NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Molten Sand Research Center

Recycled Glass Concrete

Final Design Report

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1.0 Project Understanding

Waste is a common issue today in the world, in the United States in particular. Waste materials need a lot of energy to be recycled, but there are not a lot of recycling factories. According to the Environmental Protection Agency (EPA), the amount of glass that is being recycled is 34% [1]. Material recycling facilities (MRFs) accept the glass, plastics and metals for recycling purpose under contract. Even though MRFs are able to sell plastics and metals, no one wants to take the glass. Since glass producers have no easy way for its economical reuse, the recycling of glass is facing problems.

The United States generates about 131 million tons of fly ash from burnt coal. In 2008, an industry shows that the United States reused a 43% of the generated fly ash [2]. If fly ash can be used 100% as a recycled material instead of cement, it will reduce the carbon dioxide generated that can lead to green project. But this type is appropriate to be used in small projects such as crosswalk pavement in houses, and storage space.

The purpose of this project is to research concrete mix designs for pavement in which recycled glass will be used to achieve high strength concrete considering the climatic conditions in Flagstaff, Arizona. Using recycled glass in concrete can reduce overall cost, as it can substitute for expensive components in mix designs. Moreover, it is an ecofriendly option because recycled glass helps to conserve natural resources, as well as to reduce carbon dioxide emission due to the manufacturing of cement. This recycled glass concrete mix design is purposed to be used in parking lots and sidewalks at Northern Arizona University (NAU) in replacement of conventional concrete. The final mix design must produce strength over or within the allowable limit for conventional concrete strength, and the most ecofriendly design. If this research is successful, it will be a valuable option for the concrete mix designs.

To complete the project, sets of tasks are followed to organize the process. The tasks are:

Task 1-Research

Task 2-Developing Mix Formulae

Task 3-Experimental Preparation

Task 4-Experimental Procedures

Task 5-Data Analysis

Task 6-Project Management

2.0 Research

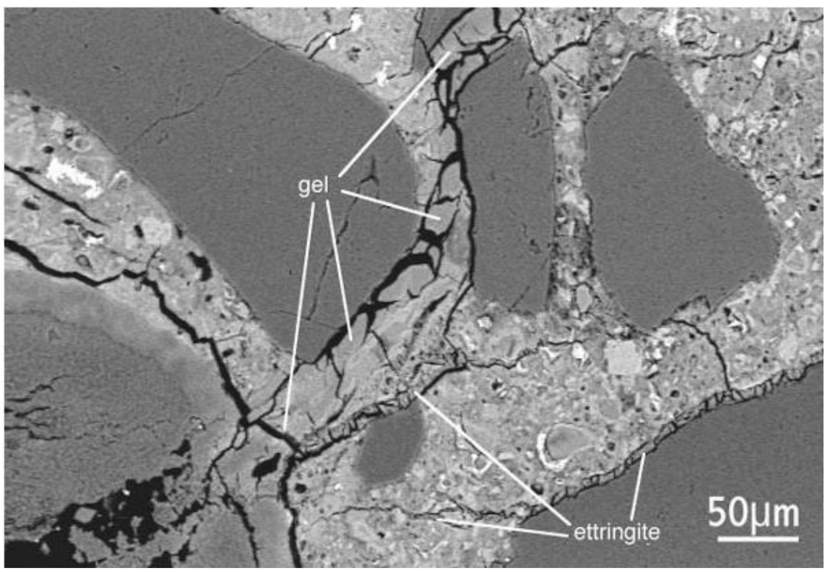
Methods and results from the past research will be assessed to assure that the most scientifically useful data are obtained.

2.1 Literature Review

2.1.1 Alkali Silica Reaction (ASR)

ASR is a reaction that caused by the silica within the aggregates and cement that over time turn into a gel. As time passes, more gel is formed causing it to take more space, causing micro cracks and reducing its tensile strength [3]. The ASR is started when the hydroxyl ions in the alkaline cement in the concrete it begins to form silica in the aggregate [3]. The following equaion shows the chemical reaction of ASR.

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca_2^+ + H_2SiO_{42}^- + 2H_2O \rightarrow CaH_2SiO_4 \cdot 2H_2O \qquad \text{Eq 2.1 [4]}$$



2. 1 Alkali Silica Reaction Gel Effect

As shown in Figure 2.1, the silica reacts with the potassium and calcium in the aggregates. When the amount of calcium increases in the gel and the amount of potassium decreases, the calcium becomes calcium silicate and when this product is hydrated, it expands.

2.1.2 Recycled Glass Size Properties

Recycled Glass (RG) is product that acts as a pozzolan, which could be either siliceous or aluminous, but in this case since it is in the form of glass, it is a siliceous product [5]. The presence of pozzolan in a concrete mix can help consume the alkali that are produced from the cement and the aggregate in the mix which in overall help to reduce the amount of ASR inside the concrete [4].

3.0 Experimental Work

This section will include mix design formula, material acquisition, mix procedure, and testing. The team follows ASTM standards to perform mixing, curing and testing.

3.1 Mix Design Formula

The team is expected to provide mix designs using three types of recycled glass; fine grade recycled glass sand, recycled glass sand, and recycled glass powder. Based on the high strength concrete design formula, the team started developing different mix formulae to produce a volume of 600 cubic inch concrete with and without fiber. The mix design formula has recycled glass, coarse aggregate (1/2", 3/8" and No.4), admixture (Water Reducer, VMA900, Air Entrainment and polymer), water, cement, sand, fiber and fly ash. Recycled glass powder was used to replace cement and recycled glass-sand was used to replace sand of the concrete. Nylon concrete fiber was added to increase the concrete strength.

The team created experimental matrixes to make it easier to follow each of the mix formulae in the design matrix and they are based upon previous researches. The mix designs changed depending on the amount of the recycled glass that was replacing the natural aggregates (sand) and cement. Table 3.1 shows the design mixes in which cement was used as a primary binder for the concrete with 13 designs. Control 1 contained 100% cement and 100% natural aggregate (sand).

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Table 3.1: Cement Binder Experimental Matrix

Mix Designs	Cement (lb. /yd^3)	RG Powder	Sand (lb. /yd^3)	RG Sand
Control 1	792.66	0%	1103.38	0%
MD# 1.1	792.66	0%	772.37	30%
MD# 1.2	554.87	30%	1103.38	0%
MD# 1.3	792.66	0%	882.71	20%
MD# 1.4	634.13	20%	1103.38	0%
MD# 1.5	792.66	0%	993.04	10%
MD# 1.6	713.40	10%	1103.38	0%
MD# 1.7	792.66	0%	551.69	50%
MD# 1.8	396.33	50%	1103.38	0%
MD# 1.9	792.66	0%	0.00	100%
MD# 1.7F	792.66	0%	551.69	50%
MD# 1.8F	317.07	50%	1103.38	0%
MD# 1.9F	792.66	0%	0.00	100%

In Table 3.2, fly ash was used for 100% of cement with the same weight distribution of the materials. In this table, fly ash and recycled glass-powder replaced cement, and recycled glass replaced the natural aggregate (sand). The percentages of RG are higher than in Table 3.1 because the goal with this design is to achieve a 100% ecofriendly concrete.

Table 3.2: Fly Ash Binder Experimental Matrix

Mix Designs	Fly Ash (lb. /yd^3)	RG Powder %	Sand (lb. /yd^3)	RG Sand %
MD# 2.0	792.66	0%	1103.38	0%
MD# 2.1	554.87	30%	0.00	100%
MD# 2.2	396.33	50%	0.00	100%
MD# 2.3	792.66	0%	551.69	50%
MD# 2.4	792.66	0%	0.00	100%
MD# 2.0F	792.66	0%	1103.38	0%
MD# 2.1F	554.87	30%	0.00	100%
MD# 2.2F	396.33	50%	0.00	100%
MD# 2.3F	792.66	0%	551.69	50%
MD# 2.4F	792.66	0%	0.00	100%

Table 3.3 represents the weight of the other materials used for all mixes. The weight of aggregates and admixtures except polymer do not change for all mix designs in Table 3.1 and 3.2. Polymer was used in Table 3.2 in order to increase the strength of fly ash mix designs. The amounts of water and water cement ratio were used based on cement mix design and fly ash mix design as described in Table 3.3.

