BETON™
CONSULTING ENGINEERS L.L.C.

Mr. Jason Barnes
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December 10, 2021

Sent by e-mail

Re: Results of Shrinkage-Compensating Concrete; 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 Green Canvas™ 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. 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

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

	8% GC	Control	6% GC	10% GC	12% GC
Cement (lb)	519	564	530	508	496
Green Canvas™ (lb)	45	0	34	56	68
Sand (lb)	1430	1430	1430	1430	1430
¾”- Gravel (lb)	1775	1775	1775	1775	1775
Water (lb)	260	260	260	260	260

	8% GC	Control	6% GC	10% GC	12% GC
C39	*	*			
C138	*	*	*	*	*
C143	*	*	*	*	*
C231	*	*	*	*	*
C266	*	*			
C878	*		*	*	*
C1064	*	*	*	*	*
C1138	*				
C1556	*	*			

Each mixture was batched with a 0.49 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. 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. 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.

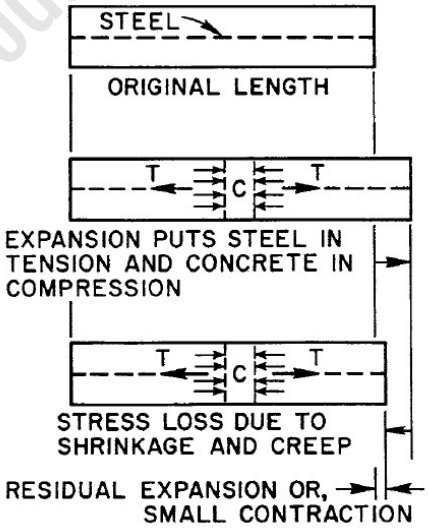

Figure 1: Basic Concept of shrinkage-compensating concrete (ACI 223R-21)

