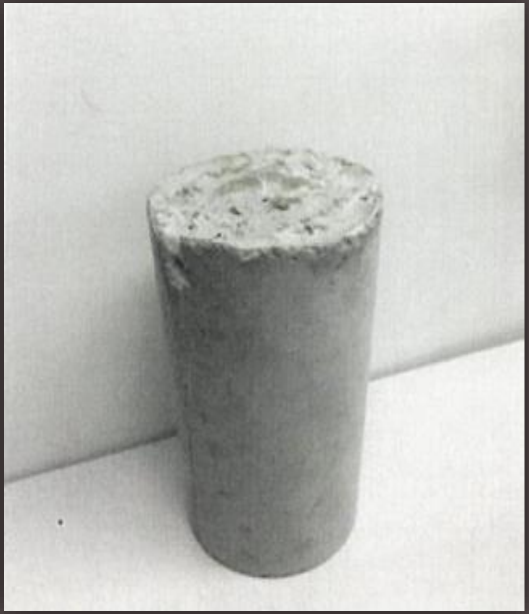
RECYCLED GLASS CONCRETE



Molten Sand Research Center

Anas Almonnieay

Khin Kyaw

Shahad Aloqaili

Molten Sand Research Center

CENE 486C
Capstone Design
December 9, 2016

PROJECT BACKGROUND

- Purpose of project
  - To research concrete mix designs for pavement using recycled glass to achieve high strength concrete
  - To reduce alkali silica reaction
  - To develop environmentally friendly concrete

- Location
  - Parking lots and sidewalks in Flagstaff

PROJECT CLIENT, TECHNICAL ADVISOR, AND STAKEHOLDERS

- Client and Technical Advisor
  - Dr. Chun-Hsing (Jun) Ho
- Stakeholders
  - Northern Arizona University (NAU)
  - Engineering Community & Society
  - Engineering Students
  - People who will use parking lots and sidewalks

PROJECT SCHEDULE

Tasks	Begin Date	End Date
Task 1.0 Research	01/18/16	11/1/16
Task 1.1 Previous Projects	1/18/16	1/28/16
Task 1.2 Alkali Silica Reaction (ASR)	1/29/16	11/1/16
Task 1.3 Glass Size Properties	1/29/16	11/1/16
Task 1.4 Material Properties	1/29/16	11/1/16
Task 2.0 Developing Mix Formulae	01/29/16	07/17/16
Task 3.0 Experimental Preparation	02/01/16	10/26/16
Task 3.1 Material Acquisition	2/1/16	10/26/16
Task 3.2 Testing Equipment	2/1/16	3/31/16

PROJECT SCHEDULE CONT.

Tasks	Begin Date	End Date
Task 4.0 Experimental Procedures	04/01/16	11/26/16
Task 4.1 Mixing	04/01/16	10/21/16
Task 4.2 Curing	04/01/16	10/21/16
Task 4.3 Testing	04/01/16	11/26/16
Task 4.3.1 Compressive Strength Test	04/30/16	11/24/16
Task 4.3.2 Freeze-Thaw Cycle Test	10/22/16	11/26/16
Task 4.3.3 Slump Test	04/01/16	10/24/16
Task 4.3.4 Tensile Splitting Test	04/29/16	11/24/16
Task 4.3.5 Electron Microprobe Lab Test	05/11/16	11/25/16
Task 5.0 Data Analysis	10/31/16	12/10/16
Task 6.0 Project Management	01/26/16	12/13/16

MATERIAL PREPARATION

- Portland Cement Type II
- Water
- Nylon Concrete Fiber
- Polymer
- Fine Aggregate (Natural Sand)
- Coarse Aggregate
  - ½”, 3/8”, and #4(0.187”)
- Admixtures
  - Water Reducer
  - Viscosity Modifier
  - Air Entrainment

- Recycled Glass Powder
- Recycled Glass Sand

Fig 1: Recycled Glass-Powder

Fig 2: Recycled Glass-Sand (Coarse)

Fig 3: Recycled Glass-Sand (Fine)

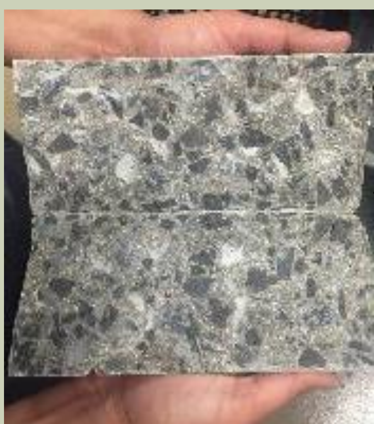
EXPERIMENTAL PROCEDURE

Sieve Aggregate

Mixing Preparation

Mixing

Compacting



Sample After Testing

Running Tensile Strength Test

Specimens (Dia 4in x H 8in)

Specimens Curing

MIX DESIGN FORMULAE

Table 1: Mix Design Formulae (Part I)

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%

w/c ratio = 0.38, Water =13.87 lb.

