BETON™
CONSULTING ENGINEERS L.L.C.

Mr. Jason Barnes
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December 1, 2021

Sent by e-mail

Re: Results of Shrinkage-Compensating Concrete with Fibers

Further to our proposal dated May 20, 2021, Beton Consulting Engineers (Beton) has prepared this report to document the results of the laboratory test program as well as to provide analysis for implementation of the Green Canvas product with FiberLite™ fibers.

Green Canvas™ is a type G expansive component as defined by ACI 223R-21. This type of expansive component is a blend of calcium dioxide and aluminum dioxide that produces calcium hydroxide platelet crystals when mixed with portland cement and water. By adding a sufficient amount of Green Canvas™ and providing proper restraint, strains caused by drying shrinkage can be offset. Thus, it is possible to minimize cracking and reduce the number of joints necessary. A testing program was developed to determine the appropriate amount of Green Canvas™ required to produce a desired amount of expansion. Green Umbrella FiberLite™ fibers were tested to determine what level of restraint they provided, and to determine their residual flexural strength. In addition to tests for design, durability tests were conducted to demonstrate enhanced properties of the hardened concrete. A list of ASTM tests performed along with a brief description is provided in the appendix.

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Mixture Proportions

The table below provides the proportions of the mixture investigated. Detailed mixture proportions with their plastic properties are appended to this report.

Table 1: Mixture Proportions

Mix	Cement (lb/yd^3)	Green Canvas (lb/yd^3)	Fine Aggregate (lb/yd^3)	Coarse Aggregate (lb/yd^3)	FiberLite (lb/yd^3)	Water
8% Green Canvas + 2/3 lb FL	519	45	1430	1775	2/3	260

The mixture was batched with a 0.46 w/cm at our Mendota Heights, MN laboratory and slump, air content and unit weight determined. All mixtures used mid-range water reducer and were non air-entrained.

Test Data

Restrained Expansion, ASTM C878

ASTM C878 is a test to determine the potential for expansion, under conditions of controlled restraint, of concrete made with shrinkage-compensating cement (figure 1). The test method may be adapted to study expansion involving different degrees of restraint. The performance of Green Canvas concrete was tested with ASTM C878 to determine the quantity of expansion. Specimens made with an 8% Green Canvas™ replacement amount for cement were tested for length change. Green Umbrella FiberLite™ monofilament acrylic fibers were used for restraint in lieu of the specified steel rod. The expansion results are shown in Figure 3. The specimens were wet cured for the initial 7 days, then subjected to drying in 50% humidity thereafter.

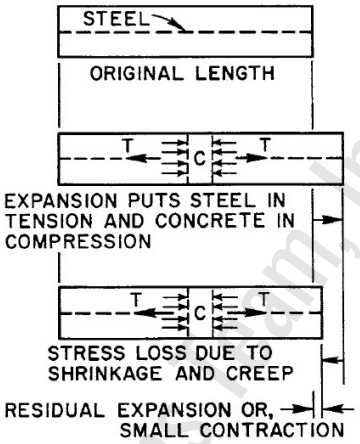

Figure 1: Basic Concept of shrinkage-compensating concrete (ACI 223R-21)

