concretes produce their expansion via the production of calcium hydroxide platelets in the concrete. Type G concrete start to produce their expansion mechanism the moment water is added and mixing is started. Type G concrete produces its calcium hydroxide platelets at approximately the same rate, and at the same time, that the concrete is curing and hardening. Type G reaches about 90% of its full expansion in 24 hours and maximum expansion is reached within 48 hours, during the same time period that the concrete is experiencing its greatest strength and hardness gains.

fig. 5.2 (calcium hydroxide based systems), in 223R-10. The finished products produced by either the Type G are equal to each other in every measure of quality, and both are of a higher quality than conventional Portland Cement concrete of equal strength.

Components

What is a component, and how is it used, are components admixtures? All excellent questions that can be addressed very easily. Components are natural mineral based, dry, cementitious materials, that are added to a standard concrete mix by weight. Components are materials that are inherent in the base cement and are modified, enhanced, supplemented and added to the concrete mix to enhance and exacerbate beneficial characteristics and properties of native components in the base cement. Admixtures on the other hand are manufactured liquid chemicals that are added to a standard concrete mix by ounces. The core purpose of shrinkage compensating components is to create an expansion mechanism in the concrete mix. As long as the expansion induced in the concrete mix during early stage curing is equal to, or slightly greater than, the anticipated shrinkage of the concrete mix in subsequent curing, the concrete will never go into tension and shrinkage cracking will not, cannot, develop. Since this is the essence of Shrinkage-Compensating concrete and the key to its success, it is worth repeating .....as long as the expansion induced in the concrete mix during early stage curing is equal to, or slightly greater than, the anticipated shrinkage of the concrete mix in subsequent curing, the concrete will never go into tension and shrinkage cracking will not, cannot, develop.

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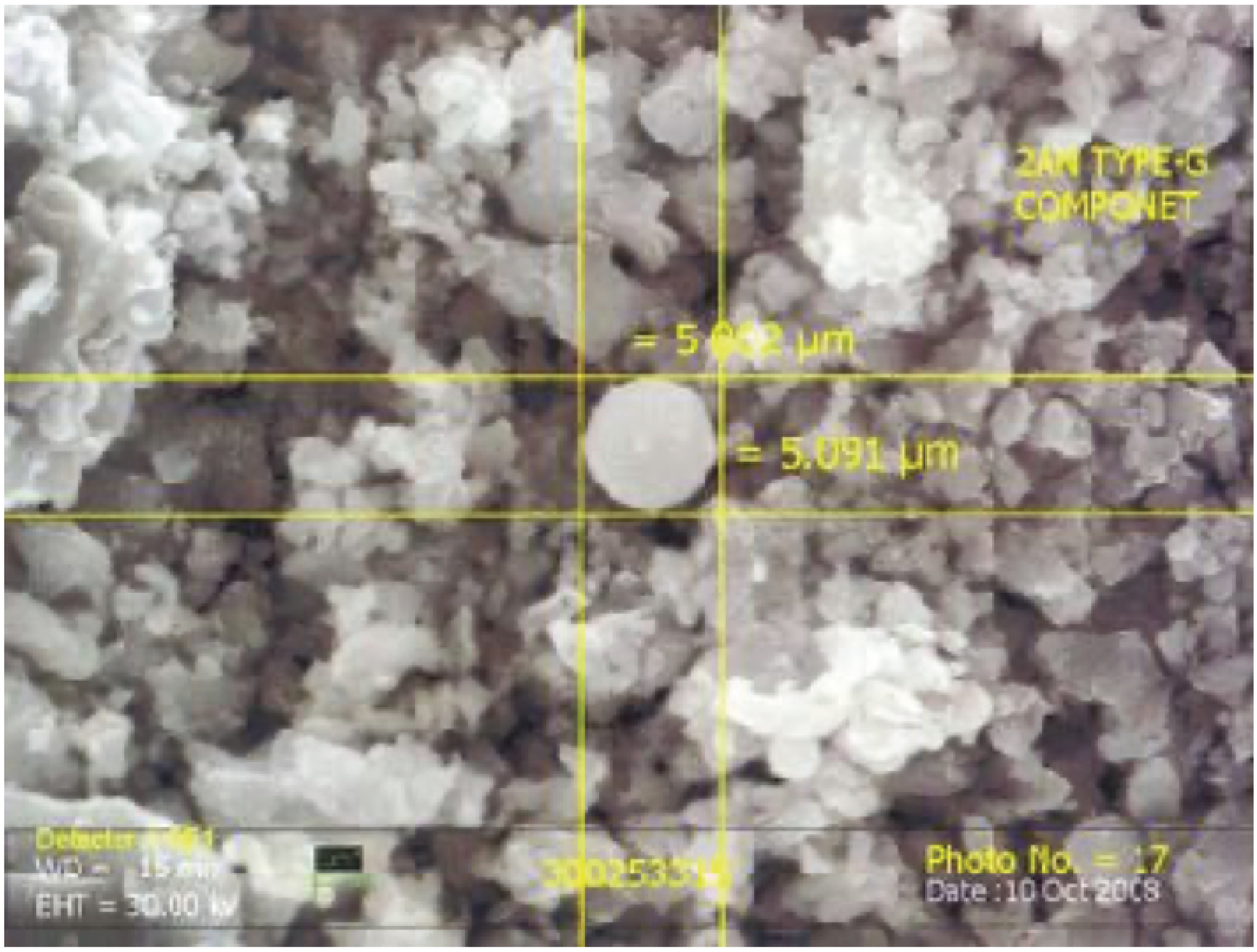