MIX DESIGNS FORMULAE CONT.

Table 2: Mix Design Formulae (Part II)

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%

w/c ratio = 0.28, Water =2.85 lb., Polymer=0.7125 lb.

MATERIAL PROPORTION

Table 3: Coarse Aggregate Proportion (All Mix Designs)

Coarse Aggregate (lb. /yd^3)		
1/2"	3/8"	#4
857.16	377.65	377.65

Table 4: Admixture Proportion (All Mix Designs)

Admixture (oz.)		
Water Reducer	VMA	Air Entrainment
0.1037	0.3696	0.1185

SLUMP TEST

- Mix Design Formula Part I (Cement & Sand Replacement)
  - No slump reduction for all samples
- Mix Design Formula Part II (Fly Ash MD)
  - After mixing (directly): Slump level drops 7” because the polymer is still in liquid state in the mix
  - 5 minutes after mixing: No slump drop because the polymer dried in the mix

TENSILE SPLITTING STRENGTH RESULTS

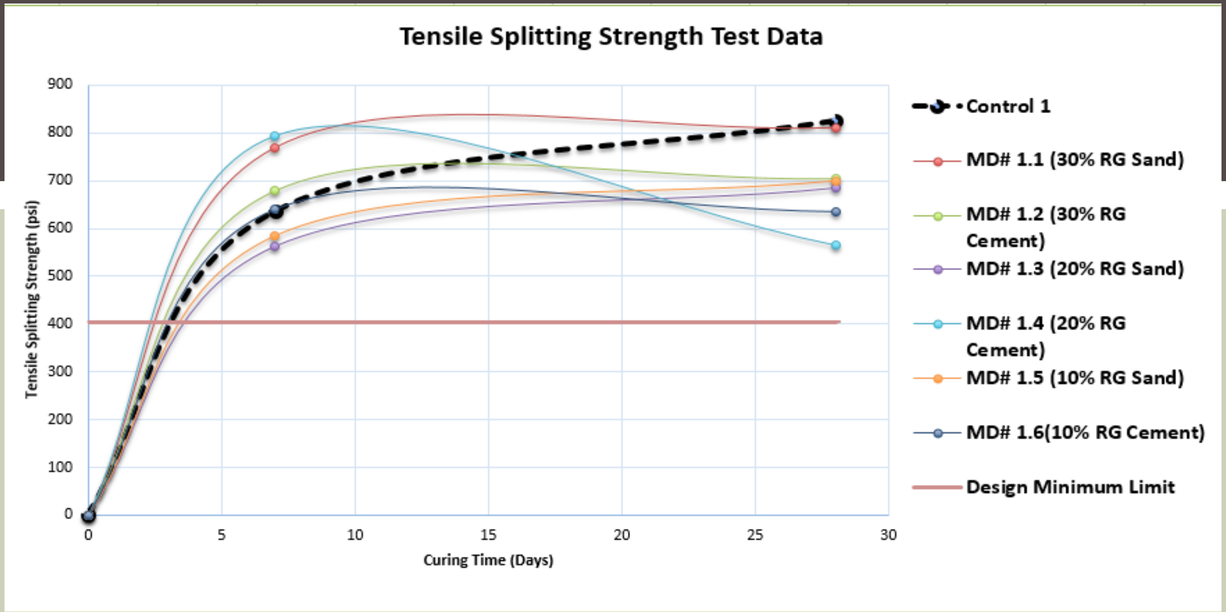


Fig 4: Comparison of Tensile Splitting Test Results (MD# Less than 50% RG Replacement)