Table 3.3: Original Experimental Matrix

Coarse Aggregates (lb./yd^3)	
#4	377.65
3/8"	377.65
1/2"	857.16
Admixture (oz.)	
Water Reducer	0.104
VMA	0.370
Micro Air	0.119
Polymer	11.41
Water (lb.)	
Cement Mix Designs	3.87
Fly Ash Mix Designs	2.85
W/C ratio	
Cement Mix Designs	0.38
Fly Ash Mix Designs	0.28
Fiber (lb./yd^3)	
Fibers	2.03

3.2 Material Acquisition

After the team developed the mix design formula, the team obtained the materials and equipment needed. The needed materials are recycled glass, Portland cement type II/IV, Class C fly ash, fine aggregate (natural sand), coarse aggregates, admixtures, nylon concrete fiber, silica fume and water. The recycled glass-powder and recycled glass-sand were purchased from a company called "Vitro Minerals" which is located in Jackson, Tennessee. This company is a leading manufacturer of recycled glass and other recycled materials. Type II/IV Portland cement from Ouikrete, which was used in all mixes, was purchased from Home Depot. Scott Palmer from Salt River Material Group Company also donated Class-C fly ash that is used for this project.

Fine aggregate (natural sand) and aggregates are donated from the CEMEX Company in Flagstaff, Arizona. The anticipated sizes of aggregate are ½ in (25.4mm), ¾ in (19mm), ⅜ in (9.51mm) and No. 4 (4.76mm). The aggregates that are obtained from CEMEX were sieved to get the anticipated sizes of aggregates that are mentioned above. Once sieving was done, aggregates were separated into different buckets marked by the aggregate size. Then, sieved aggregates were washed clean enough from the dust to be able to use in concrete mixes and were dried for one day by putting into the steel tray. Figures 3.1 and 3.2 show the anticipated sizes of aggregates and sieve sizes used through the project.

Figure 3.1: Aggregate sizes used through the project

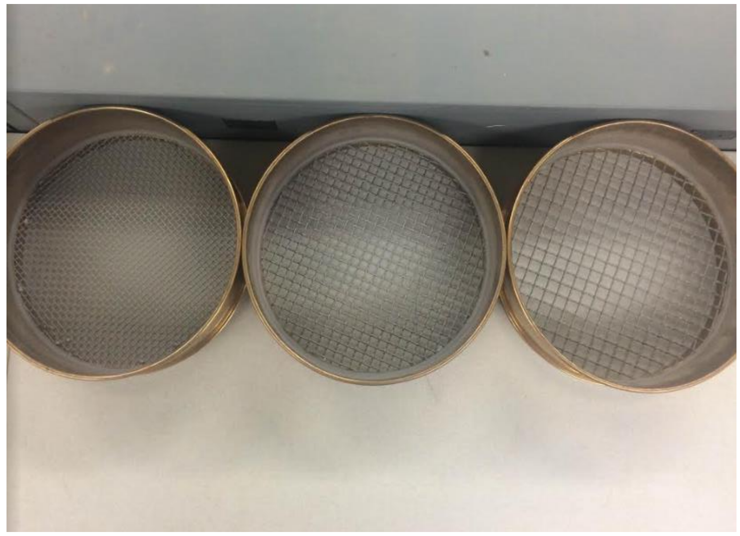

Figure 3.2: Sieve sizes used

Admixtures were used to improve strength and to provide the design mix with resistance against thermal and fatigue cracks. The admixtures used for all mix designs are Mid-Range Water Reducer, Air Entrainment (Micro Air), Viscosity Modifier (VMA) and polymer. All admixtures were found in CENE Soils and Material lab at NAU. Water Reducer is a chemical that reduces the amount of water needed for the mix to reach its high strength. This chemical improves the strength of the concrete mix (compression and tensile (flexural)), as well as the workability of the concrete. Air Entrainment is a chemical that creates air bubbles in the concrete creating air voids in the concrete mix to increase the thermal resistance of the concrete. Viscosity Modifier also helps to increase the strength and the workability of the concrete mix. Polymer, which was donated from Euclid Chemical Company, increases the strength of the concrete and the workability for few minutes after the mixing is done.

Figure 3.3: Polymer

3.3 Mix Procedure

All mix designs have the same process of mixing, creating the cylindrical samples, and curing tasks. Mixing was performed in the CENE Soils and Material labs at NAU, using a mini electric cement mixer, see Figure 3.4. To start mixing, the mini electric cement mixer was washed and cleaned.

Figure 3.4: 1.25 Cubic Foot Concrete Mixer

The procedure followed was:

(1) Three different sizes of aggregates were weighed and combined together in one bucket. Water and additives were mixed together in a large volumetric cylinder. Finally, cement or fly ash, sand, and recycled glass were added together in another bucket according to the mix formula.

(2) Half of the aggregates, as well as, half of the cement/fly ash, sand and recycled glass were placed in the mixer while rotating. After one third of the water and admixtures in the volumetric cylinder was added, they were mixed for five minutes. Then, the rest of the materials were added and mixed for one minute. Once half of the rest water in the cylinder was added and mixed for three minutes, a tamping rod was used to avoid the mix from sticking in the wall of the mixer. After adding the rest of the water was mixed for three minutes into the mixer, the mixing process was completed with total fourteen minutes.

(3) After the mixing was completed, the wet concrete was poured into a bucket, and manually mixed it by pouring into another bucket by repeating the same process twice. Then, it was poured into the steel tray to perform the slump test.

(4) The wet concrete was thoroughly compacted into one third of 4x8 inch cylindrical molds. Then, it was closed with a lid and taped not to let the air enter into the sample.

(5) The samples were de-molded after it was completely dry.

(6) Then, the cylindrical specimens were cured for 7 and 28 days in order to strengthen the concrete using hydration.

3.4 Slump Test

A Slump test determines the consistency of the fresh concrete. A Slump test is performed immediately after mixing by following ASTM C143-C143M standard method. A metal slump cone, a scale for measurement, a steel rod and a big tray from the Mechanics of Materials Lab in the engineering building at NAU was used to complete the slump test. Figure 3.5 shows the materials set for Slump test.

Figure 3.5 Material Set for Slump Test [6]

3.5 Tensile Splitting Test

A Tensile Strength test evaluates the behavior of the concrete under applied load. A tensile strength test machine (Figure 3.6) located in the Mechanics of Materials Lab in the engineering building at NAU was used to perform the tensile strength test. ASTM C496 standard method is used to accomplish the tensile strength test.

After the sample is cured, it must be completely dry to perform the tensile splitting test. The sample is horizontally laid on the platform of the loading machine. Then, a smooth surface wooding stick is placed at the bottom and top of the sample. The test results are directly obtained from the screen of the machine.

Figure 3.6: Tensile Strength Test Machine

3.6 Freeze-Thaw Cycle Test

A Freeze-Thaw Cycle test is accomplished to test the resistance of the concrete to rapid freezing and thawing. A "Gilson HM-120 Automatic Freeze Thaw Apparatus" (Figure 3.7) is used to complete the freeze thaw cycle test by following ASTM C666 standard method. The machine is located in the Construction Materials Lab in the engineering building at NAU.

The samples for the freeze-thaw cycles are placed into molds 18 inches long and 6 inches wide. Half of the mold is filled with a mix design and the other half is added with another mix design because there are not enough spaces in the cabinet with another students' samples. Figure 3.7 shows the 9 x 6 inch freeze-thaw sample.

Figure 3.7: Freeze Thaw sample

After the sample is dried, the sample is cut to a rectangular shape because the sample cannot be fully compacted in the rectangular freeze-thaw mold. If the sample did not fit into the machine, this will lead inaccurate results due to many voids at the bottom of the specimen. At 100, 150, 200, 250, and 300 cycles, the dried samples will be measured for any expansion that occurred. Also, the dry weight and the submerged weight will be reported to observe the air void change within the samples.

Figure 3.8: Gilson HM-120 Automatic Freeze Taw Apparatus [7]

3.7 Electron Microprobe Lab Test

This test determines alkali silica reaction (ASR) reaction of the materials in the concrete mix design. The NAU Electron Microprobe Lab (Figure 3.8) in Bibly Research Center at NAU was used to perform the test.

The samples for ASR (Figure 3.9) were prepared by adding silica in a moisture can by following two different ways for each experimental matrix. The first experimental matrix was for cement binder mix designs in Table 3.1. Only cement paste was used from the mix but not including the aggregates. The amount of silica within each design mix is 5% of the aggregate added to the cement weight, which is 0.003 pounds in each design mix. Finally, the samples were putting into curing twenty-eight days curing to allow the silica to react, and observed under the electron microscope to see the micro expansions due to ASR.

The second experimental matrix is for fly ash binder mix designs in Table 3.2. The fly ash samples were prepared by obtaining a sample right of the binder mix, and placed it in moisture can. After the sample was dried, the sample was put into curing for twenty-eight days. While the sample was curing, 0.003 pounds of silicon dioxide with water was added to react with the fly ash sample. Finally, the sample will be sent to Electron Microprobe Lab to observe the micro cracks that accrued from the ASR.