Fig. 1

Fig. 1 is a highly magnified electron microscope picture showing calcium hydroxide platelets, the whitish areas, in Type G concrete. The sphere in the boxed in yellow lines is a micro silica particle and provides a size comparison. Growth of the calcium hydroxide platelets will cause expansion of the curing Type G concrete. Proper restraint must be provided in order to curb the physical expansion and transform the expansion forces into a compressive stress in the concrete. Shortly after reaching maximum growth both the Type G expansion mechanisms start to relax and dissipate during the drying shrinkage phase of the concrete. The compressive stress in the concrete dissipates as the concrete goes through its shrinkage stage until it reaches a neutral state at approximately the as cast volume.

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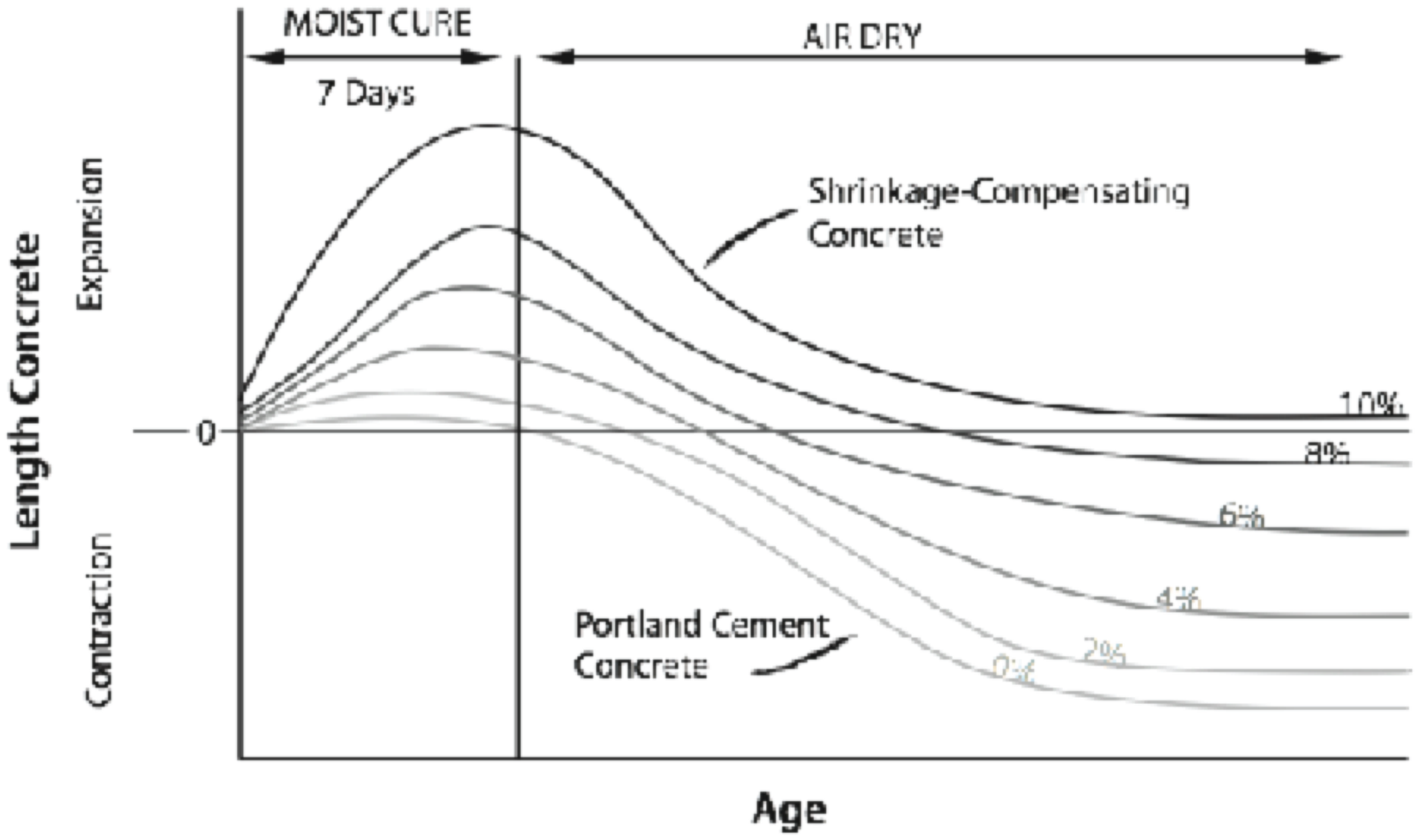