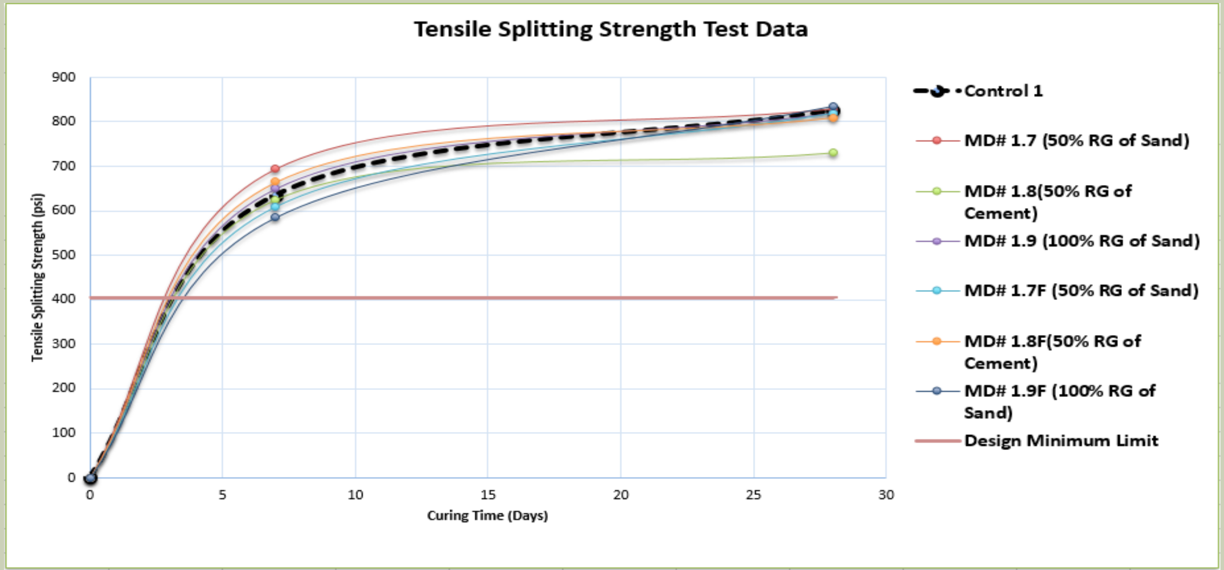


Fig 5: Comparison of Tensile Splitting Test Results (MD# 50% and 100% RG Replacement)

