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Dec 16, 2015

Northern Arizona University

Attn: Chun-Hsing Ho, PhD, PE

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Dear Dr. Ho,

Please find enclosed, the final research report for the conventional concrete with recycled glass project for Northern Arizona University. It is recommended that more research be conducted to find a final design. The final cost for this research and documentation is approximately $24,000.

We look forward to your comments and discussing the plans for future recycled glass concrete projects. If you have any questions about this final research report, please do not hesitate to call.

Best Regards,

FAB Concrete Mix & Design

CRUSHED GLASS AS A SUSTAINABLE ALTERNATIVE AGGREGATE FOR CONCRETE

CENE 486C

Dec 16, 2015

NAU Fall 2015

FAB CONCRETE MIX AND DESIGN

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Abbreviations

NAU – Northern Arizona University

ASTM – American Society for Testing and Materials

ASR – Alkali-Silica Reaction

psi – Pounds per Square Inch

Acknowledgements

This research would have not been possible if it had not been for the tremendous support from our professors and the people of Northern Arizona University.

We would like to personally thank Dr. Jun Ho for giving us the opportunity to work on this fascinating research project. At first our team had only minor knowledge of concrete; after working with Dr. Ho, we feel more prepared to use this experience in our future engineering careers.

We would also like to thank Dr. Bridget Bero, PE, and Professor Mark Lamer, P.E., for their continued support and unending ideas on how to better our research and make our goals a reality.

Last but not least, we thank our families and our fellow students who continuously pushed us and helped move the project forward.

Tyler Brumit *Feiyue Wang* *Ahmad Ibrahim*

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1.0 Project Description

Recycling paper, plastic, aluminum, and glass products has become an efficient way to deal with much of the world's environmental waste [1]. It takes a large amount of energy to take a product and recycle it into a state where it can be again molded into a useable product. The research that follows is based on taking recycled glass and substituting it into a certain construction application, for example concrete. Concrete is used everywhere in modern and developing societies, because concrete is so versatile and used so often, it would benefit the world if it were possible to add recycled glass to concrete mix designs. The final question is can glass be added to concrete without drastically changing its base characteristics: strength, workability and cost. Adding recycled glass would provide a valuable alternative in which glass could be used in mass amounts, because it is primarily considered to be found in excess around the world and would reduce the amount of waste filling landfills.

The engineers are required to produce mix designs that incorporate two types of recycled glass, recycled glass powder, and coarse recycled glass. All mix designs are based on a regular concrete design formula. The recycled glass powder replaces a portion of cement while the coarse glass replaces sand. The team will present the results based on the amount of recycled glass (by weight) that is incorporated into the mix, and by the average compressive strengths. Designs will follow all applicable ASTM standards and specifications (Appendix A Table A1). Standards for recycled glass concrete have not yet been developed. It will be up to the project engineers to develop the mix designs, and test those designs to create possible design standards for recycled glass concrete.

Conventional or typical concrete is designed to have a high compression strength that can be applied to a diverse spectrum of real world projects. Using recycled glass in concrete applications decreases the amount of glass in landfills and substitutes for expensive components in the concrete mix. Recycled glass concrete can be made by replacing a portion of Portland cement and sand with recycled glass. The purpose of introducing recycled glass into the mix design is to create a more environmentally friendly product. Adding recycled glass into the concrete mix may cause undesired effects on the strength, thermal expansion and void ratio of the concrete.

The goal is to produce adequate mix designs utilizing recycled glass that will eventually become the standard concrete design used in Northern Arizona. Northern Arizona University (NAU) and all of northern Arizona are the two primary stakeholders for this project. Final mixing designs may be used to produce products that are not only strong, durable, and environmentally friendly, but also aesthetically pleasing [2].

To begin research a required set of tasks were developed to provide guidance and structure to the process. The tasks are:

Task 1	Preliminary Research
Task 2	Acquire Materials
Task 3	Design and Experimentation
Task 4	Project Management

2.0 Research

2.1 Literature Review

A literature review was performed before the research project started. The team reviewed any material about concrete and the effects of including recycled glass. Reviewed material includes research papers, project reports, and ASTM standards.

The main area of focus for the literature review:

- Environmental benefits when using recycled glass
- Previous work on use of recycled glass aggregates in concrete
- Long term effects of using recycled glass, including but not limited to physical and chemical characteristics found when using recycled glass
- Researched ASTM standards that could influence the mix designs and experiments
- Effects of high freeze-thaw cycle, and how to mitigate it

The environmental impact of Portland cement concrete production has inspired the construction industry to develop and test alternative technologies to be incorporated into concrete. One option is using pulverized glass as a sand or cement replacement. In the United States more than 600,000 tons/year [3] of recycled glass bottles are stockpiled, primarily due to the high cost of shipping to glass melting facilities.

When using glass as an alternative aggregate in concrete certain complications arise. One major obstacle is a deleterious condition known as alkali-silica reaction or ASR. ASR is caused by a reaction between the alkaline cement and hydroxyl ions in the concrete and reactive forms of silica in the aggregate [4], this can be any type of silica found in commonly used aggregate. ASR occurs most when directly using glass aggregate. When concrete is affected by ASR, gel originates inside cracks and introduces an expansive force within the concrete, deteriorating the concrete's structural integrity.