Property of Beton Team, Inc

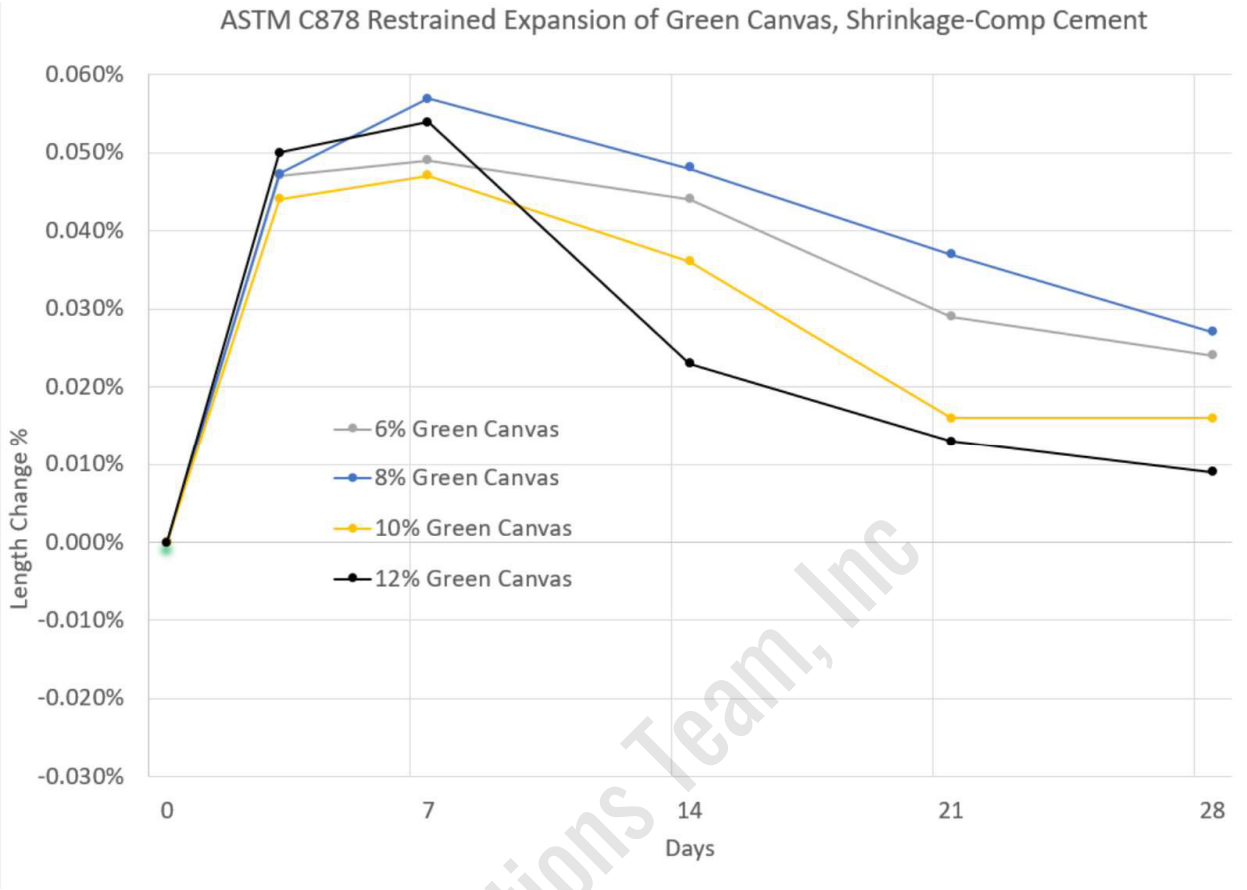

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Figure 2: Restrained Expansion of Shrinkage-Compensating Cement

The test results demonstrate that much of the expansion happens within the first 3 days of wet curing and continued to expand slightly after the initial 3 days of wet curing until the end of the 7-day wet-curing period. 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.

Compressive Strength

According to ACI 223R-21, after expansion, the tensile, flexural, and compressive strength development of shrinkage-compensating concrete is similar to portland-cement concrete. The results substantiate this statement. Table 2 below presents the compressive strength data from the trial batches. Figure 2 presents the results in graphical form.

Table 2: Compressive Strength Control and 8% Green Canvas™

Age, days	Control	8% Green Canvas
3	N/A	4880
7	5546	5710
28	7260	6870
56	N/A	7590

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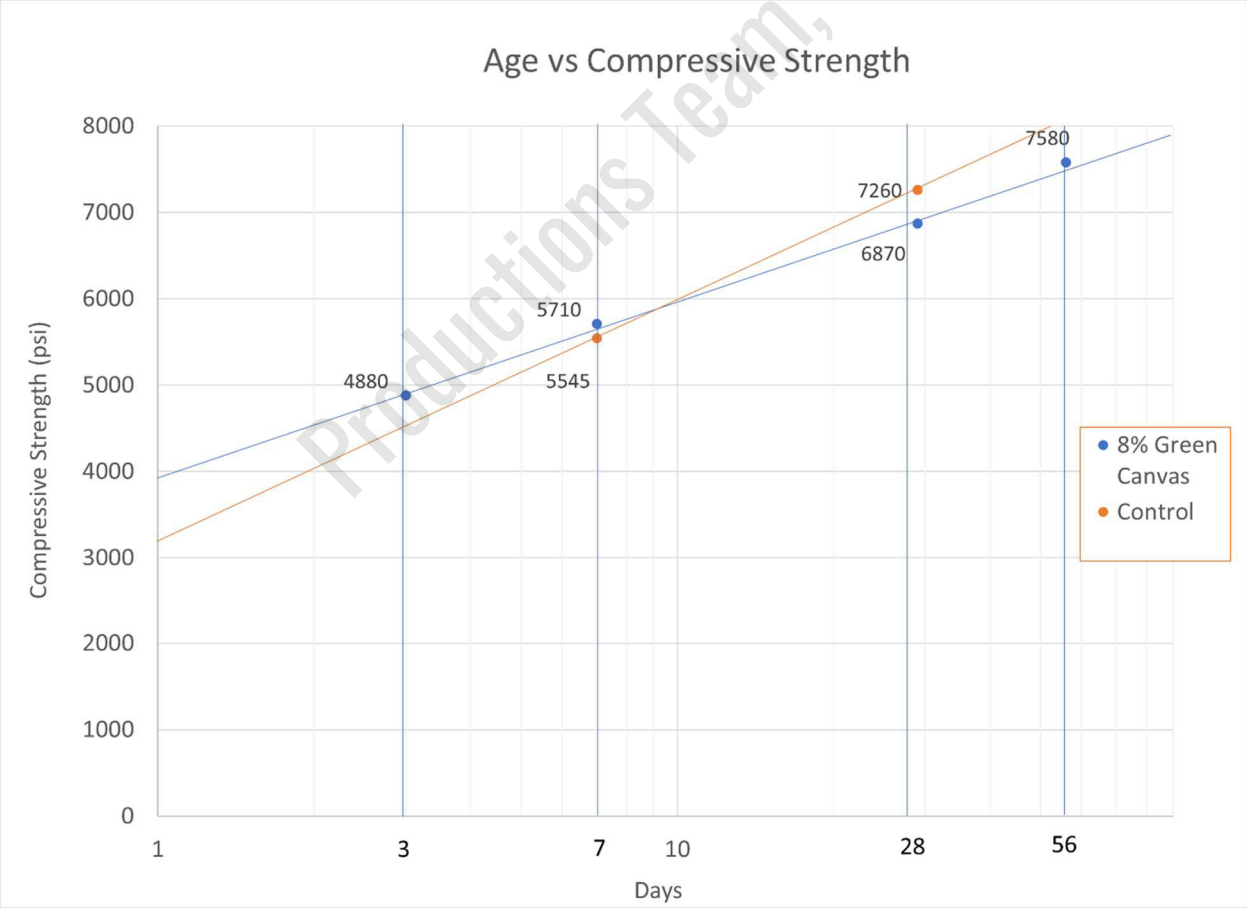