Fig. 2

Fig 2 is a reproduction of ACI 223R-10 fig 4.1. These conceptual curves were obtained from the standard test, ASTM C 878 Test Method for Restrained Expansion of Shrinkage-Compensating Concrete, for determining the amount of expansion (vertical axis), and the rate of expansion and contraction (horizontal axis), for a given trial concrete mix.

The bottom curve represents a conventional Portland Cement concrete. Note that there is a slight expansion during the initial setting of the concrete. Then at about the 2nd through the 4day conventional concrete goes into its shrinkage phase. When the curve crosses the horizontal axis, which represents the as placed volume of the concrete, the concrete goes into tension and shrinkage cracking forces start to develop. As the tension stresses continue to develop they reach a point where they exceed the tensile strength of the curing concrete and shrinkage cracks develop.

The upper curve represents Shrinkage-Compensating concrete. Note that the expansion mechanism is active for at least seven days after placement as the concrete hardens and gains strength. Shrinkage-compensating concrete then goes into its shrinkage phase and the concrete volume returns to approximately it's as placed volume at about 28 days. Since the shrinkage curve does not go below the horizontal axis tension forces in the concrete do not develop and shrinkage cracking is thereby prevented. This is the basis for developing a concrete mix design with expansion that meets, or exceeds, the anticipated concrete shrinkage which can vary from location to location depending on the concrete mix design, the aggregates used, and the practices of the concrete supplier. Target maximum expansion is typically one half of one percent, or less. Expected normal shrinkage percentages can be obtained from the concrete supplier or by project specific tests.

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We have been using the term "expansion" as the key descriptor of shrinkage-compensating concrete, and shrinkage-compensating concrete is also known as "expansive" concrete. These terms are true and accurate, but, **and the following explanation is key,** these theoretical terms do not accurately reflect what is happening in properly designed and constructed Shrinkage Compensating concrete. All concrete shrinks as it cures. When conventional concrete shrinks, it goes into tension and shrinkage cracks develop. Concrete, particularly fresh concrete, is not very strong tension. When the shrinkage forces exceed the tension strength of the curing concrete shrinkage cracking occurs. Shrinkage-Compensating concrete expands during early stage curing When shrinkage-compensating concrete goes into its shrinkage phase it "shrinks" by counter acting, or neutralizing, its expansion forces.

Restrained Expansion

In order to eliminate shrinkage cracking this theoretical expansion must be developed as RESTRAINED EXPANSION. If we add a shrinkage-compensating component to an Unrestrained concrete test specimen or a construction member, we will experience greater expansion during the initial stages of curing. As the concrete hardens it will grow and be larger than the as cast volume. More expansion than you would get with conventional concrete. Subsequently, after the concrete hardens and goes into its shrinkage phase there will be more, much more, shrinkage cracking.

If we provide restraint for the expansion, defined as **RESTRAINED EXPANSION**, the concrete specimen will approximately maintain its as placed volume. The restraint limits or prevents physical expansion and transforms the expansion stresses in the concrete into a compressive stress in the concrete. The key to eliminating shrinkage cracking is developing a compressive stress resulting from the restrained expansion. The best and most complete restraint is provided by steel reinforcing, most commonly, reinforcing bars, but other means of restraint are available. Restraint is the secret that makes shrinkage-compensating concrete work. Restraint is the secret that eliminates shrinkage cracking. Following is a step by step descriptions of how components make shrinkage-compensating concrete work:

- When the shrinkage-compensating component is added to a standard concrete mix and mixing is initiated two chemical processes begin that change this mixture of components into the final product-concrete. The cement begins its hydration process and the component begins its hydration resulting in an expansion process.