ASR is the primary reason why recycled glass concrete is not allowed to be used in any sort of structural construction. Recycled glass concrete is currently only permitted for use in bike and walk paths. There have been studies that show the use of fly ash can reduce the possibility of ASR occurring. ASR is a huge hurdle that needs to be addressed, but unfortunately ASR cannot be conquered in a 16-week research period, therefore no attempt was made to study ASR, or reduce the chances of ASR occurring.

Research was conducted on the various standards and specifications that could influence the project's progress. Any and all ASTM standards that were used or referenced can be found in Appendix A Table A1. Most standards researched were not used but kept on file just in case changes in the project occurred.

Concrete additives are recommended when developing concrete mix designs. Only liquid admixtures were recommended for use. Admixtures can change how concrete is affected immediately or over a long period of time. Admixtures can increase the strength of concrete while at the same time reducing the amount of water needed to mix it.

2.2 Slump Test Research

A slump test is generally used on to freshly poured concrete to check if the concrete has the correct level of workability. This test is performed using a metal slump cone, a flat solid surface and a tamping rod (equipment needed is shown in Figure 2.1).

Figure 2. 1: Slump test equipment [5].

Immediately after mixing, a slump test should be done. The cone must be set vertically with the larger diameter on bottom. Start by filling the cone to one third of its volume then tamp the concrete using the rod 25 times in a circular pattern, continue this process two more times. Once thoroughly tamped, scrape excess concrete off the top and continue to remove the cone slowly by pulling straight up. The “slump” is the value from the top of the slump cone measured to the top of the settled concrete, this is depicted in Figure 2.2.

Other than a true slump there are two other cases that can happen when removing the cone. These two conditions are a shear slump, and collapse slump. A shear slump happens when the top of the fresh concrete slides off one side, when this happens redo the slump test again and make sure the correct process is followed. A collapse slump happens when the entire concrete cone falls, the test should be done again, but if the mix is too wet the slump test will not yield any useable result.

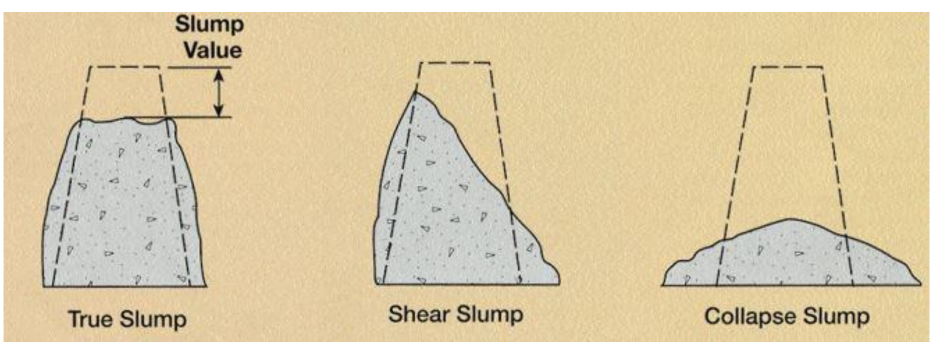

Figure 2. 2: True slump, shear slump and collapse slump [6].

3.0 Experimental Work

3.1 Mix Design Formulas

Through research and previous experience, FAB Concrete Mix and Design was able to create an experimental matrix that when testing is complete will show a large variety of designs suitable for construction applications. Mix design formulas are based on those found within "Concrete with waste glass as aggregate" by C Meyer *et al* [7]. Multiple mix designs are needed to give a wide range of values to allow for result comparison. The following table (Table 3.1) represents the original experimental matrix. There were originally 16 mix designs, but unfortunately designs 8-16 (hatched) were unable to be executed, primarily due to lack of consistent aggregate. Instead of combining aggregate from multiple locations the team decided to produce the maximum number of samples possible with the limited amount of available aggregate.

Table 3. 1: Original Experimental Matrix

Materials Required per Pour								
Mix Design	Cement (lb)	Recycled Glass Powder (lb)		Sand (lb)	Recycled Glass Coarse (lb)		Water (lb)	W/C ratio
1	19.87	0%		5.56	0%		6.95	0.35
2	17.88	10%		5.56	0%		6.95	0.35
3	15.89	20%		5.56	0%		6.95	0.35
4	13.91	30%		5.56	0%		6.95	0.35
5	19.87	0%		5.01	10%		6.95	0.35
6	19.87	0%		4.45	20%		6.95	0.35
7	19.87	0%		3.89	30%		6.95	0.35
8	17.88	10%		5.01	10%		6.95	0.35
9	17.88	10%		4.45	20%		6.95	0.35
10	17.88	10%		3.89	30%		6.95	0.35
11	15.89	20%		5.01	10%		6.95	0.35
12	15.89	20%		4.45	20%		6.95	0.35
13	15.89	20%		3.89	30%		6.95	0.35
14	13.91	30%		5.01	10%		6.95	0.35
15	13.91	30%		4.45	20%		6.95	0.35
16	13.91	30%		3.89	30%		6.95	0.35