Figure 3: Strength Gain with Time

Time of Setting

The time of setting, in minutes, is presented in Figure 3 below. The initial set of the Green Canvas™ expansive cement was faster than the control. The final set was slightly slower. As far as finishing the concrete, this difference would not impact the finishing operations.

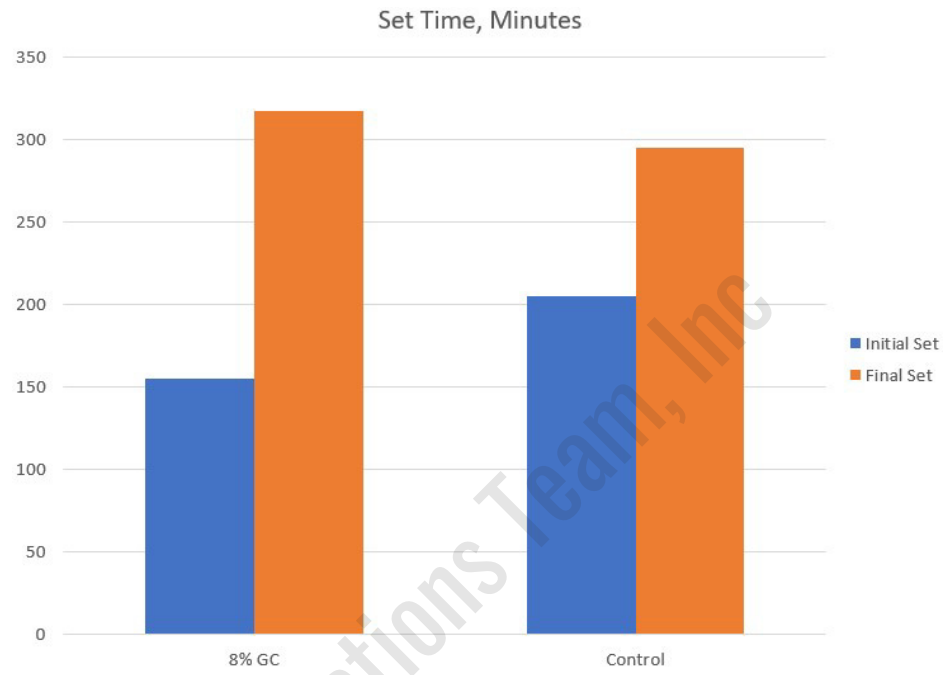

Figure 4: Time of Setting

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Abrasion Resistance

ASTM C1138, Standard Test Method for Abrasion Resistance of Concrete (Underwater Method), was performed on 8% Green Canvas™ specimens. This test method was designed to mimic the abrasive action of waterborne particles in stilling basins. Circulating water moves steel grinding balls on the surface of the concrete samples. This procedure measures the wear of a specimen's surface and calculates the average depth of wear and volume lost. Since this method is standardized, it is possible to provide a qualitative comparison of results of previous studies and data from literature. Test results were an average of 0.33 $m^3 x\ 10^{-3}$ or 4.6% of the initial volume after 72 hours. The complete report is located in the Appendix. A review of available ASTM C1138 tests from the last 40 years was investigated (Omoding et al., 2020). A figure was provided with all the test results. The Green Canvas™ samples performed better than the other natural gravel samples with the same compressive strength.