- During this initial stage, when the concrete is in its most plastic stage, there is a small amount of unrestrained expansion that is generated resulting in a slight expansion, or slip, of the plastic concrete. This is true for both Type G and Type K concretes.

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- As the concrete continues its curing process it is setting and hardening. Also, as the concrete is curing and hardening it is bonding to the reinforcing steel, or other restraining mechanism.

- As the curing continues the bonding of the concrete to the reinforcing becomes stronger. At the same time the expansion mechanism is also developing and becoming stronger in the concrete. Since the expanding concrete is bonding to the reinforcing the concrete it is trying to stretch the reinforcing. The reinforcing is much stronger in tension than the curing concrete and resists the concrete expansion. The result is that the reinforcing transforms the expansion stresses in the concrete into a compressive force in the concrete. **Instead of physically expanding, the concrete is restrained and a compressive force is being built up in the concrete.**

- Shortly after the apex of the expansion curve is reached the curve goes into its downward slope indicating concrete shrinkage.

- This portion of the curve also indicates relaxation of the compressive stresses in the concrete.

- As a result, as shown on the curve, the concrete returns to its as placed volume with, ideally, a small residual compressive stress remaining in the concrete. The vertical distance at this point between the conventional Portland Cement concrete curve and the Shrinkage-Compensating Concrete curve can be interpreted as pre-stressing that is induced into the concrete.

The small residual compressive stress in the concrete means that the concrete never goes into tension. Since the concrete does not go into tension, shrinkage cracks will not, cannot, form. This is the essence of shrinkage-Compensating concrete. Shrinkage cracking can be eliminated when properly using shrinkage-compensating concrete, in accordance with ACI 223 Guide for the Use of Shrinkage-Compensating Concrete, in lieu of conventional Portland Cement concrete.

PRIMARY ADVANTAGES OF TYPE "G" CONCRETE

Elimination of shrinkage cracking is the reason why shrinkage-compensating concrete was developed. The ability to compensate for concrete shrinkage creates two other prominent advantages that are inherent in shrinkage-compensating concrete:

- **Contraction Joints**-elimination of concrete shrinkage means that contraction joints **are no longer needed. The cost of installing contraction joints can be saved as well as** the additional cost of additional checkerboard placements due to lager monolithic placements that can be achieved using shrinkage-compensating concrete. With no Joints to be sealed Green construction points can be earned since the use of chemical joint sealants can be eliminated. Sustainability is also increased since joint maintenance requirements during the life of the structure have been eliminated and the life of the concrete is extended.

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- **Edge curling**-Edge curling can be eliminated in two ways. First- elimination of contraction joints eliminates the possibility of edge curling at non-existing contraction joints. Second - the principle cause of edge curling is differential curing of the concrete with the top surface drying, and shrinking, faster than the concrete within the slab. Within the slab the rate of curing decreases as the depth of the concrete increases, particularly when placed on a vapor barrier. As the same time that this shrinkage process is occurring the expansion mechanism of the shrinkage-compensating concrete is occurring and the expansion counteracts the top surface shrinkage, thereby eliminating edge curling at slab edges and expansion joints. Stated in a different way - the shrinkage forces that cause edge curling are counter acted by the expansion of the shrinkage-compensating concrete.

When a major improvement in a material science occurs, such as the Type G Components introduced in the August 2002 Concrete International article and incorporated in the publication of ACI 223-R10 there are usually secondary advantages that are inherent in the material that complement and build on the primary advantages of the material. These secondary advantages of shrinkage-compensating concrete include, but are not limited to:

- **Increased durability**-field project experience of shrinkage-compensating concrete highway bridge decking, particularly in areas subject to deicing material applications, indicates extended service life. This is probably due to the concrete being densified and the resulting increase in impermeability. Since the expansive forces in the concrete squeeze the mortar paste onto the rebar it creates a compressive mechanical bond of the concrete to the rebar as well as chemical bond between the two materials, thereby providing extra protection for the rebar from salt corrosion. Joint deterioration, and subsequent repairs, are eliminated by elimination of contraction joints and the larger monolithic placements that can be achieved. Abrasion resistance of pavement, floor slabs, and slabs-on-grade is 30-40% greater, as per ACI 223-R10 Section 4.5.7.

