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CONSULTING ENGINEERS L.L.C.

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December 23, 2021

Sent by e-mail

Re: Results of Shrinkage-Compensating Concrete with Fibers; Durability Tests

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 fibers.

Green Canvas is a type G expansive component, 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 type G expansive component 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. Three different fibers were tested to determine what level of restraint they provided and 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.

Mixture Proportions

Eleven concrete mixtures were developed and tested. The table below provides the proportions of the 11 mixtures investigated. Detailed mixture proportions with their plastic properties are appended to this report.

Table 1: Mixture Proportions

	Control	2/3 lb Fiberlite	4 lb Fiberflex	5 lb MacX	8% GC + 2/3 lb FL	8% GC + 4lb FF	8% GC + 5lb MX
Cement (lb)	564	564	564	564	519	519	519
Green Canvas (lb)	0	45	45	45	45	45	45
Sand (lb)	1430	1430	1430	1430	1430	1430	1430
¾"-Gravel (lb)	1775	1775	1775	1775	1775	1775	1775
Water (lb)	260	260	260	260	260	260	260

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Fibers (lb)	0	2/3	4	5	2/3	4	5
C39	*						
C138	*	*	*	*	*	*	*
C143	*	*	*	*	*	*	*
C231	*	*	*	*	*	*	*
C266	*						
C878					*	*	*
C1064	*	*	*	*	*	*	*
C1138							
C1399		*	*	*			
C1556	*						

Each mixture was batched 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. 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 6%, 8%, 10% and 12% Green Canvas replacement amounts for cement were tested for length change. Specimens with 8% Green Canvas were also tested with three (3) different types of synthetic fibers in lieu of the specified steel rod. The expansion results are shown in Figure 2. The specimens were wet cured for the initial 7 days, then subjected to drying in 50% humidity thereafter.

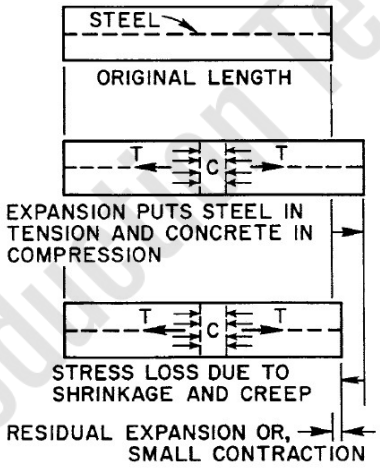

Figure 1: Basic Concept of shrinkage-compensating concrete (ACI 224R-16)

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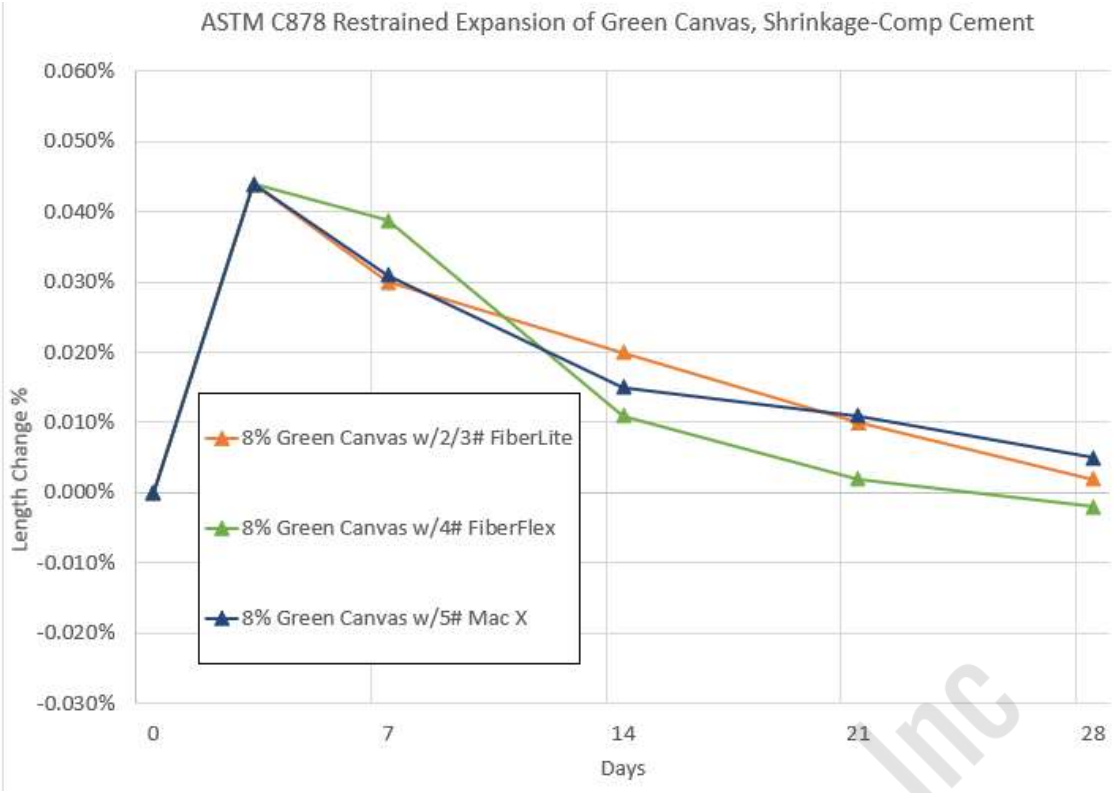