Apparent Chloride Diffusion Coefficient

The ASTM C1556 test method calculates the apparent chloride diffusion coefficient of cementitious mixtures that have not yet been exposed to external chloride ions. The results can be used to estimate chloride penetration into cementitious mixtures that are in a saturated condition. Beton tested two (2) concrete mixtures; one contained 8% Green Canvas™ and the control mix contained straight cement.

Table 3: Apparent Chloride Diffusion Coefficient Results

ID	Cs (mass %)	Ci (mass %)	Da (m/s^2)
8% Green Canvas	0.910	0.020	6.2E-12
Control	0.900	0.017	3.4E-12

Where:

Cs = projected chloride concentration at the interface between the exposure liquid and test specimen that is determined by the regression analysis, mass %

Ci = initial chloride-ion concentration of the cementitious mixture prior to submersion in the exposure solution, mass %

Da = apparent chloride diffusion coefficient, m^2/s

The apparent chloride diffusion coefficient is mainly dependent on the external concentration of chlorides and the concrete porosity. Since both samples were exposed to the same concentration of chlorides for the same amount of time, the concrete's porosity is the main controlling parameter affecting chloride ion diffusion of the samples above. When comparing the two results, they are effectively the same.

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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 9 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.

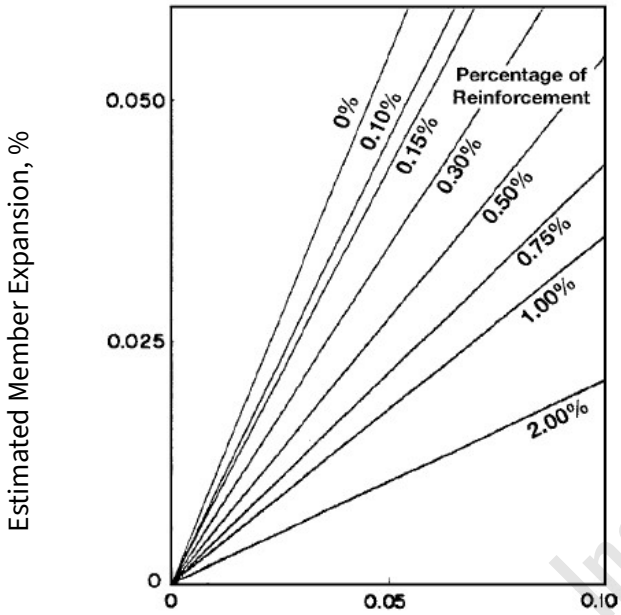

Figure 9: Member expansion as a function of ASTM C878 specimen expansion (ACI 223R-10)

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

Kevin A. MacDonald, PhD, PE, FACI
Principal Engineer

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Appendix

ASTM Standards

ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens: This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and stilled cores. It is limited to concrete having a density in excess of 50 lb/ft3

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 C266: Standard Test Method for Time of Setting of Hydraulic-Cement Paste by Gillmore Needles: This test method covers the determination of the time of setting of hydraulic -cement paste by means of the Gillmore needles.

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.

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ASTM C1138: Standard Test Method for Abrasion Resistance of Concrete (Underwater Method): This test method covers a procedure for determining the relative resistance of concrete (including concrete overlays and impregnated concrete) to abrasion under water (see Note 1). This procedure simulates the abrasive action of waterborne particles (silt, sand, gravel, and other solids).
NOTE 1—Other procedures are available for measuring abrasion resistance of concrete surfaces not under water. These include Test Methods C418, C779/C779M, and C944/C944M.

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./

ASTM C1556: Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitous Mixture by Bulk Diffusion: This test method covers the laboratory determination of the apparent chloride diffusion coefficient for hardened cementitious mixtures.

References

Omoding, N., Cunningham, L., Lane-Serff, G. (2020) Review of Concrete Resistance to Abrasion by Waterborne Solids, ACI Materials Journal, 117(3), 41-52.