- **Sustainability** is usually not a factor in construction cost but a more sustainable concrete structure yields long term dividends for the owner. Maintenance costs are reduced or eliminated and longer time periods between structure replacement typically translates into shrinkage-compensating concrete providing the lowest life cycle cost for the structure.

- **Green construction** is a growing consideration and shrinkage-compensating concrete offers many opportunities for Green construction. An example would be containment structures, such as tank farms for hazardous chemicals, that can be built without contraction joints, expansion joints, or shrinkage cracks-thereby eliminating the principle routes into the subgrade 2 for environmental contamination resulting from incidental drips and spills or vessel failure. Green construction points (white reflective surface, no organic volatiles from common roofing materials) can be earned by using shrinkage-compensating concrete for roof construction, to name a couple of examples.

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- **Economical construction** - It is definitely true that adding any component, or additive, to a concrete mix increases the unit cost per yard of the plastic concrete as delivered to the job site. Using shrinkage-compensating concrete made with a component, instead of shrinkage-compensating cement, results in considerable cost savings in the manufacture, shipping, handling, and concrete production. Construction cost savings resulting from not having to install contraction joints and being able to place larger monolithic placements, thereby reducing the number f placements and associated time commitments, will help to offset the cost of the component. Since Type G components are transparent the concrete mix the special construction procedures and techniques required with Type K components do not have to be implemented resulting in additional construction savings. Cost savings is dependent on project type, location, size, and contractor experience, meaning that each individual project will have a different break even point above at which a Type G component concrete will yield construction cost savings.

- **Water Requirements**-One of the main differences between Type G and other systems mentioned in 222 is the amount of water required in the concrete mix and during the mixing, placing, and curing process. Engineers historically specify concrete plasticity requirements as a slump of the fresh concrete at the time and location of placement. The concrete producer translates this specification into a quantity of water expressed as the water/cementitious material ratio (w/cm) of the concrete mix. Since shrinkage compensating components are cementitious materials adding a component to a standard concrete mix will increase, by weight, the cementitious content which must be taken into consideration when determining the weight of the water content, and hence gallons, in the concrete mix design. When using a Type G component the w/cm ratio remains the same as the w/cm ratio of the standard specified concrete mix design, typically 0.43-0.45. By contrast, when placing Type G concrete, a contractor can use their standard curing products and procedures as long as it is in compliance with standard ACI recommendations for curing procedures and practices.

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[2]Valentine, Lawrence J., "Environmental Containment Structures", ACI Concrete International, Vol. 16, Number 7, July 1994 pp 34-37.

[3]Chusid, Michael, "All Concrete House Turns o Years Old", ACI Concrete International, Vol 28, Number 3, Marchi 2006, pp 55-59.

[4]Valentine, Lawrence J., "Environmental Containment Structures. ACI Concrete International, Vol. 16, Number July 1994, pp 34-37