Figure 2: FiberLite Modified Acrylic Fibers

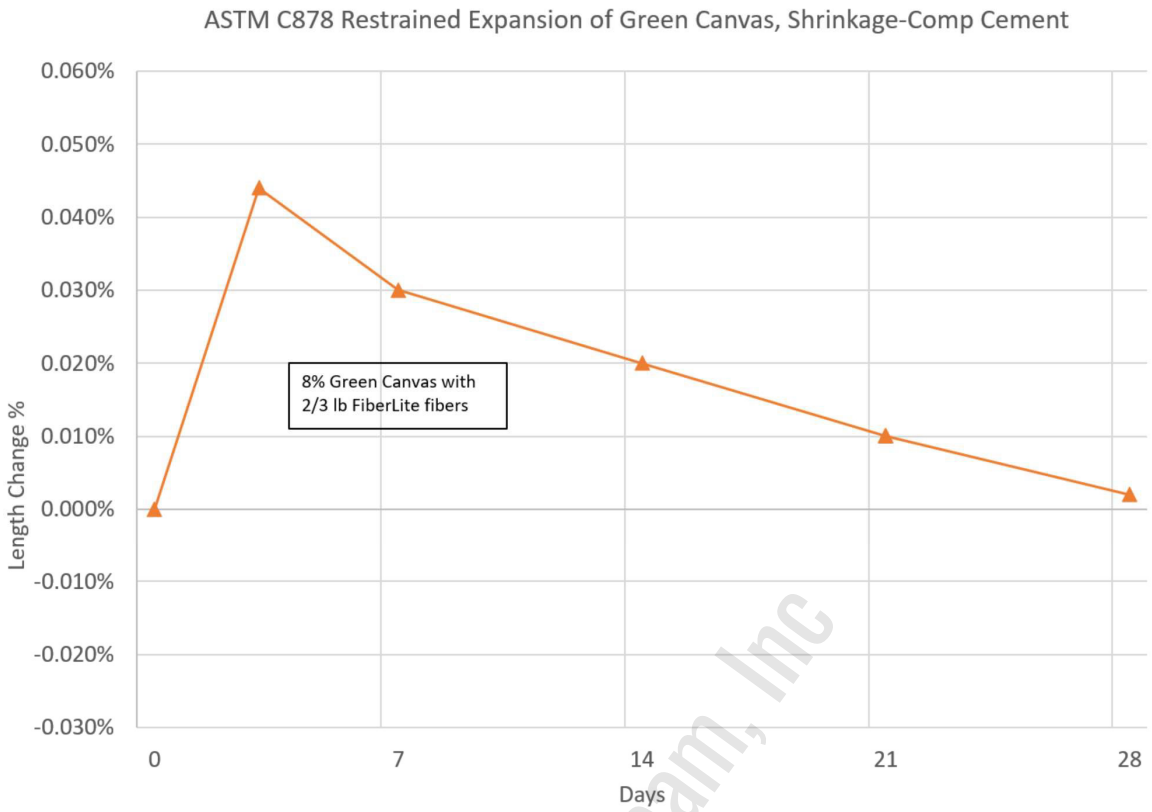

Figure 3: Restrained Expansion of Shrinkage-Compensating Cement with Fibers

Green Umbrella FiberLite ™ fibers are a modified acrylic micro-fiber (figure 2). The standard dosage rate is 2/3 lb/yd3. The test results demonstrate that much of the expansion happens within the first 3 days of wet curing then started to shrink. One issue encountered with the ASTM C878 test method, was that the specimens are not allowed to expand until the concrete has gained sufficient strength to be demolded. Therefore, the expansion that happens during the initial hours of the test cannot be captured. To account for the initial expansion, the rate of expansion during the first 3 days was assumed for the first 6 hours.

When designing shrinkage-compensating concrete for slabs on ground with increased joint spacing, the amount of expansion should be adequate to overcome the stresses that will be induced by subsequent drying shrinkage. The net result of the expansion and shrinkage should be zero. To determine the desired amount of expansion, the amount of restraint in the slab and the estimated amount of shrinkage must be calculated. The internal reinforcement, adjacent elements, and subgrade friction all provide restraint. The predicted amount of shrinkage can be obtained from ASTM C157 results. However, engineering judgement can be used based on the concrete mixture materials and proportions.

Residual-Strength of Fiber-Reinforced Concrete

ASTM C1399 is a test method to determine the residual strength of a fiber-reinforced concrete test beam. The average residual strength is computed using specified beam deflections that are obtained from a beam that has been cracked in a standard method. The data obtained from this test provides a measure of post-cracking strength of fiber-reinforced concrete. To perform this procedure, the beams

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were loaded at a set rate and continued loading until the beam cracks. After the beam has cracked, the beam is loaded to determine the amount of load that the fibers can carry. The load-deflection curve is provided below.

