Curing, Shrinkage, and Cracking of Ternary Concrete Mixes

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SR 23 bridge under construction using a ternary concrete mix.

Many state transportation agencies are exploring ways to increase the service life of concrete bridge decks. In many cases, bridge deck replacement is needed while the pavement leading to the bridge is still in good condition. With more and more restrictions on closing road sections to traffic, there is an initiative to "match" the life of the concrete bridge deck with the life of the pavement.

Cracking of concrete bridge decks is not a new issue with bridge engineers. It is one of the most important issues to be resolved because of its relationship with deterioration of the bridge deck. Many experts in the bridge community already put significant effort into reducing bridge deck cracking by way of improving construction practices and improving the appurtenances in bridge deck components, from anchoring the reinforcement to the formwork to improving the lips of the stay-in-place deck forms. While the use of admixtures and supplementary cementitious materials (SCMs) in concrete has been practiced for a long time, little attention has been given to the issue of shrinkage behavior and the cracking susceptibility of concrete ternary mixes containing fly ash and silica fume.

Research Project

The Indiana Department of Transportation (INDOT) initiated a research project to explore the issue of shrinkage cracking and its relationship to ternary mixes and curing conditions. The objective is to minimize the cracking tendency of concrete bridge decks and to achieve a 50-year service life with a "manageable" maintenance effort from the Department. The research project was conducted in cooperation with the Joint Transportation Research Program at Purdue University.

The ternary concrete mixes were proportioned based on the INDOT Class C structural concrete for bridge decks. The INDOT Class C structural concrete typically contains 658 lb/yd^3 (391 kg/m^3) of cementitious materials and a maximum water-cementitious materials ratio of 0.443 with a paste content of 29%. Mix designs were based on using a maximum cementitious materials reduction of 20% with the cement content held constant at 389 lb/yd^3 (231 kg/m^3). In this study, INDOT Class C concrete without fly ash and silica fume was used as a control.

Four ternary mixes were included in the experiment with either 20 or 30% fly ash (FA) by weight of the total cementitious materials in combination with 5 or 7% silica fume (SF). The mixes were designated as 20FA/5SF, 20FA/7SF, 30FA/5SF, and 30FA/7SF. The paste contents were 23, 24, 27, and 28%, respectively. The mixes had a 0.41 water-cementitious materials ratio, 6.5 ± 1.0% air content, and a 4.0 to 7.5 in. (100 to 190 mm) slump.

Four curing conditions were used for the prepared samples. They were: (a) air drying immediately after casting, (b) three-day curing using wet burlap, (c) seven-day curing using wet burlap, and (d) curing with a white pigmented compound for seven days after which it was removed with a stiff wire brush.

Each of the concrete mixes had three 3x3x11 in. (75x75x285 mm) free shrinkage specimens subjected to the above curing conditions. The samples were demolded at final set and cured. The shrinkage initial reading was taken immediately after demolding. At the end of the curing period, the samples were subjected to drying at 73^{o}F (23^{o}C) and 50% relative humidity.

Shrinkage Results

Figure 1 shows that if no curing is provided (air drying only), the free shrinkage at 450 days was almost identical (about 550 millionths) for all four ternary mixes. However, the free shrinkage for all the ternary mixes in the air dry condition was significantly lower than that of the INDOT Class C mix without fly ash or silica fume. After adjusting for aggregate content relative to the

INDOT Class C mix, the free shrinkage appeared to be a function of SCM content, the larger the SCM content, the smaller the free shrinkage.