Figure 3.9: Cement and Fly Ash samples

Figure 3.10: Electron Microprobe Laboratory [8]

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4.0 Testing Results

4.1 Slump Test Results

The slump results can be one of four (4) types of slump, (1) A true slump that can be measured; then the workability of the concrete can be computed, [9]. (2) Zero slump which is the most preferred type for this project; concrete with zero slump is usually used for road construction, [9]. (3) Collapse slump and (4) shear slump indicates that there is an error with the mix design and it cannot be used as a concrete for construction, [9]. The four types of slump are shown in Figure (4.1)

Figure 4.1: Types of Concrete Slump Test Results [9]

For all the mix designs in the first experimental matrix (that uses cement as a binder material) the slump test results were zero.

For all the mix designs in the second experimental matrix (that uses fly ash as a binder material) The fly ash samples have experienced a drop because the polymer that is used in this experimental matrix have the liquid characteristics, causing the mix right after mixing to be more toward the liquid state, when performing the slump in this case the sample fall under the true type with a drop of 7 inch out of 12 inches. One the polymer hardens, which takes from 5-7 minutes the slump comes back to zero type.

4.2 Tensile Splitting Test Results

The concrete cylinders are tested on the 7th and 28th day of curing. There is one sample for the 7th day and three samples for the 28th day to be tested. The tensile tension strength for the cement binder mix designs is shown into two tables. Table 4.1 represents the average tensile strength of mix designs that consist less than 50% RG replacement. Table 4.2 shows the average tensile tension strength of mix designs that consist of 50% and 100% RG replacement.

Table 4.1: Tensile Tension Strength for mixes less than 50% RG replacement

Experimental Number	Experimental Detail	7 days average (psi)	28 days average (psi)	Standard Deviation (28 days)
Control	0% RG	635	890	73
1.1	30% RG Sand	770	810	79
1.2	30% RG Cement	680	705	33
1.3	20% RG Sand	563	685	123
1.4	20% RG Cement	795	565	67
1.5	10% RG Sand	585	700	13
1.6	10% RG Cement	640	635	71

Table 4.2: Tensile Tension Strength for mixes more than 50% RG replacement

Experimental Number	Experimental Detail	7 days average (psi)	28 days average (psi)	Standard Deviation (28 days)
1.7	50% RG Sand	695	830	71
1.8	50% RG Cement	625	730	32
1.9	100% RG Sand	650	820	77
1.7F	50% RG Sand	610	820	38
1.8F	50% RG Cement	665	810	113
1.9F	100% RG Sand	585	835	76

The design mixes that contain less than 50% RG replacement compared to the mixes with more than 50% RG replacement matrix are not as strong. When the amount of RG increases and it is more consistent in distribution through out the matrix in the concrete, the concrete becomes stronger in the twenty-eight (28) days. However, in the seven (7) days, the strength of the design mixes that have less than 50% RG replacement are stronger with range of 640 to 795 psi in comparison with the designs that contain more than 50% with the range of 585-695 psi for seven days strength.

Both designs with RG higher and lower than 50%, the tensile strength did not surpass the control sample in twenty-eight (28) days. In the design mixes that contain less than 50% RG replacement, MD# 1.1 with a 30% RG replacement of sand have the least tension strength difference of 9% from the control sample in twenty-eight (28) days strength. On the other hand, for the design mix with RG replacement higher than 50%, the minimum difference in percent from the control sample, is achieved in sample 1.9F that includes a 100% recycled glass and fiber, the difference in percent is 6%, which proves that the more consistent the material distribution matrix in the mix the stronger the concrete. The comparison is shown in Figures 1 and 2, shows the difference of tensile strength relaying on the minimum design strength and the control sample, the minimum concrete compressive strength, which is 4000 psi for parking lot concrete [10]. The compressive strength is transformed to tensile using an empirical equation from (*Reinforced Concrete: Mechanics and Design* book, [11]), the equation is represented in equation 4.1.

Equation 4.1, Empirical equation relating compressive to tensile strength [11]

$$\boldsymbol{f_{ct} = 6.4\sqrt{f'_c}}$$

Where:

f_{ct}= Tensile Splitting Strength (psi)

f'_c= Compressive Strength (psi)

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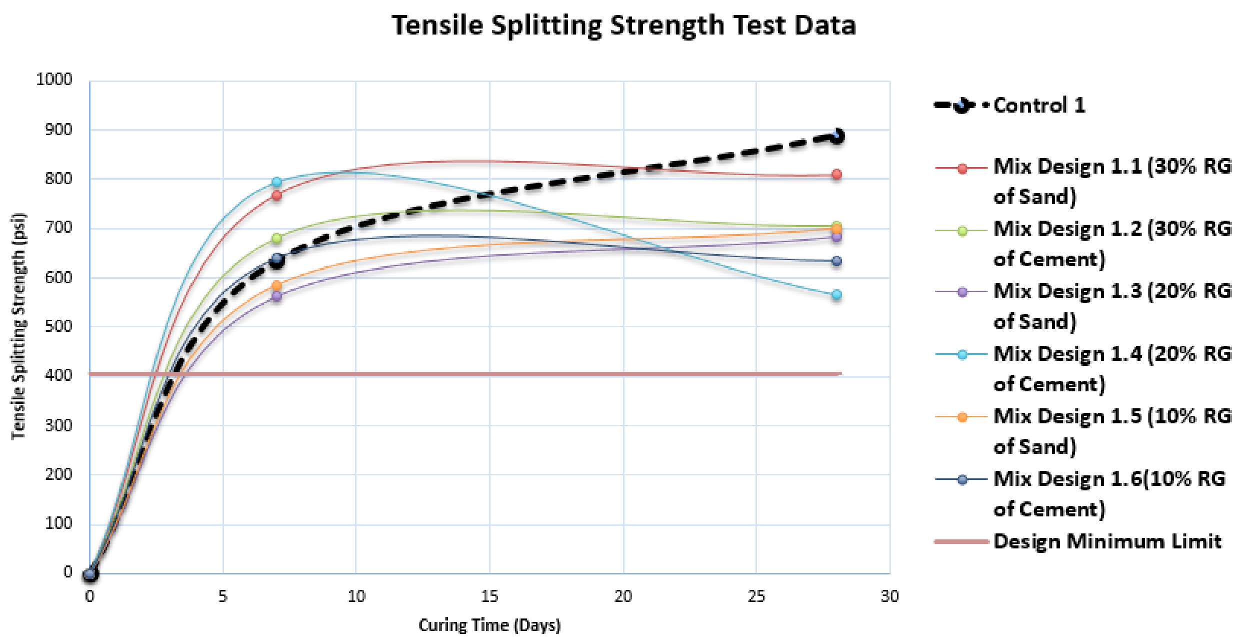

