RECLAMATION
Managing Water in the West

Scoping Study on New Technologies to Halt Concrete Shrinkage and Cracking

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Contents

Abstract

The primary objective of this scoping study was to begin the evaluation of relatively new technologies that may help reduce or completely eliminate concrete shrinkage and cracking. The report identifies those technologies that seem to show promise, identifies potential or known issues which may impact acceptance of the technologies on a large scale, discusses if using any of these technologies or a combination of technologies will benefit Reclamation and discusses future research recommendations.

Introduction

Concrete is one of the most widely used construction materials in the world. However, an important issue with concrete is shrinkage and cracking. The shrinkage of concrete is due to the fact that two of the main constituents of concrete, cement and water, combine and chemically react to form a product with less volume than the two original components. Cracking is a result of this shrinkage and rigid restraint on one or more edges of the concrete placements. Cracking in concrete structures can lead to loss of durability, rebar corrosion, poor appearance, water leakage, and structural deficiencies.

Several approaches have been used to mitigate both shrinkage and cracking in concrete structures. The use of concrete mixtures with a lower water-to-cement ratio (w/c), the use of larger aggregate or aggregate with increased stiffness, the inclusion of contraction joints, and the use of proper curing techniques all contribute to reduced shrinkage and cracking. However, none of these techniques are perfect solutions, and we often get unwanted cracks. Recently, new technologies have been developed, studied, and utilized to reduce or eliminate concrete shrinkage and cracking. There are three main categories of these new technologies: admixtures, internal curing additives, and cement additives. This report identifies and discusses these newer technologies that seem to show potential for reducing or eliminating shrinkage and cracking in concrete structures.

Conclusions

This scoping study has identified the following technologies which have been shown to reduce shrinkage and reduce and/or eliminate cracking in concrete structures:

- Shrinkage reducing admixtures (SRA)
- Internal curing via saturated, porous lightweight aggregate
- Internal curing via super-absorbing polymers (SAP)
- Magnesium oxide (MgO) as an additive or partial replacement of cement

While each of these methods has been shown to fulfill their intended purpose, there are some technological issues or obstacles to be addressed when using them. However, it is important to consider the effects of these materials on the fresh and hardened properties of concrete. Each technology provides the benefits of reduced shrinkage, reduced cracking, and in some cases increases in the mechanical properties of concrete.

The use of some of these materials may reduce long term strength, modulus, durability and/or other material properties. However, an understanding of the materials and their effects, as well as proper mixture proportioning can help mitigate or work around these issues. Further research and testing of each of the technologies is recommended. Additional research should focus on finding solutions to the detrimental effects of these technologies, as well as provide guidance for the optimal proportions of these products to ensure reliable performance. Additional research may further prove the validity of these technologies as acceptable solutions for reducing and/or eliminating shrinkage and cracking in Reclamation's concrete structures.

Discussion

Shrinkage Reducing Admixtures

Shrinkage reducing admixtures (SRA) are relatively new to the concrete industry. Recently several products have been developed and sold commercially as SRAs. The theory behind the effectiveness of SRAs to reduce concrete shrinkage is that they cause a reduction in the surface tension of the pore fluid in concrete[1]. This leads to a reduction in the stresses developed at the location of pores in the concrete matrix as the pores lose water.

Research has shown that the addition of SRAs in a concrete mixture can greatly reduce the amount and rate of free shrinkage in concrete specimens. "Reductions of shrinkage are commonly reported that range from 30% to 80% depending on the mixture composition, curing time, and drying time[2]." Typical dosages of SRAs, 2% to 5% by weight of water, have been shown to reduce overall shrinkage as well as decrease the rate of that shrinkage.

The development of tensile stresses due to shrinkage during curing is directly proportional to the rate and amount of shrinkage. Therefore, minimizing shrinkage at early ages is highly beneficial. When the tensile strength of concrete exceeds the tensile stresses developed as a result of shrinkage, cracking does not occur.

Despite having the effect of reducing shrinkage, there are some negative aspects to consider when utilizing SRAs. Research has shown that the use of SRAs will likely lead to reduced compressive strength, tensile strength, flexural strength, and modulus of elasticity. In addition, poor freeze thaw resistance is possible in concrete containing SRAs as there is a potential for poor air void development and distribution. However, this can be mitigated through the proper selection of compatible admixtures.