TENSILE SPLITTING TEST RESULTS

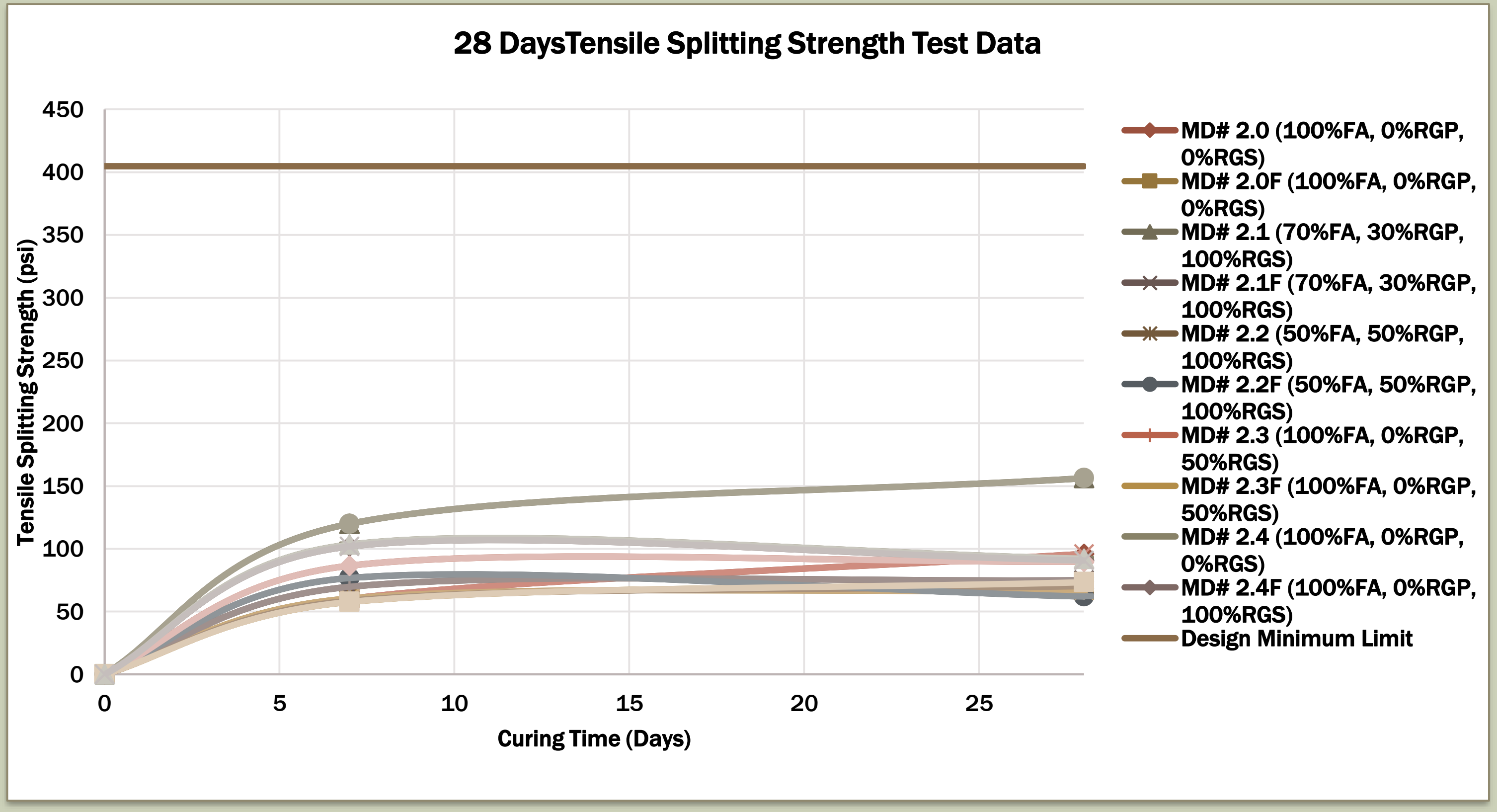


Fig 6: Comparison of Tensile Splitting Test Results (Fly Ash Mix Designs)

COMPRESSIVE STRENGTH RESULTS

- **Compressive strength results** were calculated from splitting tensile test by using the following equation:

$$f_{ct} = 6.4\sqrt{f'_c} \qquad \text{Eq. 1 } [1]$$

Where:

f_{ct}= Tensile Splitting Strength (psi)
f'_c=Compressive Strength (psi)

FREEZE THAW CYCLES TEST

- **Mixing:**
  - Freeze-Thaw samples mixed in Aluminum molds (16” long & 4” wide)
- **Freezing cycles:**
  - 10 cycles take two days and a half
  - 100 cycles are completed until now
  - 250 cycles are needed to complete for the samples

Fig 7: Top view Freeze-Thaw Sample

Fig 8: Side view Freeze-Thaw Sample

FREEZE THAW CYCLES TEST

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

Eq. 2 *[2]*

- Where:
  - P= Void Ratio (%)
  - W1=Dry Weight (g)
  - W2=Wet Weight (g)
  - $\rho_W = \boldsymbol{Water\ Density}$ (1g/cm^3)
  - Volume of Specimen (cm^3)

Table 5: Void Ratio Test Results

Sample	Length (cm)	Width (cm)	Hight (cm)	ratio (%)	cycle	Sample	Length (cm)	Width (cm)	Hight (cm)	ratio (%)	cycle
2.1	19.3	8.04	6.77	-1.55129	0	2.1	18.7452	7.85	6.1	-9.12	100
2.2	12.7	7.28	7.7	-1.33716	0	~~2.2~~	-	-	-	-	~~100~~
2.4	17.78	8.04	3.81	-68.2971	0	~~2.4~~	-	-	-	-	~~100~~
2.0F	20.32	8.04	5.08	3.887603	0	2.0F	19.05	8.09	4.66	-145.53	100
2.1F	13.08	8.22	5.42	19.17312	0	~~2.1F~~	-	-	-	-	~~100~~
2.2F OLD	9.39	8.48	5.62	20.57562	0	~~2.2F OLD~~	-	-	-	-	~~100~~
2.2F NEW	16.51	8.41	2.79	74.21514	0	~~2.2F NEW~~	-	-	-	-	~~100~~
2.3F	20.57	8.42	8.17	19.76968	0	2.3F	19.2024	7.89	6.15	-21.19	100
2.4F	20.83	8.52	6.76	17.50552	0	2.4F	20.4724	8.001	5.56	0.63	100

ALKALI SILICA REACTION (ASR)

- Alkali Silica Reaction Equation

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca_2^{+} + H_2SiO_{42}^{-} + 2\ H_2O \rightarrow CaH_2SiO_4 \cdot 2\ H_2O$$

Eq. 3 *[3]*

- The Silica Gel created by:
  - Adding Silica (SiO_2)
  - Calcium (Ca) existing in the cement paste, acting as an acid-base reaction ($Ca(OH)_2$)