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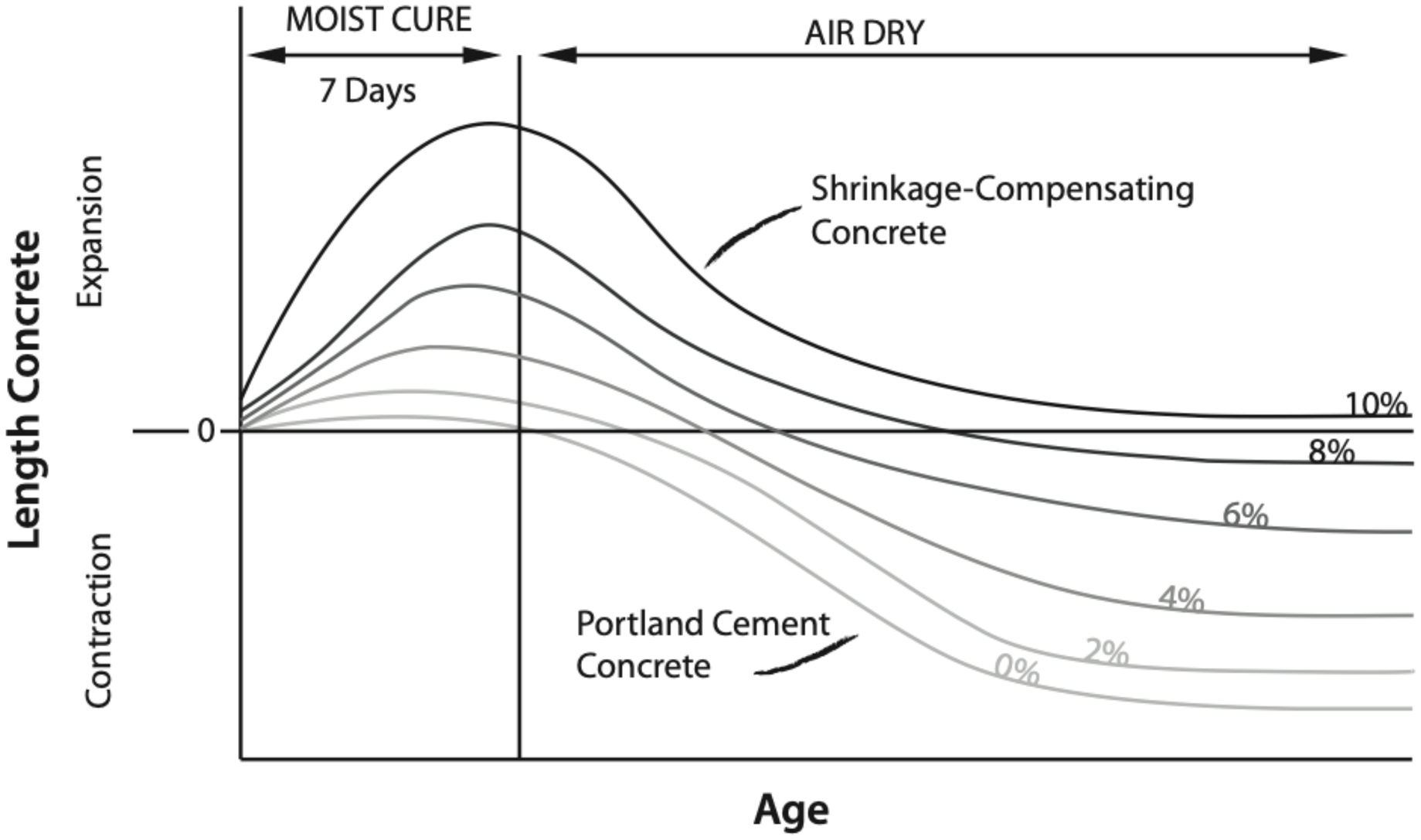
- **Partial shrinkage compensation** - while the ability to eliminate concrete shrinkage is available, economical, and user friendly, there is also a movement in the industry to limit concrete shrinkage to acceptable limits on some projects through the use of Shrinkage Reducing Admixtures (SRA's). Type G components can be, and are used to satisfy limited shrinkage specification requirements. Let's take a second look at fig 2 but this time we will interpret the upper curve as full, or 100%, shrinkage compensation. Full shrinkage compensation can usually be obtain by dosing a standard concrete mix for structural concrete with 10 % Type G component by weight of the total cementitious material in the standard concrete mix design. The lower curve, which is conventional Portland Cement concrete, provides 0 % shrinkage compensation and contains 0% Type G component by weight of cementitious material in the standard concrete mix. By



interpretation we can add intermediate curves at various percentages. We can then plot a specific point showing the specified limit on shrinkage by volume (vertical axis) and time (horizontal axis). A trial dosage rate for a Type G component can then be selected for ASTM C-878 laboratory testing to show compliance with specified requirements. As the above graphic illustrates, partial dosage of a Type G component can be used to achieve a specified shrinkage (vertical axis) at a specified time (horizontal axis) after placement. Use of a Type G component in lieu of an SRA (Shrinkage Reducing Admixture) will often be more economical and without the loss of air content and/or strength often associated with SRA's, Since shrinkage-compensating components are made of native materials, green construction points can be earned by not using a manufactured chemical additive such as an SRA.

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Conclusion

The advantages of components in general, and Type G components in particular, can bring many advantages to a project and are worthwhile investigating. As a general rule of thumb, the larger the picture, the better a component project will prove out. To illustrate, the cost of ready mix concrete with a Type G component at discharge from the truck at the project site will always cost more than conventional Portland Cement concrete of the same strength. Conversely, when determining project life cycle costing, a component concrete structure will always provide the most cost effective, durable, and serviceable LEED compliant structure when compared to the same structure constructed with conventional Portland Cement concrete.

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