Figure 2: Restrained Expansion of Shrinkage-Compensating Cement with and without Fibers

The test results demonstrate that much of the expansion happens within the first 3 days of wet curing. All the samples without fibers continued to expand slightly after the initial 3 days of wet curing until the end of the 7-day wet-curing period, however the samples with fibers started to shrink after the initial 3 days. This would indicate a greater level of restraint in concrete made with fibers. This could be explained by increased surface area of the matrix of fibers distributed throughout the concrete versus the singular rod in the middle of the specimen. 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 reduced 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.

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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 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. Three (3) different synthetic fibers were tested,4 lb FiberFlex, 2/3 lb FiberLite, and 5 lb Mac X fibers. The load-deflection curves are provided below.

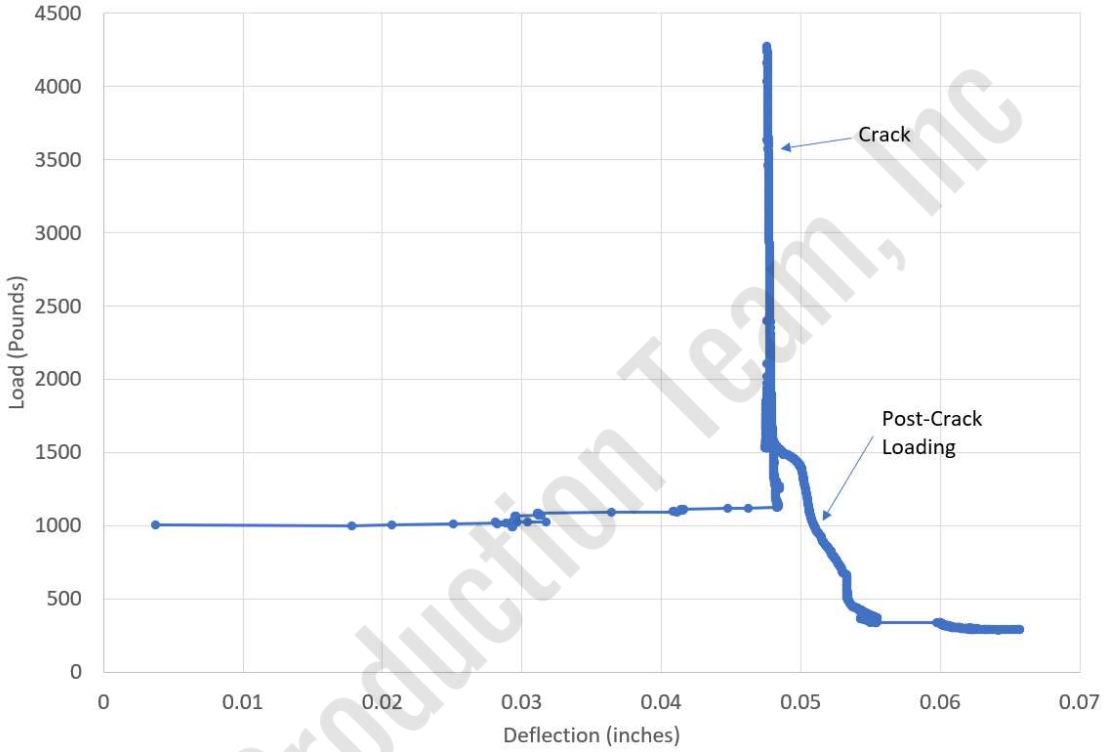

Figure 6: Load vs. Deflection 4 lb FiberFlex

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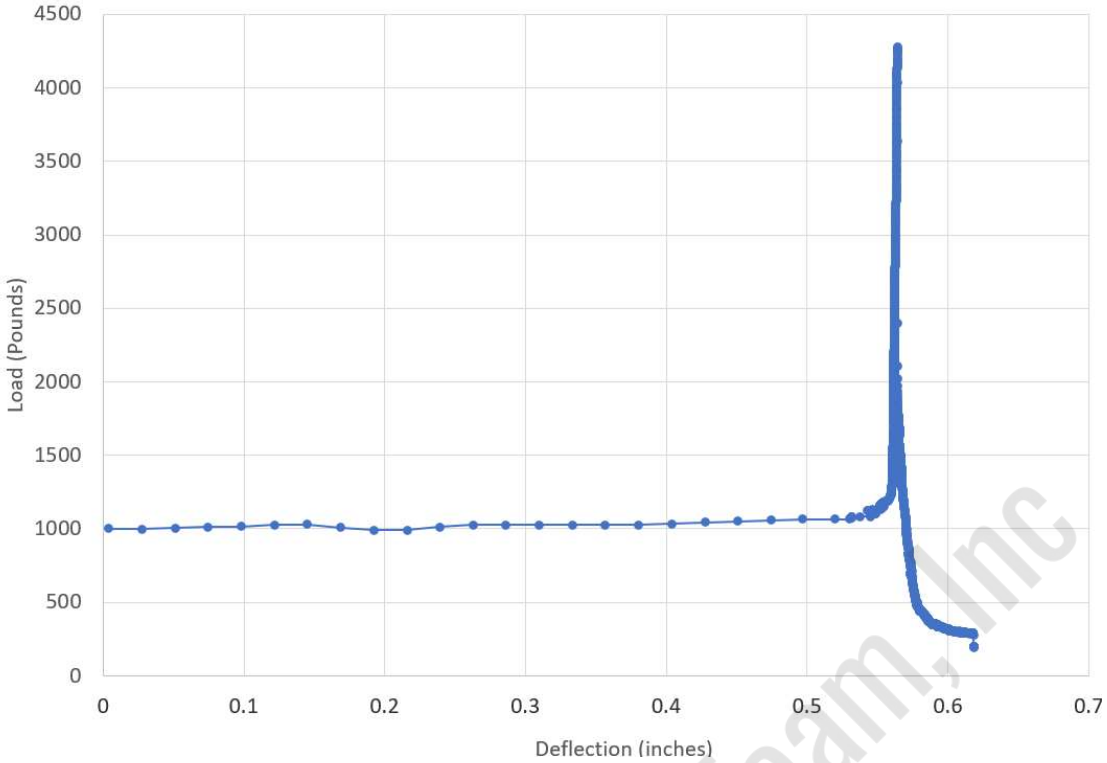

Figure 7: Load vs. Deflection 2/3 lb FiberLite

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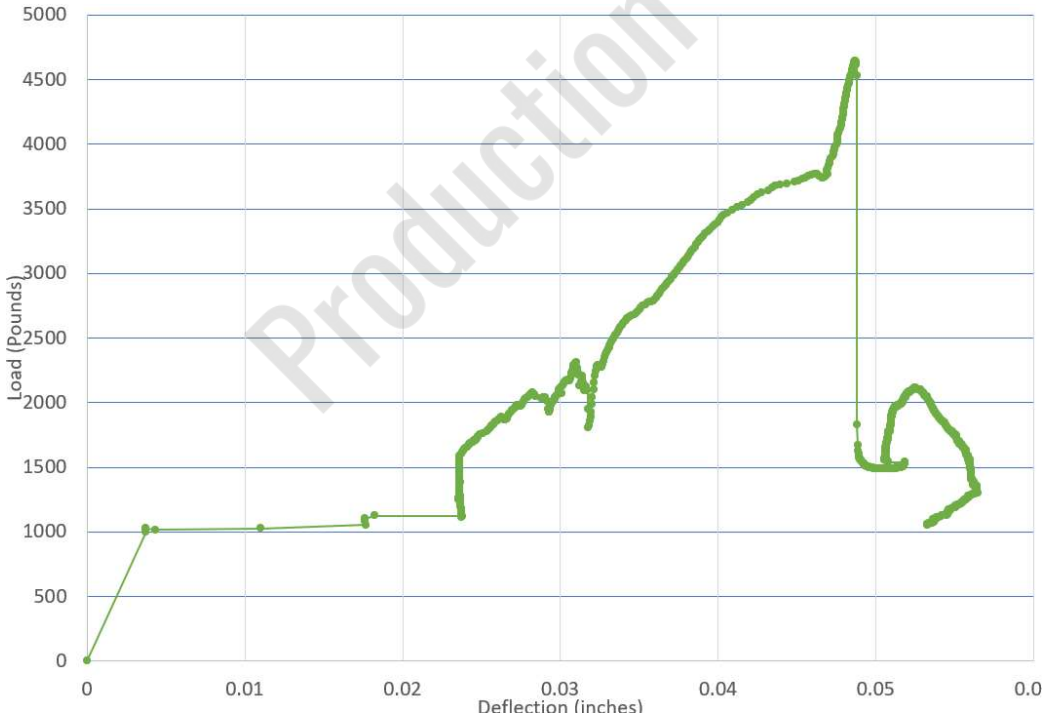

