Improved Bridge Deck Performance with Lightweight Aggregate Concrete

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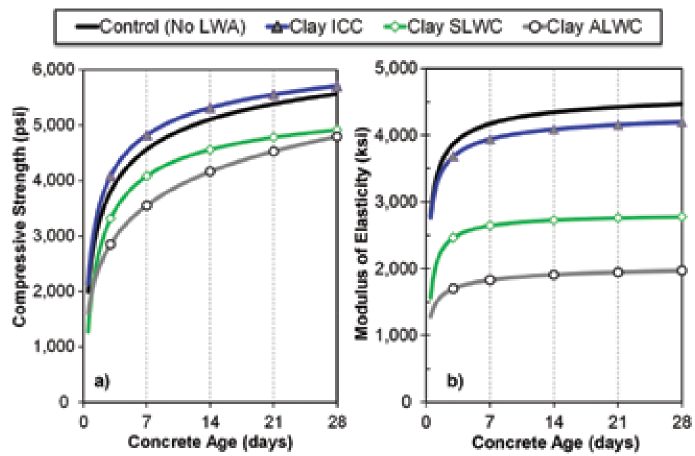

Figure 1. Mechanical properties of expanded clay LWA concretes: a) compressive strength and b) modulus of elasticity development (Byard et al. 2012).

Early-age cracking of concrete bridge decks, typically caused by drying, autogenous, and thermal shrinkage effects, can have detrimental effects on long-term behavior and durability. Darwin and Browning (2008) recently reported that "by controlling early-age cracking, the amount of cracking at later ages should remain low." They also reported that early-age cracking could significantly increase the rate and amount of chloride penetration (from deicing salts), which may accelerate the corrosion rate of embedded reinforcing steel.

Thus, it is essential for improved durability and sustainability that bridge deck concrete is proportioned and placed to minimize early-age cracking. Tensile stresses are induced in bridge decks when the girders restrain concrete volume changes. Early-age volume changes occur due to the combined effect of temperature, autogenous shrinkage, and drying shrinkage. The amount of stress produced when concrete volume change is restrained is a function of the extent of volume change, modulus of elasticity, degree of restraint, stress concentrations, and relaxation of the concrete, which all vary with the maturity of the concrete.

Lightweight aggregate (LWA) was evaluated to determine its benefits in bridge deck applications to mitigate early-age cracking. You might be wondering: *Why do lightweight aggregates help to minimize cracking in bridge decks?* The answer lies in the fact that, when using LWAs, the concrete's modulus of elasticity and coefficient of thermal expansion is reduced when compared to normalweight aggregates. Reducing the coefficient of thermal expansion will result in less strain from a temperature change, and reducing the modulus of elasticity will result in reduced stress when volume change effects are restrained.

Another reason to use LWAs in bridge deck applications is that they are pre-wetted during batching, which allows them to provide internal curing to the concrete. Internal curing is provided as the absorbed water within the LWA is desorbed at early ages with the progress of hydration that needs and consumes water. The release of the internal curing water from LWA increases cementing material hydration and reduces capillary stress caused by self-desiccation. For more details about internal curing, the reader is referred to a 2012 STRUCTURE article titled *Internal Curing: Constructing More Robust Concrete* (Weiss et al. 2012). That article states that, by "reducing the autogenous and drying shrinkage, internally cured concrete can also provide concrete with the ability to undergo greater temperature variations before cracking."

Experimental evidence that supports that the use of LWAs effectively delays the occurrence of early-age cracking in bridge deck concrete is discussed below. Also discussed is the experience of using lightweight aggregates in various bridge decks in the State of New York.

Experimental Findings

The effect of lightweight aggregate on the cracking tendency of bridge deck concrete was evaluated using cracking-frame testing techniques. Cracking frames measure the restrained concrete stress development due to thermal and autogenous shrinkage effects from setting until the onset of cracking under conditions that match those of in-place bridge decks. In a large study (Byard and Schindler 2010), expanded shale, clay, and slate lightweight coarse and fine aggregates were used to produce internal curing (IC), sand-lightweight (SLW), and all-lightweight (ALW) concretes. The behavior of these concretes containing these different types of LWAs was then compared to that of a normalweight concrete in bridge deck applications. This study evaluated concrete placed during both fall and summer placement conditions.

Internal curing (IC) concretes were produced by replacing a fraction of the normalweight fine aggregate