Figure 4.2: Tensile Strength for Mix Designs Less Than 50% RG Replacement

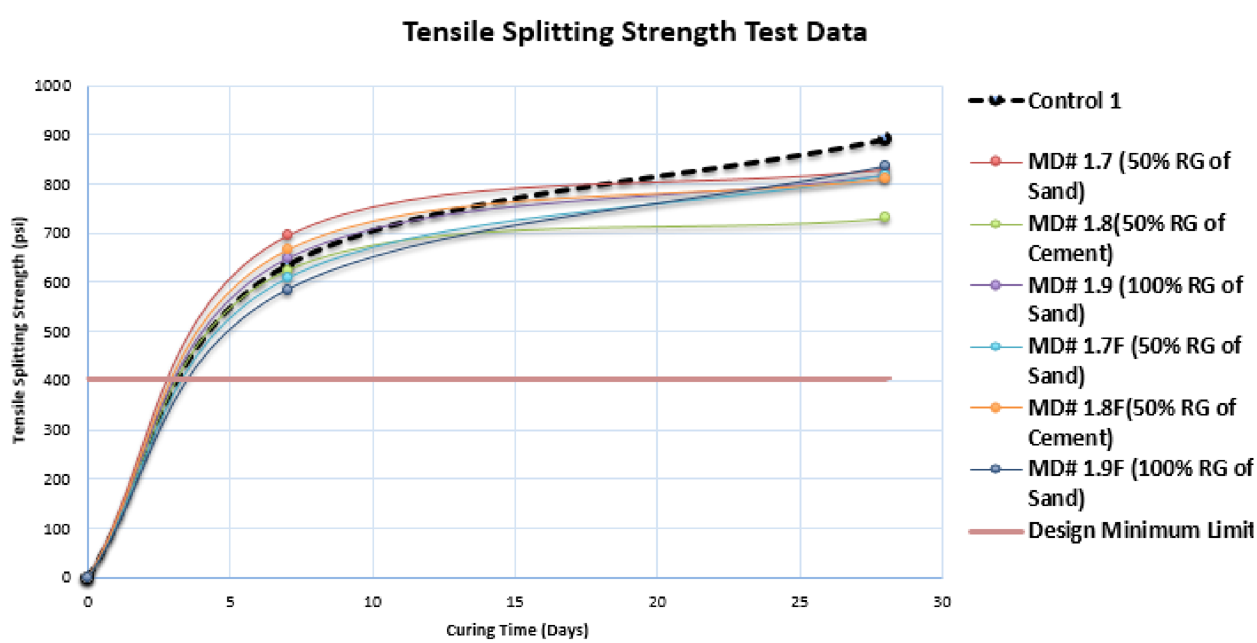

Figure 4.3: Tensile Strength for Mix Designs More Than 50% RG Replacement

All fly ash mix designs have filed to obtain the minimum allowable strength, which is around 404 psi for paving materials such as sidewalks, or parking lots. Otherwise, the use of recycled glass in the fly ash samples can significantly increases strength when recycled powder is used to replace fly ash. The mix design (MD# 2.1) have a 30% RG powder replacing fly ash and 100% RG sand replacement, obtained the highest strength of the fly ash mix designs with an increase of 270% from the fly ash control mix design (MD# 2.0). Table 4.3 shows the tensile strength for the fly ash samples that were obtained in 7 and 28 days curing. The mixes in the table that labeled new means that the mix has to be done again due to mixing errors.

Table 5.3: Tensile Tension Strength for Fly Ash mixes

Experimental Number	Experimental Detail	7 Days Average (psi)	28 Days Average (psi)	Standard Deviation (28 days)
MD# 2.0 (no polymer)	(100%FA, 0%RGP, 0%RGS)	36	44	4.7
MD# 2.0	(100%FA, 0%RGP, 0%RGS)	60	96	5.7
MD# 2.0F	(100%FA, 0%RGP, 0%RGS)	60	67	5.3
MD# 2.0F New	(100%FA, 0%RGP, 0%RGS)	36	44	5.07
MD# 2.1	(70%FA, 30%RGP, 100%RGS)	120	156	25.33
MD# 2.1F	(70%FA, 30%RGP, 100%RGS)	70	75	5.91
MD# 2.1F New	(70%FA, 30%RGP, 100%RGS)	233	186	0.99
MD# 2.2	(50%FA, 50%RGP, 100%RGS)	59	70	5.4
MD# 2.2F	(50%FA, 50%RGP, 100%RGS)	77	62	1.11
MD# 2.3	(100%FA, 0%RGP, 50%RGS)	87	89	11.31
MD# 2.3F	(100%FA, 0%RGP, 50%RGS)	58	73.4	5.19
MD# 2.4	(100%FA, 0%RGP, 0%RGS)	103	92	2.65
MD# 2.4F	(100%FA, 0%RGP, 0%RGS)	102	91	33.59

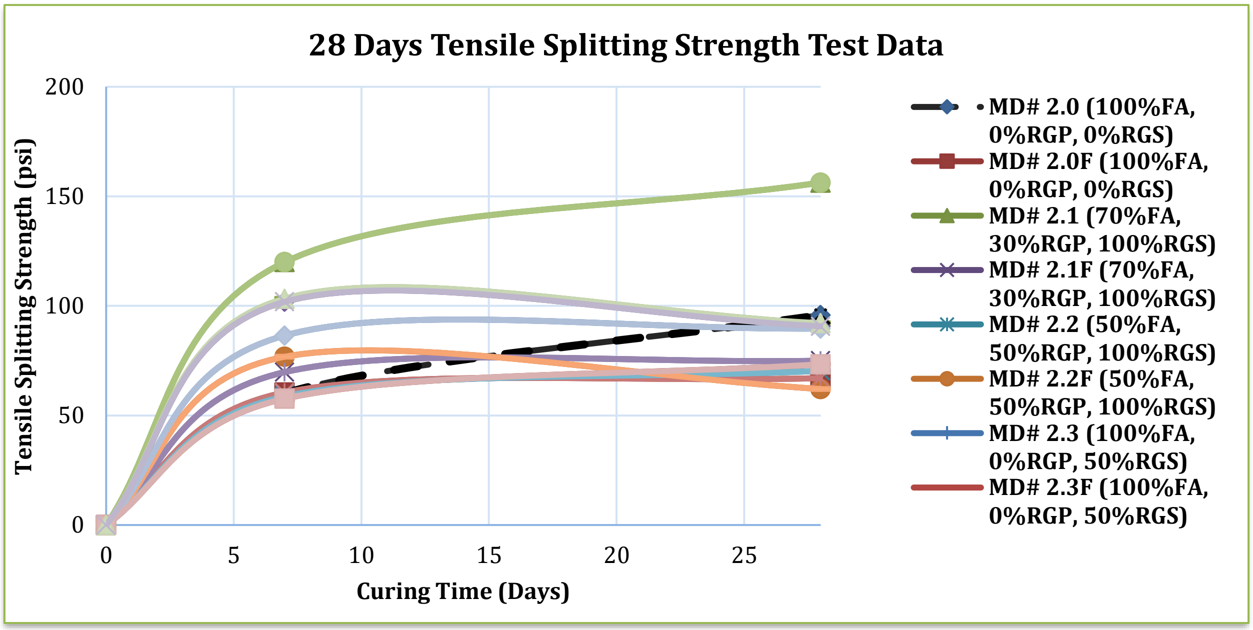

Figure 4.4: Tensile Strength for Fly Ash Mix Designs

4.3 Compressive Strength Test Results

Compressive strength results are generated using equation 1. The equation is an estimate of how much tensile strength is generated due to compression, where the equation is modified to solve for compression instead of tensile. The results are represented in seven (7) and twenty-eight (28) days in two tables. Table 4.3 shows the compressive strength results for design formulae that consist less than 50% RG replacement. Table 4.4 shows the compressive strength results for design formulae that consist more than 50% RG replacement.

Table 4.4:Compressive Strength for mixes less than 50% RG replacement

Experimental Number	Experimental Detail	7 Days Average (psi)	28 Days Average (psi)	Standard Deviation (28 days)
Control	0% RG	10080	19375	3184
1.1	30% RG Sand	14435	14640	3111
1.2	30% RG Cement	11350	12170	1117
1.3	20% RG Sand	7740	11650	3854
1.4	20% RG Cement	15400	7870	1920
1.5	10% RG Sand	8325	12010	451
1.6	10% RG Cement	10010	9920	2257

Table 4.5: Compressive Strength for mixes more than 50% RG replacement

Experimental Number	Experimental detail	7 Days Average (psi)	28 Days Average (psi)	Standard Deviation (28 days)
1.7	50% RG Sand	11865	16810	2886
1.8	50% RG Cement	9535	13030	1174
1.9	100% RG Sand	10325	17000	3211
1.7F	50% RG Sand	9120	16480	1515
1.8F	50% RG Cement	10825	16150	4352
1.9F	100% RG Sand	8385	17190	3109

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As the mentioned above, the concrete is needed to overcome 4000 psi in compression, which is the minimum allowable strength for parking lots and sidewalks. Figures 4.3 and 4.4 show that mix designs can be used as a pavement for parking lots and sidewalks because all mix designs exceed 4000 psi. Graph 4.3 and 4.4 show mix designs in comparison with minimum possible design and the control sample.

