The Influence of Lightweight Aggregate on Internal Curing and Its Impact on Autogenous Shrinkage of High-Performance Concrete

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Introduction/Abstract

In bridge deck construction high performance concrete is often desirable, however in practice it is generally susceptible to early-age shrinkage cracking resulting in an overall reduction in service life. This research seeks to assess the potential for reducing early-age shrinkage in new bridge deck construction through the use of internal curing, a process in which internal reservoirs supply water to the hydrating cement paste during the early stages of cement hydration. In North America, internal curing is typically achieved by replacing a portion of the normal fine aggregate with an expanded fine lightweight aggregate (LWA). For this study, the free and restrained autogenous shrinkage behavior was quantified for two field mixtures: a high performance concrete (HPC) and an internally cured high performance concrete (IC-HPC). The results indicate that internal curing successfully reduces the generation of autogenous shrinkage strain. When this shrinkage is restrained, it was shown that the IC-HPC mixture was less susceptible to developing cracks in comparison to the HPC mixture. These findings suggest that internal curing can be used successfully in the field to reduce the potential for early-age shrinkage cracking, leading to production of bridge decks with longer service lives. Future research will implement these results in a service life estimation model to demonstrate the added value of internal curing bridge decks.

Methodology

•Autogenous shrinkage was measured by first creating different mortars, which is a mix of water, cement, and fine aggregate. The fine aggregate was what differed, where different batches contained different amounts of sand and lightweight aggregate.

•Then, corrugated tubes were filled. Once capped properly, a device was used to measure the shrinkage developed over the course of several days.

•The process for measuring restrained shrinkage starts with the creation of a concrete mix, which contains water, cement, fine aggregate, and coarse aggregate that does not exceed ½" in any dimension.

Figure 1: Several buckets of coarse aggregate of different gradations

Figure 2: A barrel of lightweight aggregate

Methodology Continued

•Once mixed, the concrete is placed into a mold consisting of two invar steel rings protected by a thin plastic layer. Each invar ring holds 4 strain gages.

•When concrete placement is complete and the concrete cylinders created, the ring system and the concrete cylinders are transferred to a temperature-controlled environment.

•For several days, as the concrete shrinks, the developed strain is recorded. Later, the concrete cylinders undergo compression and strain tests to check for strength and creep properties.

Autogenous Strain Equations

$$\epsilon_{autogenous} = \frac{L(t) - L(t_{fs})}{L(t_{fs})} * 10^6 = \frac{R(t) - R(t_{fs})}{L(t_{fs})} * 10^6 \mu m/m$$

$$L(t) = L_{ref} + R(t) - 2 * L_{plug}$$

- $t = time\ elapsed\ from\ the\ first\ addition\ of\ the\ cementitious\ materials\ to\ the\ water\ during\ mixing$
- $L_{ref} = length\ of\ reference\ bar, mm$
- $R(t) = reading\ of\ length\ gauge\ with\ specimen\ in\ the\ dilatometer, mm$
- $L_{plug} = average\ length\ of\ end\ plugs, mm$
- $t_{fs} = time\ of\ final\ setting, when\ the\ first\ length\ measurement\ is\ performed, min$

Figure 3: A row of mortars undergoing autogenous shrinkage

Figure 4: Dual Ring Apparatus in insulation chamber, Reference: J. L Schlitter et. al.

Restrained Shrinkage Equations

$$\sigma_{Actual\ -Max} = -\epsilon_{Steel}(t) * E_s * C_{3R} * C_{4R}$$

- $\sigma_{Actual\ -Max} = actual\ maximum\ stress$
- $\epsilon_{steel}(t) = strain\ of\ the\ inner\ ring\ as\ a\ function\ of\ time$
- $E_s = modulus\ of\ elasticity\ of\ the\ steel, taken\ as\ 141\ GPa\ for\ invar$
- $C_{3R} = \frac{R_{OS}^2 + R_{OC}^2}{R_{OC}^2 - R_{OS}^2} = \frac{(165\ mm)^2 + (203\ mm)^2}{(203\ mm)^2 - (165\ mm)^2} = 4.894\ for\ Dual - Ring\ Schlitter\ Test$
- $C_{4R} = \frac{R_{OS}^2 - R_{IS}^2}{2R_{OS}^2} = \frac{(165\ mm)^2 - (146\ mm)^2}{2(165\ mm)^2} = 0.114\ for\ Dual - Ring\ Schlitter\ Test$

Summary

Based off of research by Barrett et. al., it can be speculated that internal curing affects high-performance concrete by reducing the autogenous shrinkage that occurs during the curing process. Therefore, it can be concluded that there is potential for internal curing to reduce autogenous shrinkage-induced early-age cracking in new bridge decks. While similar conclusions exist in previous research, this research seeks to further reinforce the notion that internal curing can reduce early-age cracking induced by autogenous shrinkage, thereby potentially increasing the service life of newly cast bridge decks.

Figure 5: Bridge deck in the casting process

References

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