Figure 8: Load vs. Deflection 5 lb Mac X Fibers

The 4 lb FiberFlex and 5 pounds of Mac X fibers provided some 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. None of the fibers carried enough load to calculate an ARS, but they did carry a sufficient load post-crack to allow an increased joint spacing. If using the FiberFlex or Mac X fibers, a 20% increased distance in control joints could be achieved.

Discussion

The Green Canvas product appears to provide adequate expansion for most slab-on-ground applications if cured properly. None of synthetic fibers tested provided enough residual strength to quantify per ASTM C1399. Therefore, none of the fibers would be suitable to replace steel reinforcement. They would be acceptable for plastic-shrinkage crack control or in the case of the FiberFlex and Mac X fibers, a 20% increase in joint spacing.

Conclusions

Green Canvas would be an ideal product to design slabs on ground with extended joint spacing. ACI 223R-10, *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 9 may be used for this calculation. 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.

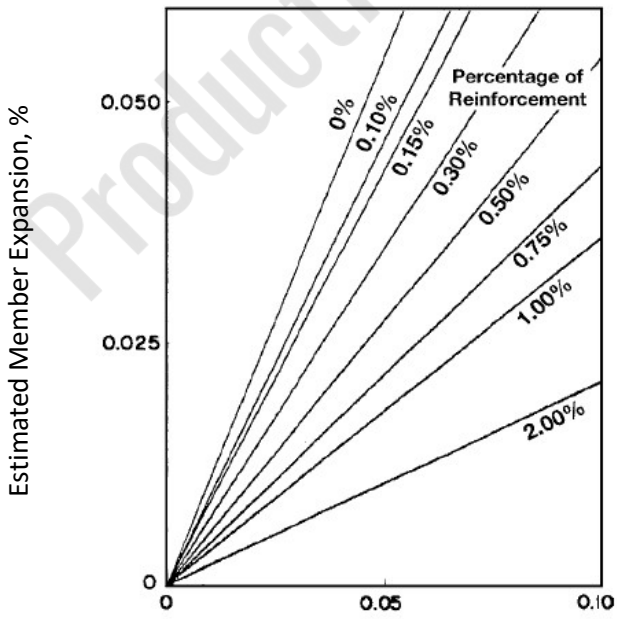

Figure 9: Member expansion as a function of ASTM C878 specimen expansion (ACI 223R-10)

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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

Sara Shuga
Senior Engineer

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Principal Engineer

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Appendix

ASTM Standards

ASTM C138: Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete: This test method covers determination of the density (see Note 1) of freshly mixed concrete and gives formulas for calculating the yield, cement content, and air content of the concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

NOTE 1—Unit weight was the previous terminology used to describe the property determined by this test method, which is mass per unit volume.

ASTM C143: Standard Test Method for Slump of Hydraulic-Cement Concrete: This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field.

ASTM C231: Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method: This test method covers determination of the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure.

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.