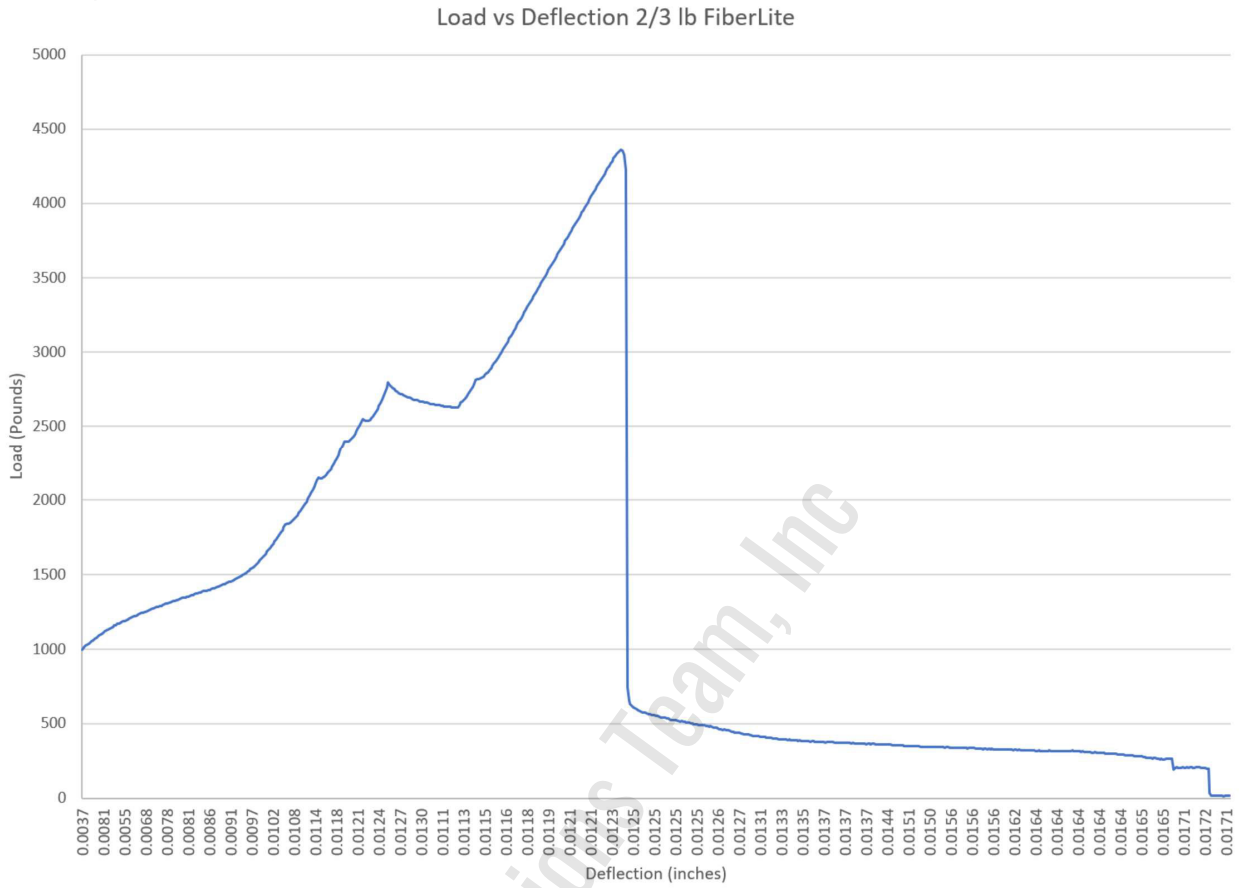

Figure 4: Load vs. Deflection 2/3 lb FiberLite

The 2/3 lb FiberLite™ dosage provided no residual strength. To calculate the average residual strength (ARS), the beams would need to carry a load, post-crack, for an additional 0.02 – 0.05 inches of deflection. These fibers would be most appropriate for plastic-shrinkage crack control.