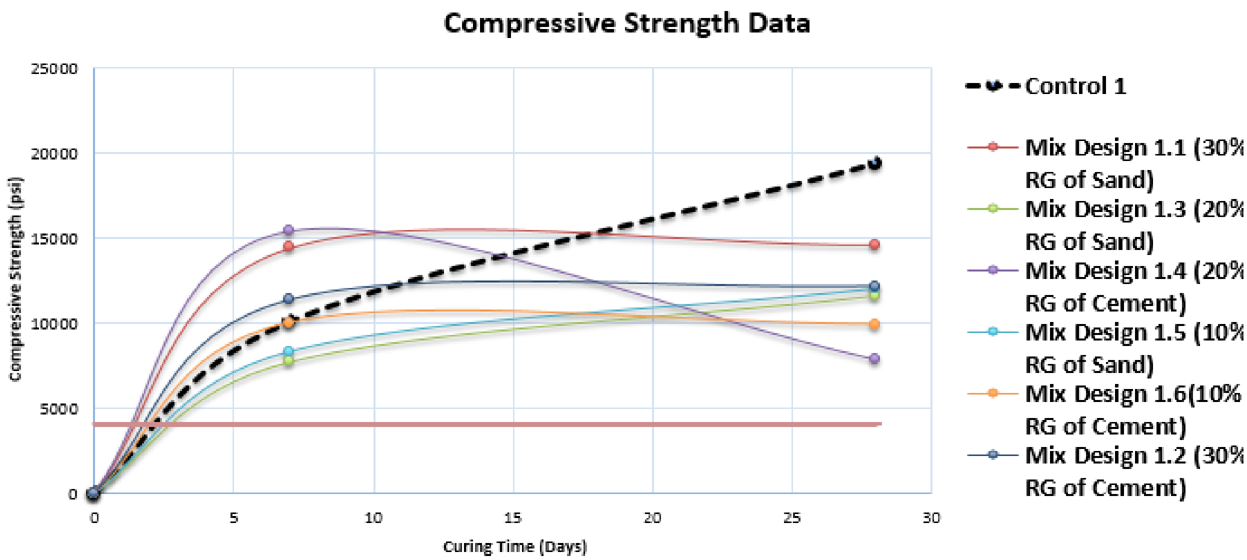

Figure 4.5: Compressive Strength for Mix Designs Less Than 50% RG Replacement

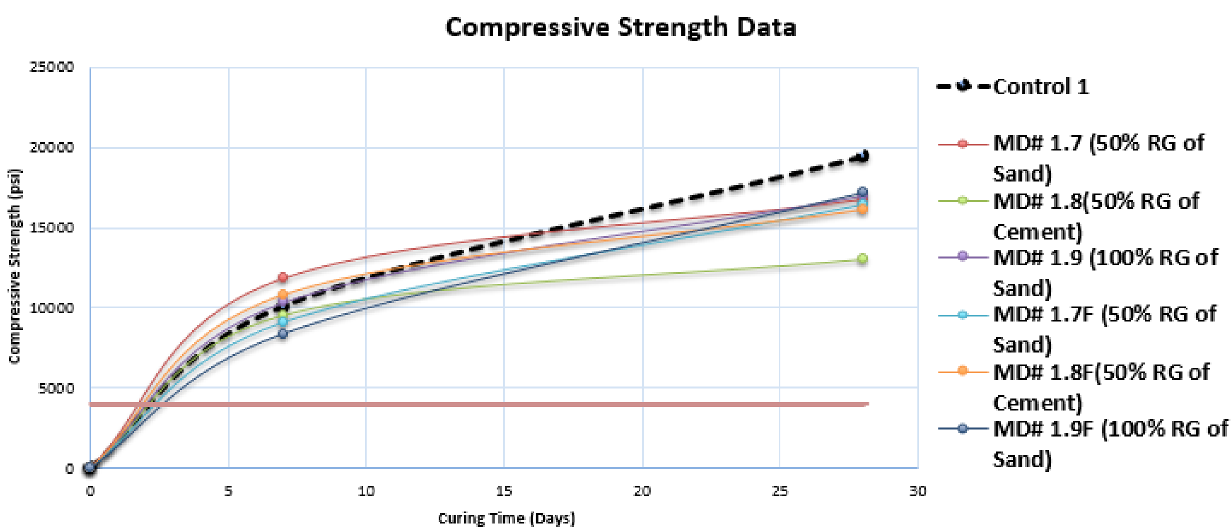

Figure 4.6: Compressive Strength for Mix Designs More Than 50% RG Replacement

The fly ash compressive strength results for 7 and 28 days are shown in Table 4.6. Since the compressive strength results were generated from tensile strength results, the compressive strength for the fly ash samples did not exceed 4000 psi for all mix designs.

Table 4.6: Compressive Strength for Fly Ash Mixes

Experimental Number	Experimental Detail	7 Days Average (psi)	28 Days Average (psi)	Standard Deviation (28 days)
MD# 2.0 (no polymer)	**(100%FA, 0%RGP, 0%RGS)**	36.00	44.00	136.00
MD# 2.0	**(100%FA, 0%RGP, 0%RGS)**	88.18	224.74	26.00
MD# 2.0F	**(100%FA, 0%RGP, 0%RGS)**	89.36	73.40	17.00
MD# 2.0F New	**(100%FA, 0%RGP, 0%RGS)**	36.00	44.00	10.00
MD# 2.1	**(70%FA, 30%RGP, 100%RGS)**	351.56	606.87	191.00
MD# 2.1F	**(70%FA, 30%RGP, 100%RGS)**	118.90	138.55	21.00
MD# 2.1F New	**(70%FA, 30%RGP, 100%RGS)**	233.00	186.00	4.00
MD# 2.2	**(50%FA, 50%RGP, 100%RGS)**	84.10	121.59	19.00
MD# 2.2F	**(50%FA, 50%RGP, 100%RGS)**	144.00	94.17	3.00
MD# 2.3	**(100%FA, 0%RGP, 50%RGS)**	260.50	198.37	50.00
MD# 2.3F	**(100%FA, 0%RGP, 50%RGS)**	81.28	131.97	18.00
MD# 2.4	**(100%FA, 0%RGP, 0%RGS)**	260.50	207.35	12.00
MD# 2.4F	**(100%FA, 0%RGP, 0%RGS)**	253.51	219.35	162.00

The fly ash compressive strength data are shown in Figure (4.6), where the control sample for the fly ash represented in a dashed black line to distinguish between the samples in the Figure.

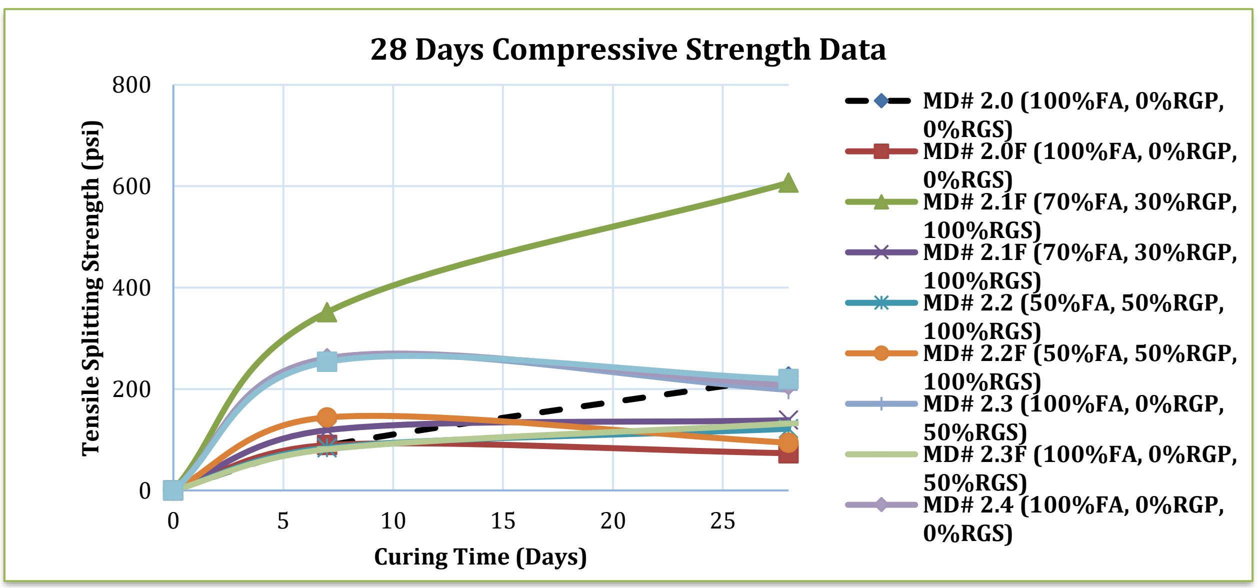

Figure 4.8: Compressive Strength for Fly Ash Mix Designs

4.4 Freeze-Thaw Cycle Test Results

The samples for the freeze thaw cycle were mixed by using the 16-inch long by 4-inch wide molds. Each mold contained two samples, the samples were needed to be cut using a chain saw to obtain a straight surface without voids. The results obtained so far are the 100 cycles out of 300 cycles. The measurement parameters for this test are the dimensions of the samples to get the volume, and the dry and wet weight of the sample. These measurements help calculating the void ratio for the samples using equation (4.2) from ASTM standards C30 (Method of Test for Voids in Aggregate for Concrete). Table 4.7 shows the dry and wet weight of the samples, and Table 4.8 shows the dimensions and volumes of the sample. Table 4.9 shows the void ration calculated using equation (4.2). Unfortunately, the freeze cycle test was only performed on fly ash samples, due to time constrains the team could not mix for the cement samples.