- The reaction affects:
  - Cracks in the cement paste and aggregate

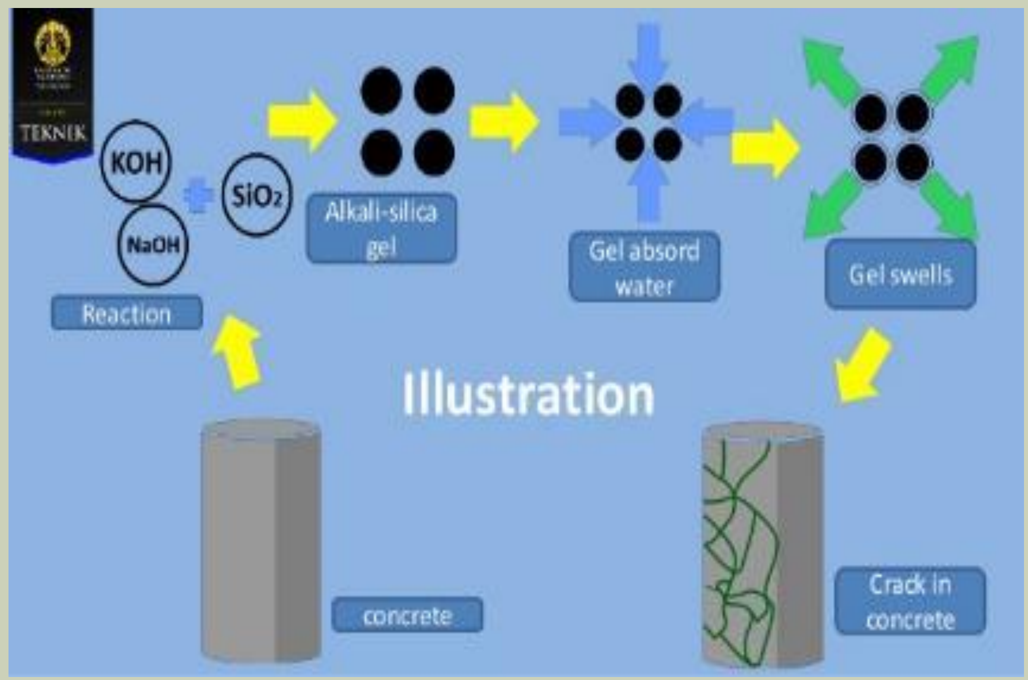


Fig 9: The Process of ASR [4]

ALKALI SILICA REACTION (ASR)

- **Preparation:**
  - Samples were prepared using moisture cans for cement
  - Fly Ash samples were collected after mixing
- **ASR:**
  - The reaction is initiated by adding Silicon Dioxide (SiO_2)
  - The samples were sat in the water for 60 days

Fig 10: Cement & Fly Ash Samples for ASR

Fig 11: Silicon Dioxide (SiO_2)

ASR TEST OBSERVATION

- The analysis taken at 500 Microns (zooming scale)
- Calcium(Green dots)
- Silicon (Red dots)
- Overlap of Calcium & Silicon creates Silica Gel