ASTM C1064: Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete: This test method covers the determination of temperature of freshly mixed hydraulic-cement concrete./

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

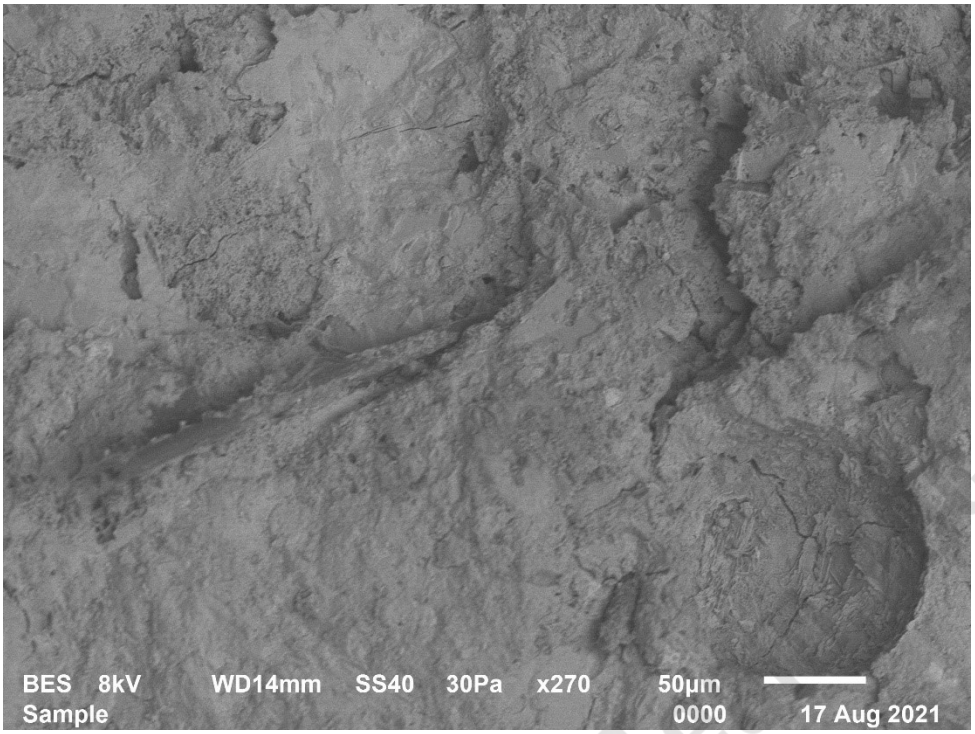

Figure 1: 2/3 lb FiberLite fibers 270 x magnification

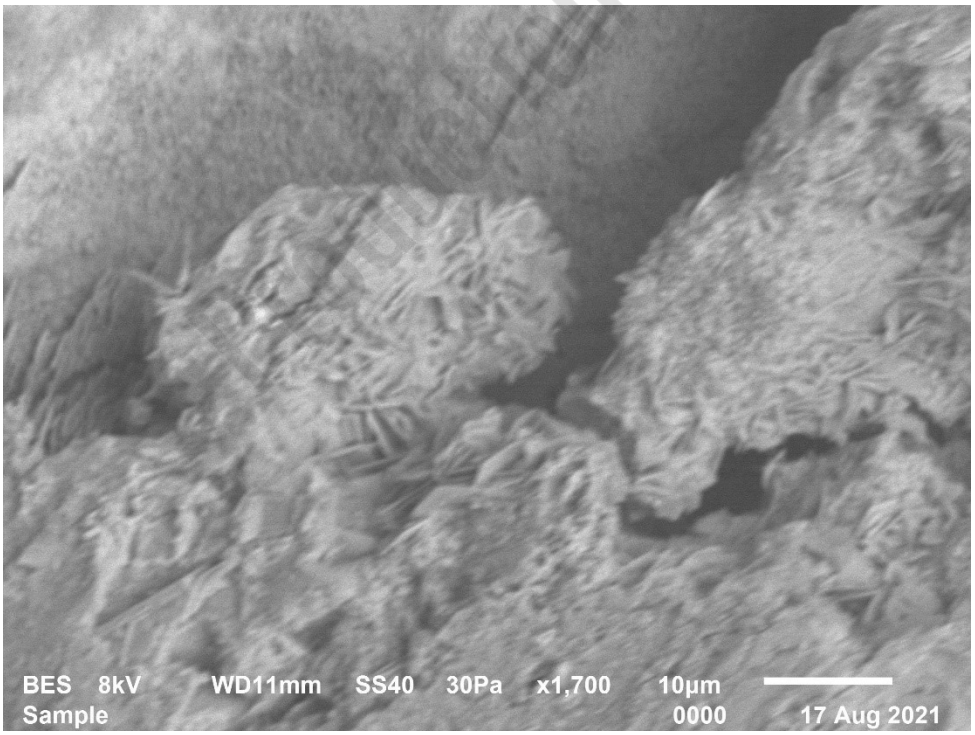

Figure 2: 2/3 lb FiberLite fibers 1700 x magnification