Equation 4.2, Void Ratio in Concrete [12]

$$P = \left[1 - \frac{W_2 - W_1}{\rho_w * Volume}\right] * 100(\%)$$

Where:

P= Void ratio

W_2= Dry weight in grams

W_1= Wet weight in grams

ρ_w=Density of water 1g/cm

Table 4.7: Freeze Thaw Cycles Samples Dimensions and Volume

Sample	Length (cm)	Width (cm)	Height (cm)	Volume (cm)	Cycles No.
2.1	19.30	8.04	6.77	1050.51	0
2.2	12.70	7.28	7.70	711.91	0
2.4	17.78	8.04	3.81	544.64	0
2.0F	20.32	8.04	5.08	829.93	0
2.1F	13.08	8.22	5.42	582.75	0
2.2F OLD	9.39	8.48	5.62	447.50	0
2.2F NEW	16.51	8.41	2.79	387.39	0
2.3F	20.57	8.42	8.17	1415.04	0
2.4F	20.83	8.52	6.76	1199.71	0
2.1	18.75	7.85	6.10	897.61	100
2.2	----	----	----	----	100
2.4	----	----	----	----	100
2.0F	19.05	8.09	4.66	718.17	100
2.1F	----	----	----	----	100
2.2F OLD	----	----	----	----	100
2.2F NEW	----	----	----	----	100
2.3F	19.20	7.89	6.15	931.77	100
2.4F	20.47	8.00	5.56	910.73	100

Table 4.8: Freeze Thaw Cycles Wet and Dry Weight of the samples

Sample	Dry Weight (g)	Wet Weight (g)	Cycle	Sample	Dry Weight (g)	Wet Weight (g)	Cycles No.
2.1	2448	1380	0	2.1	2300	1320	100
2.2	1683	961	0	2.2	----	----	100
2.4	2272	1355	0	2.4	----	----	100
2.0F	2033	1235	0	2.0F	2863	1100	100
2.1F	1163	692	0	2.1F	----	----	100
2.2F OLD	910	554	0	2.2F OLD	----	----	100
2.2F NEW	700	600	0	2.2F NEW	----	----	100
2.3F	2580	1445	0	2.3F	2560	1430	100
2.4F	2214	1223	0	2.4F	2105	1200	100

Table 4.9: Freeze Thaw Cycles Samples Void Ratio (%)

Sample	Void Ratio (%)	Cycles No.	Sample	Void Ratio (%)	Cycles No.
2.1	-1.55	0	2.1	-9.12	100
2.2	-1.34	0	2.2	----	100
2.4	-68.30	0	2.4	----	100
2.0F	3.89	0	2.0F	-145.53	100
2.1F	19.17	0	2.1F	----	100
2.2F OLD	20.58	0	2.2F OLD	----	100
2.2F NEW	74.22	0	2.2F NEW	----	100
2.3F	19.77	0	2.3F	-21.19	100
2.4F	17.51	0	2.4F	0.63	100

As shown in Tables (4.7-4.9), some of the fly ash mix designs are missing due to the poor mixing for these samples. They are not mixed in an appropriate mold, where they were mixed in aluminum molds covered with plastic wrapping. As shown in the freeze thaw tables, some of the fly ash samples have broken down to piece, where the test has failed for these samples at 100 cycles. These samples mix designs are (MD#2.2, MD#2.4, MD#2.1F, MD#2.2F OLD, and MD#2.2F NEW). As shown in Table 4.9, the void ratios in some of the samples are negative percentage. It means that the samples does not absorb water while it is sitting in the water tank, making the submerged weight for the sample lower than it should be. Another error is that the void ratio should increase in a positive percent, but instead all the left samples decreased in void percentage meaning that the sample instead of expanding due to freezing and thawing it breaks in the edges which lower its weight.

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4.5 Electron Microprobe Lab Test Results

The test was done using samples that were prepared for alkali silica reaction, to observe the silica gel resistance. This test is performed to observe the resistance of recycled glass to silica gel, where the samples will be placed under an electron microscope. The samples were taken to Microanalysis Core Facility in Northern Arizona University. With a help of a specialist, a small piece from each of the samples was taken and placed in an aluminum platform. The samples were coated with Plutonium (Pu) and gold (Au) too enhance the resolution of the imaging on the samples.

The mix designs that the test was performed on are the cement samples up to 30% RG powder and sand replacement (Control 1, MD#1.1, MD#1.2, MD#1.3, MD#1.4, MD#1.5, MD#1.6), and all the fly ash mix designs. The electron microscope generates picture by running the software. There are three types of analysis can be performed to find the chemical elements within the sample. These tests are point and shoot (analysis at a certain point within the image), overview (analysis at a whole image), and a line scan (analysis within a line on the image).

The point and shoot analysis helps to identify the analysis at one point within the chosen surface that microscope was on. The more zoomed in the microscope is the better the analysis. Figure 4.7 shows a picture of a point and shoot for MD#1.2 sample on the image. The magnification represents the zooming units, where the point is taken at the bottom right in the picture in the.

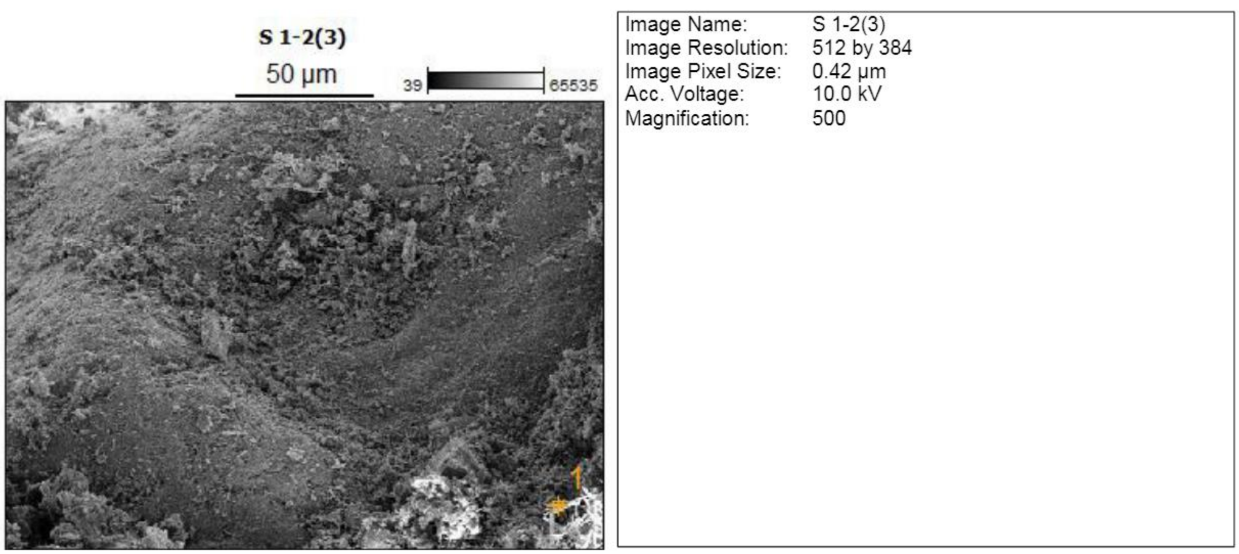

Figure 4.9: Point and Shoot Image

Figure 4.8 show the analysis generated from the point and shoot analysis where it is represented in a graph that represents the amount of counts in the (y-axis), and the electron microvolts level that the element react to.