Conclusions

Green Canvas™ would be an ideal product to design slabs on ground with extended joint spacing. ACI 223R-21, Guide for the use of Shrinkage-Compensating Concrete, provides design information. First, the anticipated final drying shrinkage of the slab would need to be calculated. Next, the percentage of reinforcement is used to calculate the minimum amount of expansion to compensate for the anticipated shrinkage. Figure 4 may be used for this calculation. The type of reinforcement can be rebar, welded-wire mesh, macro-synthetic fibers, or steel fibers. It is also permissible to adjust the reinforcement percentage based on expected shrinkage and expansion. Suggested details are provided in ACI 223 for locations that require additional consideration such as isolation joints, columns, footings, and door openings.

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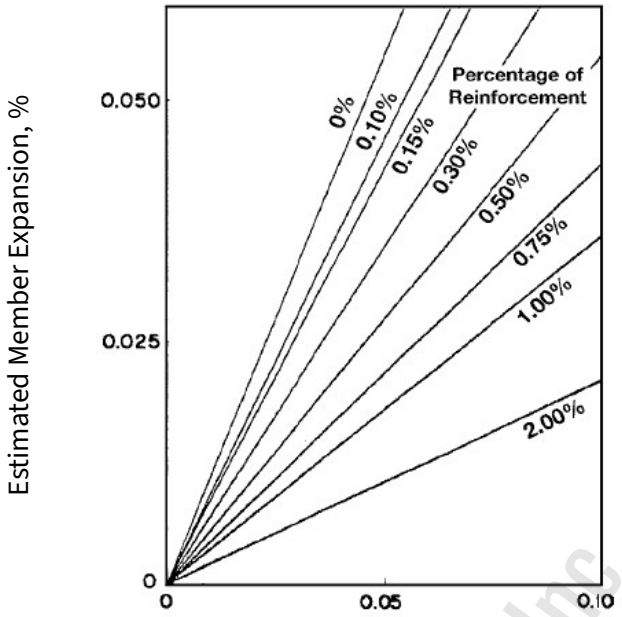

Figure 4: Member expansion as a function of ASTM C878 specimen expansion (ACI 223R-21)

We trust that this letter is self-explanatory. I look forward to additional discussions and thank you for the opportunity to be of service.

Sincerely,

Beton Consulting Engineers, LLC

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Senior Engineer

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Principal Engineer

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Appendix

ASTM Standards

ASTM C878: Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete: This test standard method covers the determination of the expansion of concrete made with shrinkage-compensating cement.

ASTM1399: Standard Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete: This test method covers the determination of residual strength of a fiber–reinforced concrete test beam. The average residual strength is computed using specified beam deflections that are obtained from a beam that has been cracked in a standard manner. The test provides data needed to obtain that portion of the load–deflection curve beyond which a significant amount of cracking damage has occurred and it provides a measure of post–cracking strength, as such strength is affected by the use of fiber–reinforcement.