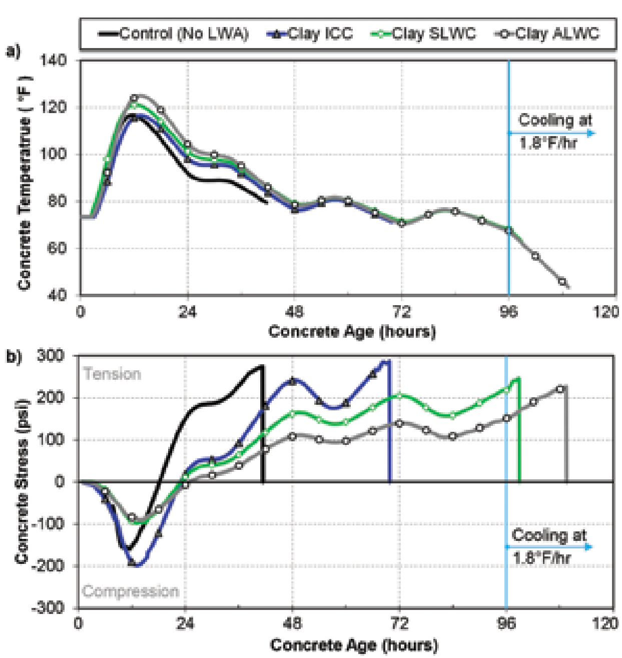

Figure 2. Fall placement condition in bridge deck with expanded clay LWA concretes: a) modeled temperature profile and b) restrained stress development (Byard et al. 2012).

with lightweight fine aggregate. SLW concretes were produced using lightweight coarse aggregate and normalweight fine aggregate. ALW concretes used both lightweight fine and lightweight coarse aggregate.

The compressive strength development of some of these concretes are shown in *Figure 1a*. All concretes exhibited 28-day compressive strengths above the 4,000 pounds per square inch (psi) target. As shown in *Figure 1a*, the IC concretes exhibit similar or slightly greater compressive strengths compared to the Control mixture. The increased compressive strength of the IC concretes is attributed to the additional hydration that IC concretes generally exhibit. The compressive strengths of the SLW concretes are similar to or less than that of the Control concretes (*Figure 1a*). The compressive strengths for the all-lightweight concretes were approximately 13% to 19% lower when compared to those of the normalweight control concrete.

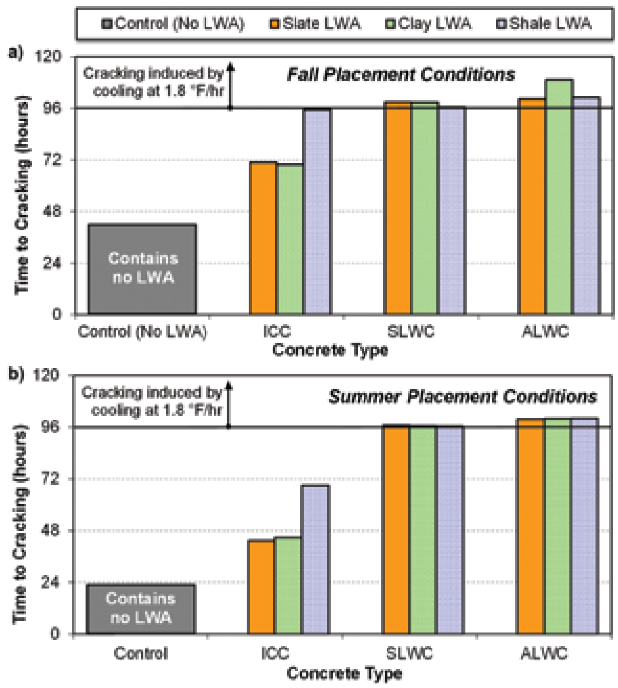

Figure 3. Time to initial cracking for different concretes placed under: a) fall conditions and b) summer conditions (Byard et al. 2012).

The modulus of elasticity results of some of these concretes are shown in *Figure 1b*. The modulus of elasticity of the concrete depends heavily on the stiffness of the aggregate. It is clear from this figure that the more LWA used in the concrete, the lower the concrete's modulus of elasticity. This effect can accurately be estimated by using the well-known expression in ACI 318, *Building Code Requirements for Structural Concrete and Commentary*, that indicates that the modulus of elasticity is directly proportional to the unit weight to the 1.5 power and the square root of the compressive strength.

Typical results of the in-place concrete temperature and the measured restraint stress development for bridge decks placed under fall conditions are shown in *Figure 2*. The results from the rigid-cracking frame provide a relative index of cracking sensitivity, with a mixture with increased cracking time being an indication of improved cracking performance in the field. This increased performance may be in the form of increased crack spacing, decreased crack widths, or fewer cracks.

Concrete made with LWA has a lower thermal diffusivity; therefore, as shown in *Figure 2a*, this leads to higher temperatures compared to normalweight aggregate. However, the restrained stress development in *Figure 2b* indicates that the magnitude of the peak temperature alone does not provide a direct indication of the cracking tendency of the concretes. While the magnitude of the peak temperature is important, the decreased coefficient of thermal expansion of the LWA concretes causes a reduced strain per unit temperature change. Furthermore, the reduced modulus of elasticity of the LWA concretes causes reduced stress for a given strain. Although the SLW and ALW concretes experience higher peak temperatures, the significant reduction in modulus of elasticity and coefficient of thermal expansion leads to a reduction in tensile stress and a significant overall delay in early-age cracking in bridge deck concrete applications.