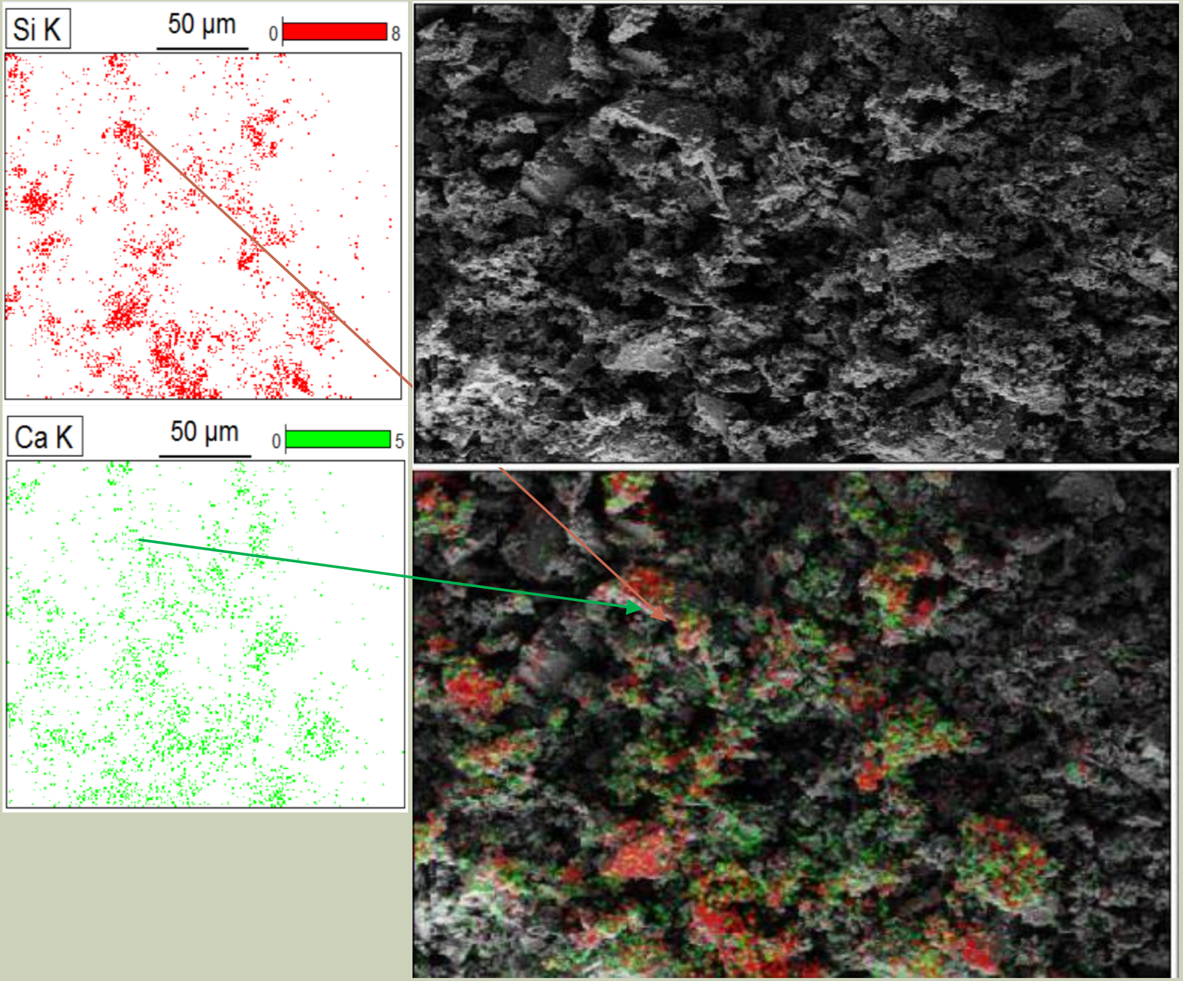


Fig 12: ASR Reaction on Sample

TYPES OF OBSERVATION (CEMENT SAMPLES)