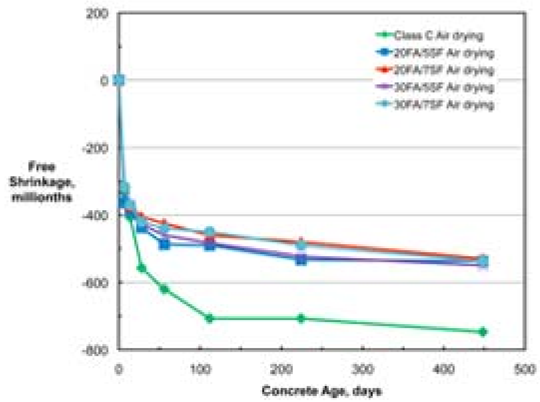

Fig. 1. Air drying results

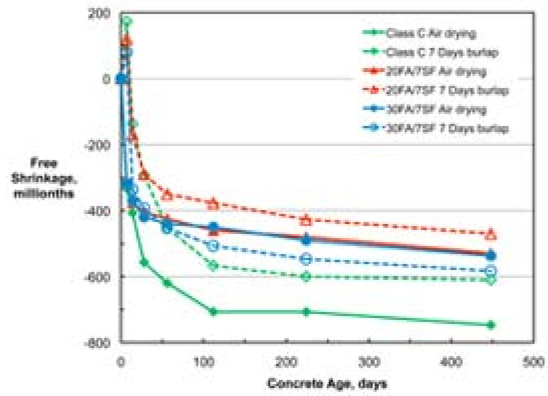

Fig. 2. Air drying versus 7 days burlap curing

As shown in Fig. 2, the wet burlap curing generally resulted in less free shrinkage than air-dried specimens. This phenomenon is mainly due to the initial expansion that occurred during the first few days of wet burlap curing. However, the 30% FA specimens gave higher free shrinkage values in all curing conditions compared to the air drying condition. This phenomenon may be due to the dry conditioning of the specimens at an early age when a significant amount of water evaporates from the specimens due to its fairly open pore structure.

Crack Tendency

The concrete mixtures were also tested for restrained shrinkage cracking using the AASHTO T 334 testing method. Each concrete mix had two specimens for testing. All specimens were subjected to the four curing conditions. While the AASHTO T 334 method doesn't specify a minimum monitoring period, the test was terminated a few days after cracks occurred. Otherwise, the shrinkage was monitored until the shrinkage values stabilized over time, up to 196 days.

Increasing Resistance to Shrinkage Cracking

Increasing Resistance to Shrinkage Cracking

7 Days Curing Compound	33, 94	82, 134	20, >185	20, 23	
Air Dry	>165, >165	>129, >129	23, 40	25, 25	16, 35
3 Days Wet Burlap	>196, >196	>129, >129	>152, >152	23, 29	
7 Days Wet Burlap		53, >196		42, >196	53, 151
	20FA/5SF	20FA/7SF	30FA/5SF	30FA/7SF	INDOT Class C

Increasing Paste Content

Fig. 3. Age at cracking, days, for the restrained shrinkage cracking test (Green is better performance, red is poorest performance, and yellow is in between)

Figure 3 shows the results of the restrained shrinkage testing for all the concrete mixes with their associated curing conditions. In general, the cracking potential of the ternary concrete mixes increased with the increase in paste content of the mixes. The paste content, in this case, includes the supplementary SCMs of fly ash and silica fume. The curing conditions also influenced the resistance to shrinkage cracking. In most cases, curing of the mixes using wet burlap had a positive effect in reducing the potential for shrinkage cracking of ternary mixes. In addition, the INDOT Class C concrete without SCMs had a significant effect from the wet burlap curing. Mixes with lower paste content also exhibited better resistance to shrinkage cracking. The specimens made with 20% fly ash mixes did not have any shrinkage cracking even when air dried. However, this does not mean that concrete in the field does not require wet curing. The significant benefit of curing on shrinkage cracking potential is clearly demonstrated in this study.

Implementation

At the conclusion of this study, INDOT implemented the research results in actual construction in the field. Beginning in 2004, INDOT constructed a few bridge decks using the ternary mix formula of 20 FA/5SF from this study. The first bridge was the concrete deck on SR 23 in South Bend, IN. A few more bridge decks have been constructed using ternary concrete mixes with the wet burlap curing extended to 10 days to ensure adequate wet curing.

More Information

More details about this research, including the concrete mix proportions and additional test results, are available in ACI's *Concrete International*, Vol. 33, No. 1, January 2011, pp. 49-55.