Saturated, Porous Lightweight Aggregate

Lightweight aggregate (LWA) has been successfully used in concrete structures since the 1950's to decrease the density of concrete. However, it wasn't until the 1990's that engineers realized its ability to provide additional curing water to concrete during the curing process[3]. The pores of LWA are relatively large compared to the pores developed in the cement matrix, allowing water to be drawn from the aggregate into the cement matrix and ensures all the pores within the cement paste are completely saturated[4]. The amount of internal curing water required can be estimated based on the amount of autogenous shrinkage. Providing additional water within the cement paste actually leads to an early "swelling" of the paste, compensating for shrinkage occurring at the initial time of set. The additional water also allows for a greater degree of hydration of the cement, and thus develops a more stable and stronger structure.

Typically, saturated, porous, lightweight sand is used to provide an internal water source. Utilizing sand sized particles rather than large porous aggregates for internal curing purposes provides a few benefits. Firstly, the sand allows for better utilization of the provided internal curing water in two ways. Better distribution of the saturated sand sized particles decreases the distance the water will need to cover. Additionally, sand sized particles have a larger surface area than courser particles and release a greater percentage of their absorbed water[5]. Furthermore, retaining denser, stronger course aggregates helps to ensure the concrete will have the desired mechanical properties.

The use of saturated LWA for internal curing has produced varying effects on the mechanical properties of concrete. For example, "in some cases concrete made with saturated LWA may have slightly lower strengths at early age, due to an increased water-entrained porosity."[3]. On the other hand, compressive strength can be improved by the greater degree of cement hydration due to the provided internal curing water. Additionally, because water is being provided internally, the mix water can be reduced, resulting in a lower water-cement ratio, higher strength and greater durability.

Super-absorbing Polymers

Another method of providing internal curing water is the use of super-absorbing polymers (SAP). "SAP have a very high ability to absorb water, sometimes even up to 500 times their own weight[6]" making them ideal candidates for providing internal curing water in concrete. As discussed above, providing adequate internal curing water leads to a higher degree of hydration of cement, and thus higher strength. However, there are some aspects to consider when using SAP.

Studies have shown that the use of SAP for internal curing of concrete may negatively affect some mechanical properties. For instance, as the amount of SAP increases, strength and modulus decrease. This may be explained by the "higher amount of larger pores…and a reduction in the amount of smaller pores, that are assumed to be filled with hydration products,[6]" after the SAP have dried. While well distributed air voids help provide freeze-thaw resistance, excessive voids lead to a decrease in strength. Nevertheless, proper mixture proportioning and an understanding of the mechanism of action of SAP can ensure the desired mechanical properties are achieved.

Magnesium Oxide

Magnesium oxide (MgO) has previously been used in concrete mixes in other countries within the past 30 years. However, its use, and the subsequent benefits of its use, was not initially intended. Engineers working on the Baishan concrete arch gravity dam in Northeast China observed no significant cracking in the dam concrete despite extremely harsh curing conditions. Engineers discovered the content of MgO in the cement was quite high, and that this was the only possible reason for such little cracking[7].

When added to concrete mixes at the correct proportions, magnesium oxide can lead to autogenous expansion of the concrete. This expansion can compensate for some or all of the shrinkage that would occur in concrete mixes without higher contents of MgO, but the type and quantity of MgO powder added can have different effects. For example, a lightly burnt MgO powder will cause a larger magnitude of early-age expansion whereas a heavily burnt MgO powder will exhibit a lesser magnitude of early-age expansion. Additionally, the heavily burnt MgO powder has a much longer hydration process, leading to a very stable expansion. However, high quantities of "dead-burnt" crystalline MgO produce excessive expansion during hydration at late ages, leading to damage of the concrete[7]. ASTM specifies a maximum MgO content in cement of 6% to avoid this undue expansion. Therefore, it is the supplementation of additional, controlled amounts of MgO that helps to mitigate concrete shrinkage.

According to research studies, concrete made with additional MgO will generally have higher compressive and tensile strengths than concrete made without additional MgO[7]. Multiple factors could contribute to this increase in strength. Firstly, the higher temperature during curing increases the hydration rate of both the MgO and the cement, leading to a more sufficient hydration and thus a denser microstructure. Secondly, there is a decrease in the number and size of cracks due to the expansion. Lastly, substitution of some cement with MgO powder decreases the water demand in the mix, leading to a lower water-cement ratio. In addition to strength gain, decreased permeability and increased abrasion/erosion resistance can be realized.

Reclamation recently tested a prototype product that incorporated MgO and an SRA. Results were very promising[8] and further investigations are in the planning phase.

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