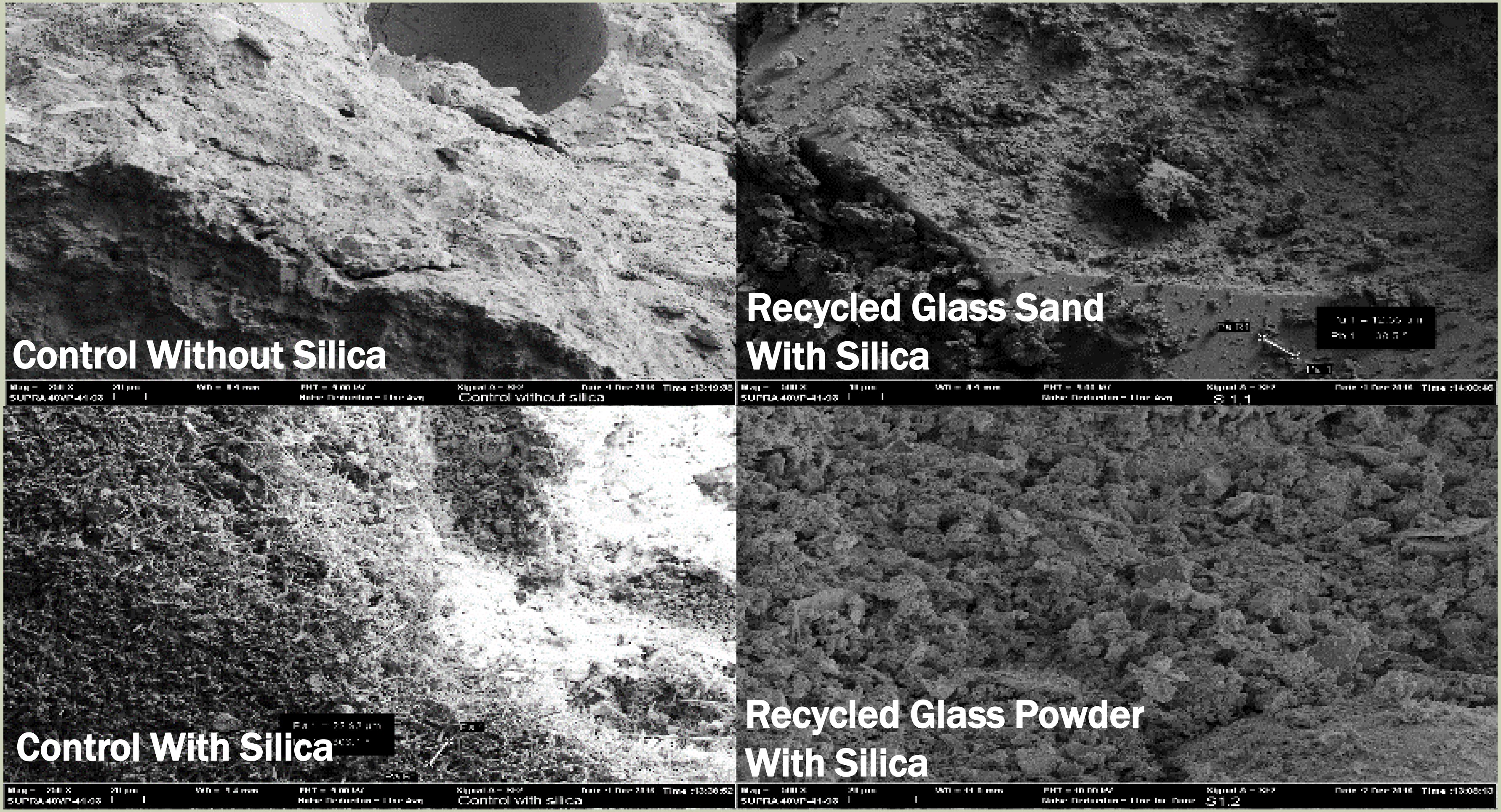


Fig 13: Observation of ASR on Control & RG Samples

TYPES OF OBSERVATION (FLY ASH SAMPLES)