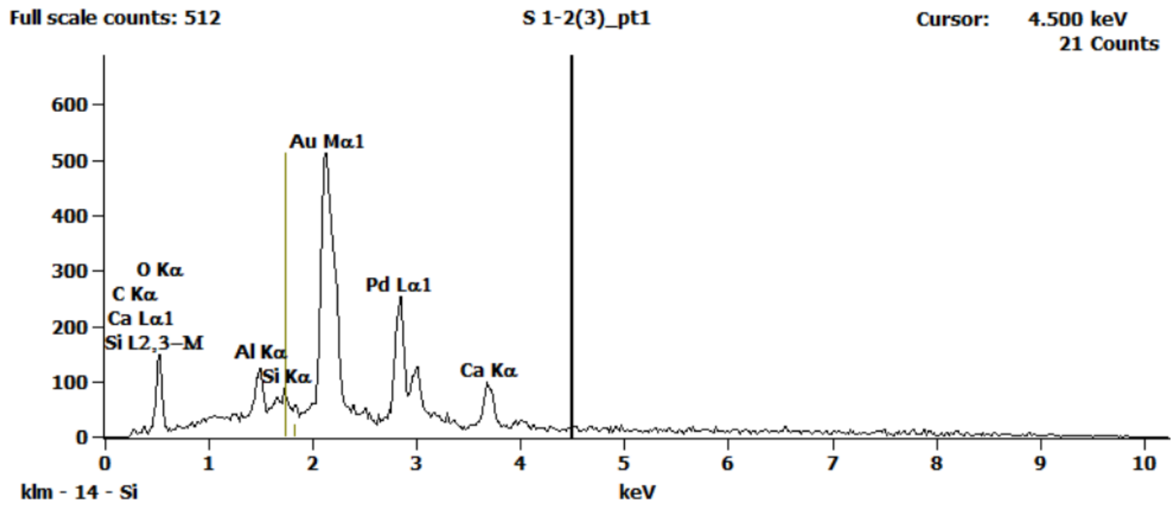

Figure 4.10: Point and Shoot Analysis

Finally, the report that was generated form the point and shoot test shows the element by weight percent within that pint represented in a table. From Table 4.10 to 4.11 show an example of the element table that was generated from the test report, and the error of the measurement for the weight percent values generated.

Table 4.10: Weight percent of the element at the point

Weight %

	C-K	O-K	Al-K	Si-K	Ca-K	Pd-L	Au-M
S 1-2(3)_pt1	0.08	3.80	1.80	0.79	7.92	31.51	54.09

Table 4.11: Weight percent error range

	C-K	O-K	Al-K	Si-K	Ca-K	Pd-L	Au-M
S 1-2(3)_pt1	±0.03	±0.20	±0.19	±0.13	±0.68	±1.69	±1.37

Weight % Error (+/- 1 Sigma)

The overview test generates the same results as the point and shoot test, but the generated image can show the elements distribution within the image. Through this test, the team understood the form of silica gel within the samples based on observation, which was based on the appearance of an overlap for calcium and silica in the image. Figure 4.9 shows the overview overlap of calcium and silicon on the image of 20% RG powder mix sample. For further prove, the team tested the control sample without silicon dioxide to see the diffrance of images and test results. Figure 4.10 shows the over view results for the control sample without silica.

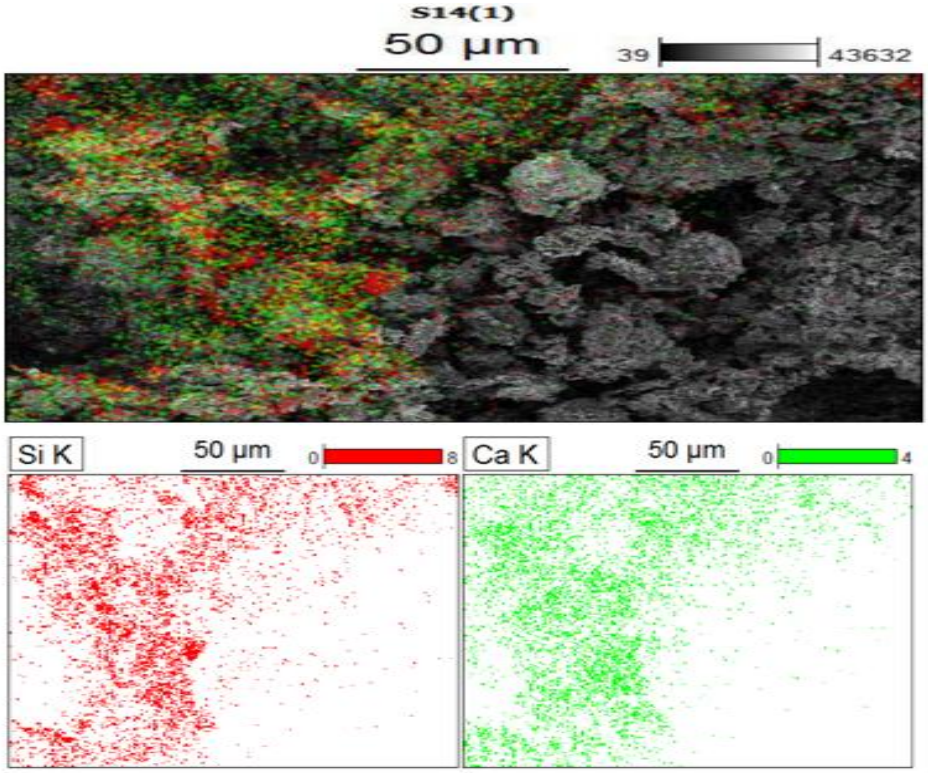

Figure 4.11: Silica gel represented in a sample

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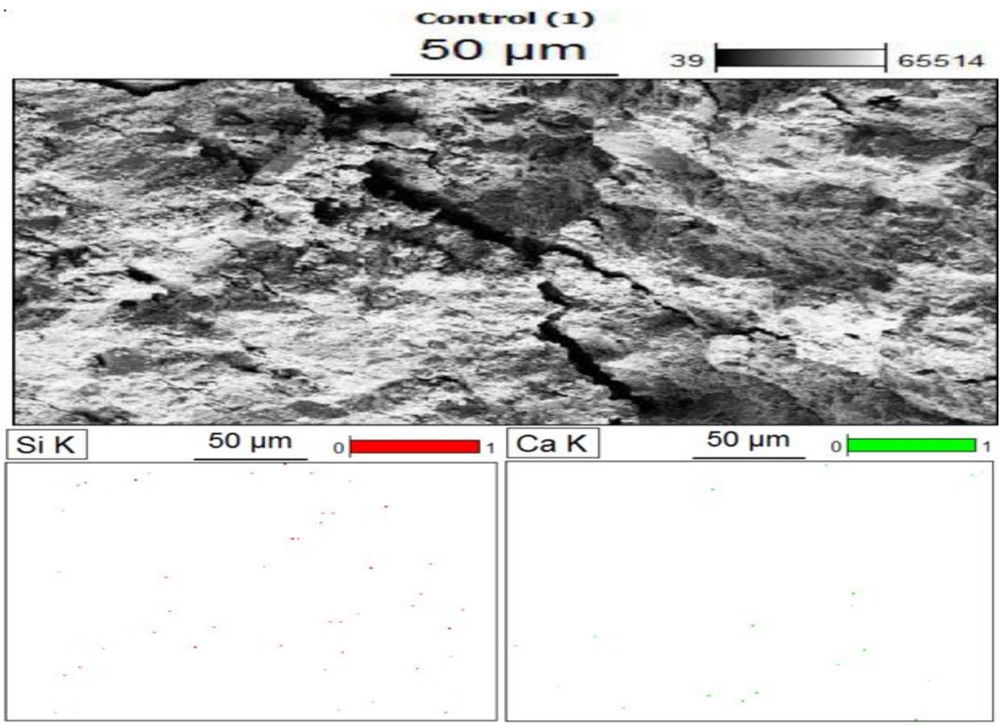

Figure 4.11: Control sample without silica dioxide added

From this test, the team observed other samples and only using point and shoot analysis. The recycled glass sand increment helps reducing the silica gel reaction. Figure 4.11 shows the image for the cement sample that contains 30% RG sand replacement. The measured stuff is the silica gel forming in on the sample.

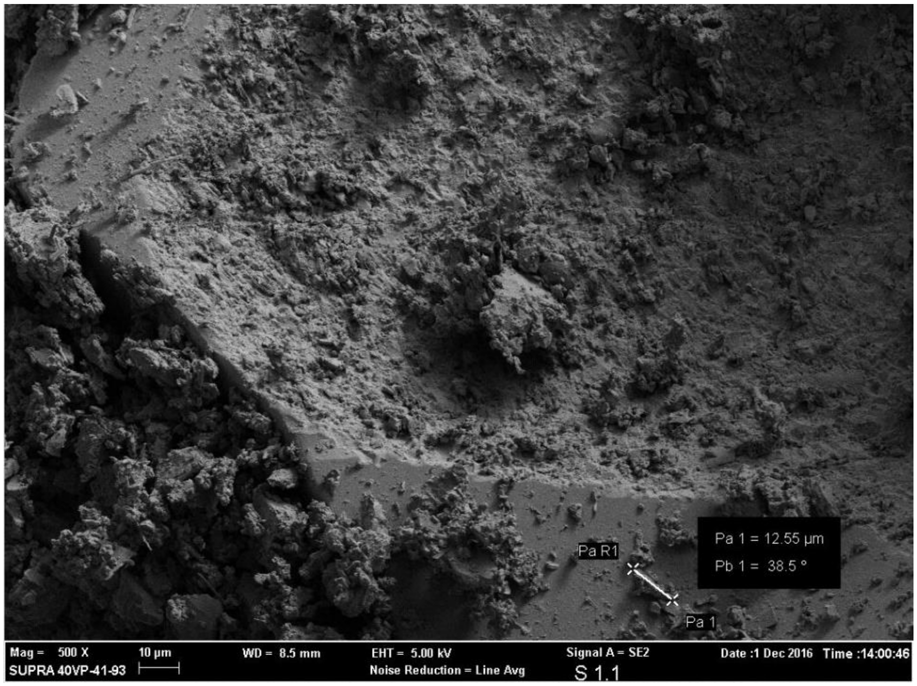

Figure 4.12: MD#1.1 microscopic picture.