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SEM Images

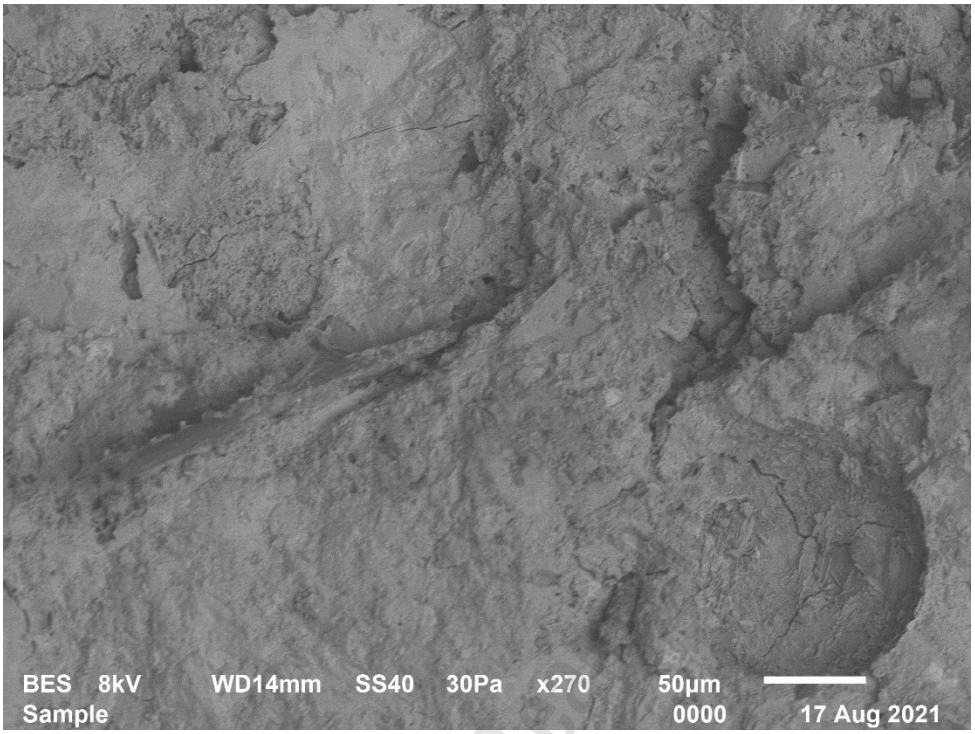

Figure 1: 2/3 lb FiberLite fibers 270 x magnification

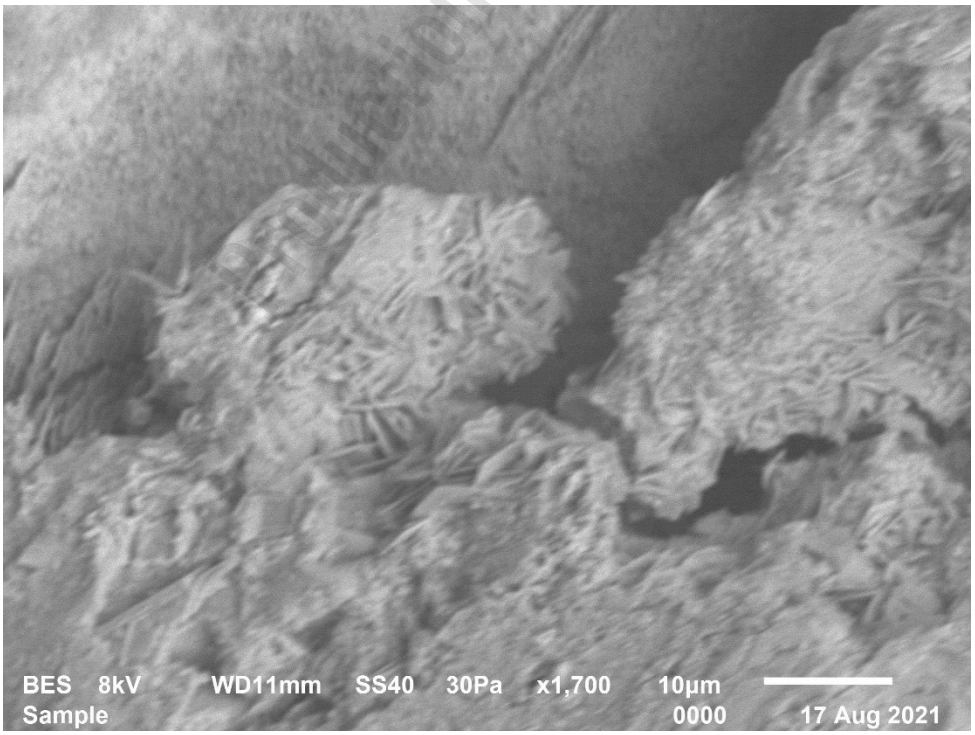

Figure 2: 2/3 lb FiberLite fibers 1700 x magnification