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SEM Images

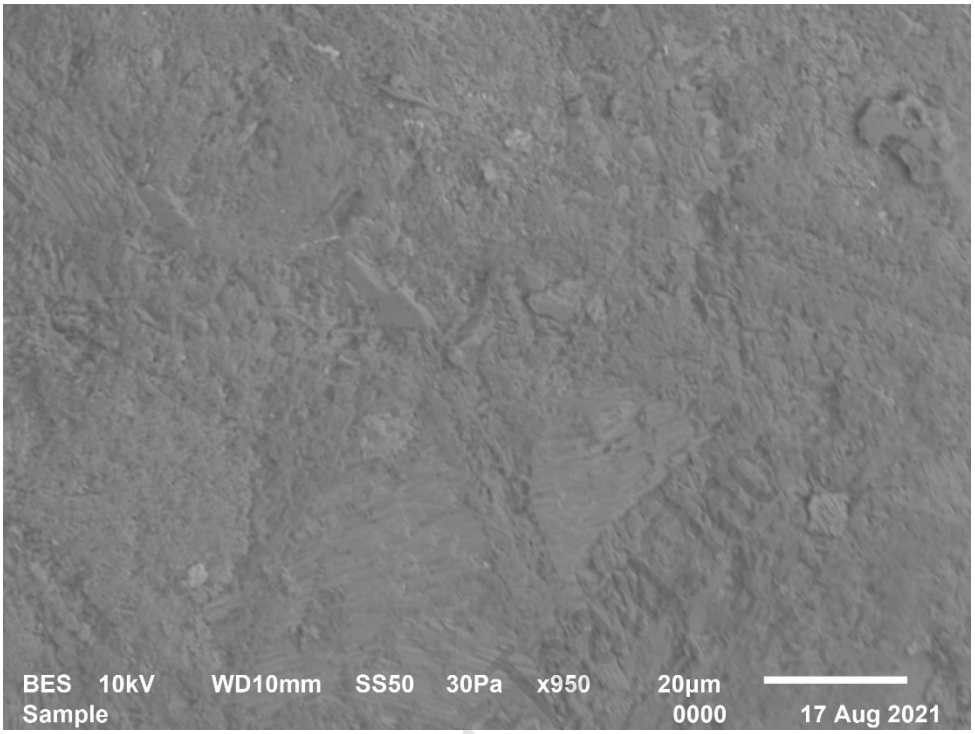

Figure 2: 8% Green Canvas™ 950 x magnification

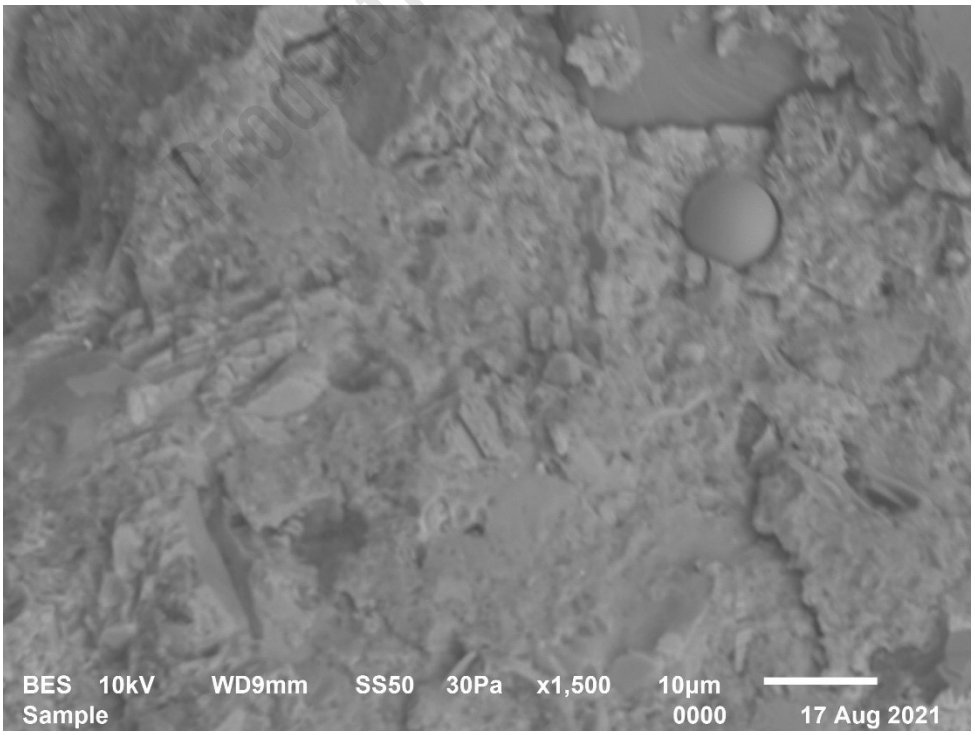

Figure 1: 8% Green Canvas™ 1500 x magnification