To compare the surface with a sample that allowed the silica gel reaction in another image with the same sample but instead with 10% RG sand replacement (MD#1.5). Figure (4.12) shows the image of the 10% RG sand replacement.

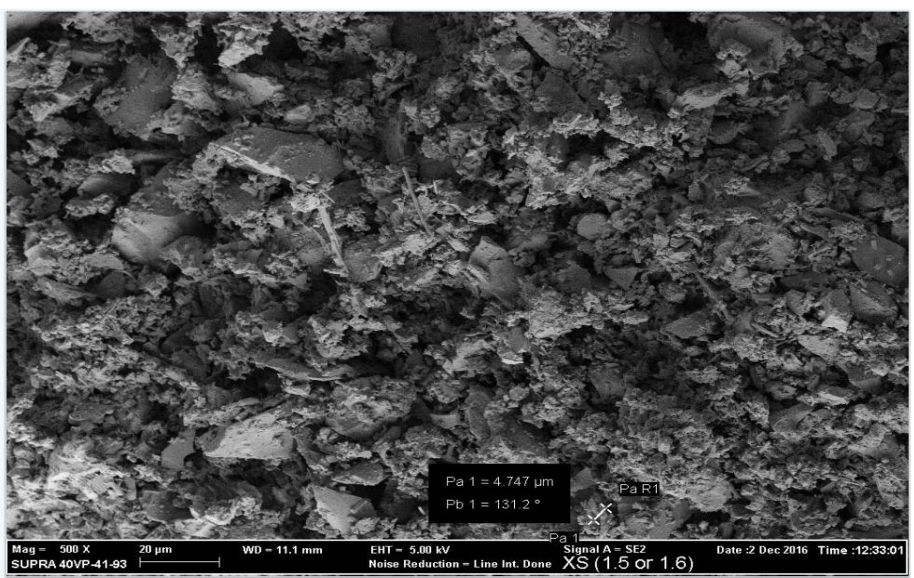

Figure 4.12: MD#1.5 microscopic picture.

In Figure 4.10, the surface of the sample is clearer. Figure 4.11, the reaction is appeared in a larger scale. The measurement was taken for the smallest line that observed to compare with longer lines.

5.0 Summary of Project Costs

The cost of this project includes buying the materials used in the mixes, meeting hours, renting the lab, trips to get aggregates, and completing tasks and deliverables. Table 5.1 shows the total material cost, which is around $430 for the whole project. Table 5.2 shows the rates of different workers who work on different tasks. Table 5.3 shows the estimated and actual cost for completing this project. The total cost of engineering services for this project is $63,784.

Table 5.1: Total Material Cost

Material	**Rate**	**Amount**	**Price ($)**
Cement	$0.11 /lb.	115.09 lb.	12.98
Fly Ash	$0.018 /lb.	85.56 lb.	1.50
Sand	$0.015 /lb.	175.81 lb.	2.55
RG Powder	$1.55 /lb.	32.59 lb.	50.52
RG Sand	$1.3 /lb.	164.46 lb.	95.37
Nylon Concrete Fiber	$16.29 /lb.	0.21 lb.	3.41
Aggregate	$0.020 /lb.	476.93 lb.	9.55
Silicon Dioxide (Silica)	$0.44 /lb.	9.75 lb.	10.14
Molds	$1.20 /mold	120 molds	144.00
Total Material Cost			$ 430.02

Table 5.2: Rates of Workers

Classification	Rate, $/hr.
Senior Engineer	195
Engineer	67
Lab Assistant	48
Intern	22
Administrative Assistant	56

Table 5.3: Total Cost of Engineering Services

Estimated and Actual Total Cost of Engineering Services				
Service	Estimated	Actual	Estimated Cost	Actual Cost
1.0 Personnel	598 Hours	990 Hours	$ 36,975	$ 54,292
2.0 Travel	2 trips x 7.4miles/trip ($0.40/mi)	2 trips	$ 12	$ 12
3.0 Lab Rental	120 Hours ($30/hr.)	316 Hours	$ 3,600	$ 9,480
4.0 Total			$ 40,437	$ 63,784

6.0 Conclusion and Recommendation

After finishing the experiments and analyzing the results, recycled glass concrete can still operate in terms of strength as paving material for sidewalks and parking lots. Recycled glass concrete is an alternative paving material for public projects. It has been found out that recycled glass sand can reduce ASR reaction according to Microprobe Lab test results. Since recycled glass is more expensive than cement, recycled glass concrete cost slightly higher than conventional concrete. However, if construction companies crush the recycled glass, there is a slight chance that recycled glass can cheaper than cement. Finally, the team would like to recommend the future capstones to continue fly ash concrete mixes because there are studies 100% fly ashes instead of cement can achieve a reasonable strength.

8.0 REFERENCES

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Appendix A: (Experimental Matrices)

Table A1: Experimental matrix for the cement design

Mix Designs No.	**Cement (lb. /yd^3)**	**Sand (lb. /yd^3)**	**RG Powder (lb. /yd^3)**	**RG Sand (lb. /yd^3)**	**Fiber (lb. /yd^3)**	**% of RG Replacement**	
						Cement	Sand
						RG Powder	RG Sand
Control 1	792.66	1103.38	0.00	0.00	0.00	0%	0%
MD# 1.1	792.66	772.37	0.00	331.01	0.00	0%	30%
MD# 1.2	554.87	1103.38	237.80	0.00	0.00	30%	0%
MD# 1.3	792.66	882.71	0.00	220.68	0.00	0%	20%
MD# 1.4	634.13	1103.38	158.53	0.00	0.00	20%	0%
MD# 1.5	792.66	993.04	0.00	110.34	0.00	0%	10%
MD# 1.6	713.40	1103.38	79.27	0.00	0.00	10%	0%
MD# 1.7	792.66	551.69	0.00	551.69	0.00	0%	50%
MD# 1.8	396.33	1103.38	396.33	0.00	0.00	50%	0%
MD# 1.9	792.66	0.00	0.00	1103.38	0.00	0%	100%
MD# 1.7F	792.66	551.69	0.00	551.69	2.03	0%	50%
MD# 1.8F	317.07	1103.38	396.33	0.00	2.03	50%	0%
MD# 1.9F	792.66	0.00	0.00	1103.38	2.03	0%	100%

Table A2: Fly Ash Experimental matrix

Mix Designs No.	**Fly Ash (lb. /yd^3)**	**Sand (lb. /yd^3)**	**RG Powder (lb. /yd^3)**	**RG Sand (lb. /yd^3)**	**Fiber (lb. /yd^3)**	**% of RG Replacement**		
						Cement		Sand
						Fly Ash	RG Powder	RG Sand
MD# 2.0	792.66	1103.38	0.00	0.00	0.00	100%	0%	0%
MD# 2.1	554.87	0.00	237.80	1103.38	0.00	70%	30%	100%
MD# 2.2	396.33	0.00	396.33	1103.38	0.00	50%	50%	100%
MD# 2.3	792.66	551.69	0.00	551.69	0.00	100%	0%	50%
MD# 2.4	792.66	0.00	0.00	1103.38	0.00	100%	0%	100%
MD# 2.0F	792.66	1103.38	0.00	0.00	2.03	100%	0%	0%
MD# 2.1F	554.87	0.00	237.80	1103.38	2.03	70%	30%	100%
MD# 2.2F	396.33	0.00	396.33	1103.38	2.03	50%	50%	100%
MD# 2.3F	792.66	551.69	0.00	551.69	2.03	100%	0%	50%
MD# 2.4F	792.66	0.00	0.00	1103.38	2.03	100%	0%	100%

Appendix B: (Standard Method)

Tensile Splitting Test: ASTM C496
Slump Test: ASTM C143-C143M
Freeze-Thaw Cycle Test: ASTM C666 standard method
Air Void in Aggregate for Concrete: ASTM C30-37