ABSTRACT

Barrett, Timothy J. Ph.D., Purdue University, August 2015. Improving Service Life of Concrete Structures Through the Use of Internal Curing: Impact on Practice. Major Professor: Jason Weiss.

The Indiana Department of Transportation (INDOT) commissioned the construction of six bridge decks utilizing a new class of internally cured high performance concrete (IC HPC) structural concrete. The first four bridge decks were constructed in the summer of 2013, while the fifth was built in November of 2014 and the sixth is planned for the summer of 2015. These decks implement research findings presented in the FHWA/IN/JTRP-2010/10 report (Schlitter, Henkensiefken, et al. 2010) where internal curing was proposed as one method to reduce the potential for shrinkage cracking, leading to improved durability. In addition, the use of higher performance concrete mixtures and a new specification composed of prescriptive and performance based measures was implemented with the intention of extending the service life of the bridge decks. The objectives of this thesis is to provide documentation of the construction and performance of the IC HPC bridge decks cast in Indiana and provide a viable, practice-ready method for the assessment of the potential durability of these concretes. In fulfillment of these objectives, samples of the IC HPC used in construction

were compared to a reference high performance concrete (HPC) which did not utilize internal curing and was made by the same producer with the same constituent materials. The samples collected in the field were transported to the laboratory where the mechanical performance, resistance to chloride ingress, and potential for shrinkage and cracking was assessed. Using experimental results and mixture proportions, the diffusion based service life of the bridge decks was able to be estimated. This is the second page of the abstract.
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The construction process was documented for first four bridge decks made using internal cured high performance concrete (IC HPC). These concretes were able to be designed, batched, and placed and are now in service. While avoidable issues were observed during batching construction related to corrections of batching water, batching tolerances and fluctuations in air content (which apply to any concrete), the IC HPC was able to be batched and placed using slight modifications to conventional methods. The production of the IC HPC mixtures was implemented using a mixed specification using prescriptive and performance based measures representing an improvement on previous specifications which did not specifically have provisions that consider durability. To aid in the implementation of internal curing in the field, a new quality control technique for lightweight aggregate utilizing a centrifuge has been implemented is now standardized in Indiana Testing Method 222 (Miller, Barrett, et al. 2014).

The results of laboratory testing indicate that the compressive strength, modulus of elasticity, and tensile strength of the IC HPC mixtures was not substantially different than the HPC mixtures and as such current codified equations are able to be used to predict the modulus of elasticity and

tensile strength if the compressive strength is known. The diffusion of chlorides in these concretes was assessed, where it was shown that each of the mixtures tested had a charge passed in the rapid chloride permeability test of less than 1500 C at 91 days (AASHTO T277-07 2007); additional testing provided equivalent results when performing the Nordtest (NT Build 492 1999), Stadium migration test , or electrical resistivity test. Using experimental results which determined the chloride diffusion and permeability, the diffusion based service life of the IC HPC bridge decks was estimated to be between approximately 60 to 90 years, compared to approximately 18 years for the conventional class C bridge deck concrete used in Indiana. The susceptibility to early age shrinkage and cracking was evaluated where it was shown that IC HPC concretes exhibited a reduction in early age shrinkage of 70 to 90%, resulting in a reduction in residual stresses of 80% or more while reducing thermally induced stress by up to 55% when compared to HPC mixtures. Collectively, these results indicate that the IC HPC mixtures that were produced as a part of this study exhibit the potential of for substantially increased service life while markedly reducing the potential for early age cracking.

The second phase of this thesis investigated the role of initial sample conditioning and the effect of changes in degree of saturation on the measured electrical resistivity, where a new relationship was developed to describe this relationship in air entrained concretes. The consistency and variability in the determination of the chloride diffusion coefficient was investigated through standardized testing methods, where it was shown that the coefficient of variation associated with the accelerated tests was approximately 15% or less and are dependent on the test. Chloride profile measurements made on cores taken from samples which were exposed with a known deicing solution and the temperature fluctuations of West Lafayette, Indiana indicated that on average, the coefficient of variation for determining the apparent chloride diffusion coefficient under is 30% or less. In addition, the use of resistivity measurements on sealed samples was used to evaluate the variability of the concrete produced throughout the construction of the fifth IC HPC bridge deck while comparisons of the samples from the first four bridge decks produced in the laboratory and in the field were also made. The results indicated that the coefficient of variation associated with the resistivity measurements made on the fifth bridge deck was less than 5%, while experimental results indicated that industrial production consistently results in lower performance as measured by the resistivity test when compared laboratory production. In this study it was also shown that measurements of mechanical properties are not indicative of the potential durability of the concrete.

The conclusions of this thesis and the findings presented in the FHWA/IN/JTRP-2010/10 report (Schlitter, Henkensiefken, et al. 2010) and the CDOT-2014-3 report (Jones et al. 2014) indicate that internal curing is a practice-ready, engineered solution that may lead to the production of higher performance concretes which have a reduced potential for cracking. To aid in the implementation of internal curing in practice, spreadsheets which automate calculations necessary for quality control for lightweight aggregates, mixture proportioning, and moisture adjustments have been developed by Miller (Miller 2014) and have been made available with the report documenting the construction of the first four bridge decks (T. J. Barrett et al. 2015). This thesis also provided the framework for a durability based design approach using sealed electrical resistivity measurements which may be implemented in practice. This method has been shown to be a viable way to rapidly evaluate the chloride diffusion coefficient of concrete and is appropriate for testing large numbers of samples during construction. It is recommended that the approach outlined in this work be implemented in performance based specifications in lieu of other accelerated testing methods which define the performance of the concrete based on the result of that test.

Finally, it should be emphasized that the implementation of technologies such as those that are presented in this thesis alone does not guarantee higher performance, as the production of such concrete requires a degree of technical competence in design, production, and construction of concrete materials. As is the case with the production of any concrete, internally cured or not, performance will be directly tied to the careful accounting of water, be it on the surface of aggregates, in the mixing drum after washing, or elsewhere. Special attention should be paid to the proper operation of batching systems, while placement techniques should be reviewed to minimize unwanted effects, and proper finishing and curing techniques must always be practiced. Only after performing the basics of concrete production properly will the full benefits of internal curing be actualized.