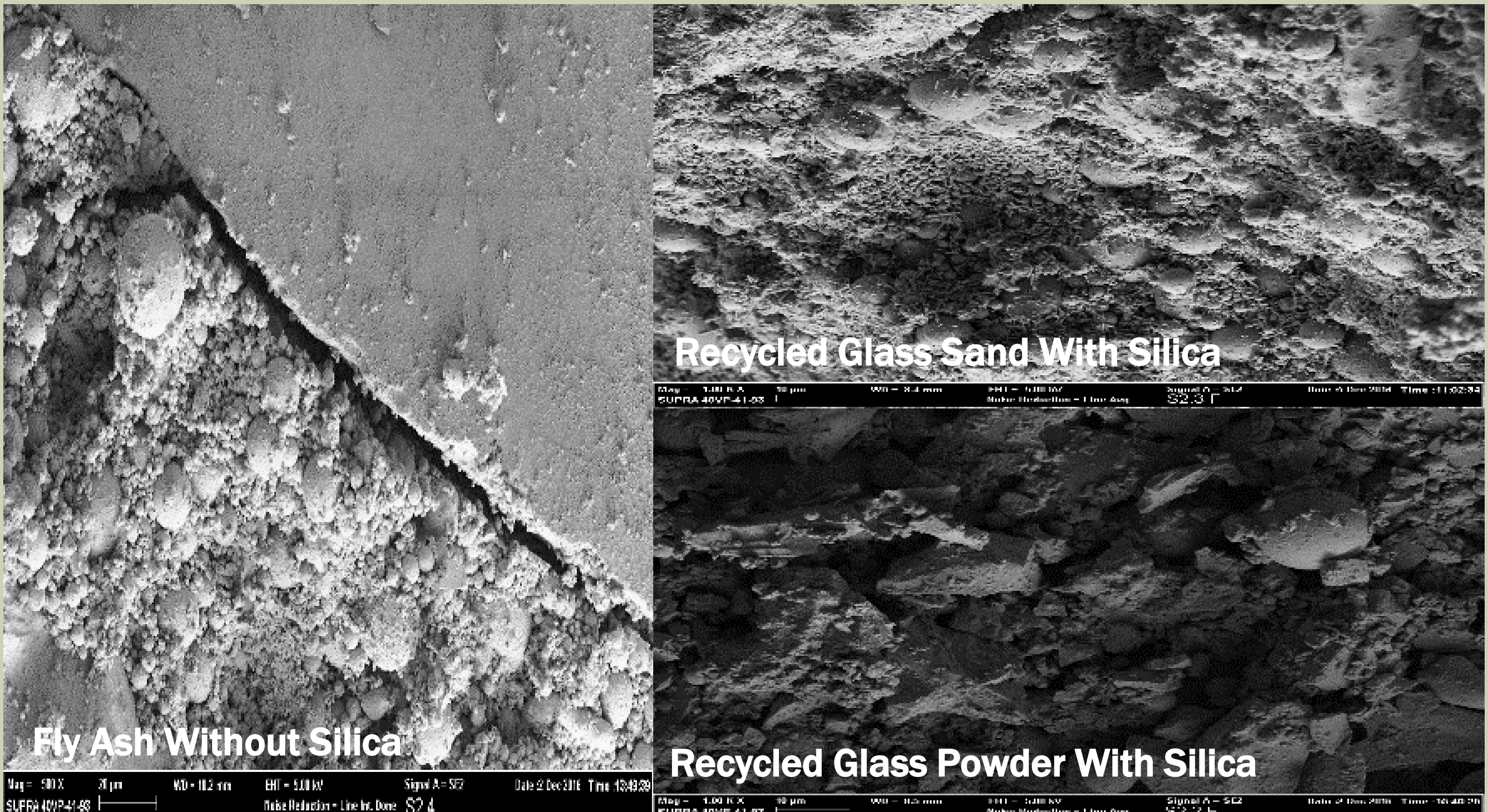


Fig 14: Observation of ASR on Fly Ash Samples

STATISTICAL ANALYSIS

- Two tests were used to confirm the strength results:
  - One Way ANOVA
  - T-Test (Assuming different variances)
- The value of interest is the P value for both tests
  - P value (>0.05) reflects to true results

Table 6 : Information for Statistical Analysis

Sample ID	Tensile (PSI)	Sample ID	Tensile (PSI)
1-3	815.7	1.8F-2	681
1.4	830.8	1.8F-3	900
1.5	970	1.8F-4	843
1-6	937		

Table 7: Statistical Analysis for Mix Designs

Sample ID	P value (T-Test)	P value (ANOVA)	Pass/Fail	Sample ID	P value (T-Test)	P value (ANOVA)	Pass/Fail
MD#1.1	0.242	0.242	Pass	MD#1.7	0.331	0.336	Pass
MD#1.2	0.012	0.012	Fail	MD#1.8	0.02	0.022	Fail
MD#1.3	0.039	0.039	Fail	MD#1.9	0.394	0.382	Pass
MD#1.4	0.002	0.002	Fail	MD#1.7F	0.188	0.227	Pass
MD#1.5	0.009	0.009	Fail	MD#1.8F	0.368	0.31	Pass
MD#1.6	0.007	0.007	Fail	MD#1.9F	0.428	0.418	Pass

STATISTICALLY ACCEPTED MIXES

- Mix Design #1.1 (30% RG Sand)
- Mix Design #1.7 (50% RG Sand)
- Mix Design #1.9 (100% RG Sand)
- Mix Design #1.7F (50% RG Sand with fiber)
- Mix Design #1.8F (50% RG Powder with fiber)
- Mix Design# 1.9F (100% RG Sand with fiber)

MATERIAL COST ESTIMATE

Table 8: 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

COST OF ENGINEERING SERVICES

Table 9: Total Cost of Engineering Services

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

IMPACTS

- Society
  - Educational opportunity for research
  - Alternative paving materials for public projects
- Environmental
  - Using RG powder can reduce the amount of CO_2 emission
  - Replacing RG sand can reduce the carbon footprint to remanufacture the glass
- Economic
  - Recycled glass is more expensive than cement
  - If construction companies crush the recycled glass, there is a slight chance that recycled glass can be cheaper than cement

CONCLUSION & RECOMMENDATION

- Conclusion
  - Recycled glass concrete can still operate in terms of strength as paving material for sidewalks and parking lots
  - Recycled glass sand can reduce ASR reaction

- Recommendation
  - To continue fly ash research because there are studies that 100% fly ash instead of cement can achieve a reasonable strength

ACKNOWLEDGEMENTS

- Dr. Chun-Hsing Jun Ho: Technical Advisor & Client
- Dr. Bridget Bero: Grading Instructor
- Junyi Shan : NAU Graduate Student
- Phoo Myat Sandy Maung : Undergraduate Student
- Scott Palmer from Salt River Materials Group Company: Fly Ash Supplier
- Euclid Chemical Company: Polymer Supplier
- CEMEX Flagstaff: Aggregate Supplier

REFERENCES

[1]J. Wight and J. MacGregor, *Reinforced Concrete: Mechanics and Design*, 5th ed. Prentice Hall, 2008.

[2]"Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate1", 2016.

[3]“The Use of Waste Glass as a Partial Substitution for Fine Aggregate in Concrete Design” Charles Darwin University, 2016.

[4]"Alkaline Silica Reactivity", *LinkedIn Corporation*, 2016.

[5] Fiberreinforced.org, "Fiber Reinforced Concrete Association - FRCA", 2016.

[6] Fibermesh.com, "FIBERMESH 150", 2016.

[7] Pavementinteractive.org, "Portland cement Strength Pavement Interactive", 2016.

[8] Buildeazy.com, "What is cement and how is it made", 2016.

[9] Cement, A. Irrigation: Definition and D. Flat Slab Analysis, "Uses of Cement - Civil Engineering", *Civiltoday.com*, 2015.

THANK YOU!