The cracking times for all the concretes placed under fall and summer conditions are summarized in *Figure 3*. A comparison of the results provided in *Figures 3a* and *3b* reveals that the time to cracking for all concretes made with LWA, when placed under *summer* placement conditions, is greater than the time to cracking of the normalweight concrete when placed under *fall* conditions. This indicates that the use of pre-wetted LWA may be especially beneficial during summer placement conditions to minimize the occurrence of early-age cracking. This figure also shows that, regardless of the type of expanded LWA and as more pre-wetted lightweight aggregates are added to the concrete, the time to initial cracking is delayed, which will improve the in-place performance of bridge decks.

Field Project Findings

In 2010, the New York State Department of Transportation (NYSDOT) constructed a single-point urban interchange (SPUI) over Interstate 87 in Latham, NY. A portion of the bridge can be seen in *Figure 4*. Because of the unique geometry of the bridge, cracking of the concrete bridge deck was a concern. One method employed to reduce cracking was to utilize lightweight concrete. The deck was cast with sand-lightweight concrete with an equilibrium density of 110 pounds per cubic foot. After 10 years of use, the exposed deck has performed excellently through the severe winters experienced in Upstate New York.

To improve the durability of bridge decks, the NYSDOT has been utilizing internal curing as one of their crack reducing strategies. The normalweight, high-performance concrete found in these decks contain supplemental cementitious materials (SCMs). While these SCMs do a great job of reducing the permeability of the concrete, cracking of the deck is a concern as wide cracks provide easy pathways for contaminants to reach the reinforcement quickly. The concrete's susceptibility to cracking is improved by replacing 30% by volume of the normalweight fines with an equal volume of saturated lightweight aggregate fines to cure the concrete internally. The NYSDOT evaluated internally cured concrete as part of a large research study on multiple bridge decks that included the Court Street Bridge in Syracuse, New York, which is shown under construction in *Figure 5, page 10*. Current projects include the

Figure 4. SPUI Bridge deck utilizing lightweight concrete to reduce cracking.

elevated portion of the Bruckner Expressway in New York City. For this project, 12,000 cubic yards of internally cured concrete was implemented to reduce the cracking of the concrete and to improve the life span and sustainability of these bridge decks.

In Summary

The use of lightweight aggregate decreases the modulus of elasticity and coefficient of thermal expansion of the concrete. Based on the experimental results and regardless of the type of expanded LWA used, as more pre-wetted lightweight aggregates are added to the concrete, the time to initial cracking is delayed, which will improve the in-place performance of bridge decks. State highway agencies have recognized the benefits of reducing cracking through the use of saturated lightweight aggregates. The NYSDOT's most recent version of their bridge manual requires that high-performance, internally cured concrete be used on all continuous-span bridges and all simple-span prestressed concrete bridges using adjacent box beams or slab units.

Note that, while there are many benefits associated with internal curing, the recommended practice is that contractors continue to provide conventional (external) curing. As a result, by providing both internal curing with LWA and external curing, it is possible to greatly minimize the risk of unwanted early-age cracking, which will lead to improved bridge deck performance.▪

References are included in the PDF version of the article at **STRUCTUREmag.org.**

Figure 5. Internally cured concrete being placed on the Court Street Bridge in Syracuse, New York.

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References

Byard B.E., A.K. Schindler, and R.W. Barnes, 2012, "Early-age Autogenous Effects in Internally Cured Concrete and Mortar," Special Publication titled *The Economics, Performance, and Sustainability of Internally Cured Concrete, Special Publication 290*, Edited by A.K. Schindler, J.G. Grygar, and W.J. Weiss, American Concrete Institute, Farmington Hills, Michigan.

Byard, B.E., and A.K. Schindler, 2010, *Cracking Tendency of Lightweight Concrete*, Final Research Report, Highway Research Center, Auburn University, 82 pages.

Byard, B.E., A.K. Schindler, and R.W. Barnes, 2012, "Early-age Cracking Tendency and Ultimate Degree of Hydration of Internally Cured Concrete," *ASCE Journal of Materials in Civil Engineering*, Vol. 24, No. 8, pp. 1025-1033.

Byard, B.E., A.K. Schindler, and R.W. Barnes, 2014, "Cracking Tendency of Lightweight Aggregate Bridge Deck Concrete," *ACI Materials Journal*, Vol. 111, No. 2, pp. 179-188.

Darwin, D., and J. Browning, 2008, "Construction of Low Cracking High-Performance Concrete Bridge Decks: Field Experience," *Proceedings of the Concrete Bridge Conference,* St. Louis, MO, May 4-7, pp. 1-16.

New York State Department of Transportation, *New York State Department of Transportation Bridge Manual*, May 2019, Chapter 3, pp 3-4.

Springenschmid, R. and R. Breitenbücher, 1994, "Influence of Constituents, Mix Proportions and Temperature on Cracking Sensitivity of Concrete," In *RILEM Proceedings 25*: Thermal Cracking in Concrete at Early Ages, R. Springenschmid, ed., E & FN Spon, London, pp. 41-50.

Weiss W.J., D.P. Bentz, A.K. Schindler, and P. Lura, *Internal Curing: Constructing More Robust Concrete*, STRUCTURE, January 2012.