The final experimental matrix shown in Table 3.2 tells us that every ingredient has a specific weight required in each mix design. The design team first decided to replace some of the cement with recycled glass powder, next sand would be replaced by another type of recycled glass which closely resembles sand, this glass is referred to as coarse recycled glass. Each type of recycled glass would replace its counterpart by weight, in increments of 10%, 20%, and 30%. This is represented in both Table 3.1 and Table 3.2. A mix design that has no recycled glass in it will be used as a control to give a basis to allow for result comparison. All designs are basically the same, only changing the volume of recycled glass.

Table 3. 2 Final Experimental Matrix

Materials Required per Pour								
Mix Design	**Cement (lb)**	**Recycled Glass powder**		**Sand (lb)**	**Recycled Glass Coarse**		**Water (lb)**	**W/C Ratio**
1	19.87	0%		5.56	0%		6.95	0.35
2	17.88	10%		5.56	0%		6.95	0.35
3	15.89	20%		5.56	0%		6.95	0.35
4	13.91	30%		5.56	0%		6.95	0.35
5	19.87	0%		5.01	10%		6.95	0.35
6	19.87	0%		4.45	20%		6.95	0.35
7	19.87	0%		3.89	30%		6.95	0.35

3.2 Material Preparations

Concrete is primarily produced using the following materials: Portland cement, water, coarse aggregate, sand, and sometimes admixtures. Materials were provided by Northern Arizona University. Both the recycled glass powder and coarse recycled glass was donated by Vitro Minerals, a leading manufacturer of glass powders and sands.

All equipment and aggregate must be washed and dried before being able to begin any experiment. Once the aggregate is dry, the next step to is sieve the material. Sieving separates the aggregate by size, using metal screens and mesh, this particular mix design requires the aggregates to be separated into 1/4", 3/8" and #4 passing.

Figure 3. 1: Steel tray being washed

Figure 3. 2: sieving aggregates

Admixtures are used in mix designs to improve, strength and functionality of concrete mixes. This design uses three different admixtures, which are, Delvo, P900, and Micro Air. Delvo it is a liquid chemical stabilizer that increases strength (compressive and flexural), and improves workability. P900 is a polymer plasticizer. Much like Delvo it also increases the strength and workability of the concrete mix. Micro Air is a liquid chemical surfactant that creates tiny air bubbles in concrete, these tiny uniformly spaced air bubbles increase resistance to freeze-thaw cycle damage. All materials are shown in (Appendix B Fig B4).

3.3 Mix Procedure

Mixing procedures are identical, and independent of mix design formula. All concrete is mixed one at a time, and all experiments are to be done individually.

Using the guidelines found in ASTM C192, mixing begins by cleaning four mixing containers. Aggregates are weighed and combined together in one bucket, water and admixtures are mixed in another, sand and cement can be combined prior to mixing, and finally the appropriate amount of recycled glass (if any) is prepared in the final container.

Initially all aggregates are placed in the mixer while its rotating. Next is to add half of the cement and sand, let it rotate until there is an even coating over all the aggregate. Half of the water is then added, use a tamping rod to make sure no cement is “caked” to the walls. After it has been confirmed that the materials are mixing properly the rest of the ingredients are added. ASTM C192 states that to be done properly the concrete must be mixed for three (3) minutes, then left to rest for another three (3) minutes, and then mixed again for two (2) minutes, for a total mixing process of eight (8) minutes.

Figure 3. 3: Separated buckets of mixing materials

Figure 3. 4: 1.25 Cubic Foot Concrete mixer

Figure 3. 5: Specimen placed in water for curing days

Figure 3. 6: Tinius Olsen compression machine

After mixing is complete, the wet concrete is immediately poured on a steel tray and slump tested. The wet concrete is then thoroughly tamped into six (6) 4X8 inch cylindrical molds in molds. The concrete molds are carefully labeled to insure that the correct results can be documented during each experiment. The first number represent the powder glass percentage, the second number represent the coarse glass percentage and the last number represent the numbered sample.

The molds are covered with lids for 48 hours, or until they are hard enough to be removed from the plastic. Once removed the concrete is placed under water to cure properly. After curing for seven (7) days three (3) concrete cylinders are dried and tested using the Tinius Olsen compression machine, the same process occurs to the last three (3) concrete specimens after another 21 curing days, a total of 28 curing days. In order to appropriately test the concrete samples, the tops are trimmed and squared so that when tested by the Tinius Olsen there are no imperfections that could possible cause point loads. A point load would give an invalid result. Trimming and squaring the concrete also allows each specimen to fit into special steel caps that are used when testing with Tinius Olsen.

3.4 Compressive Strength Test

The Compressive Strength Test finds how much pressure a specimen can withstand before failing. To perform this test, a concrete cylinder is needed. The cylinder is centered on the Tinius Olsen and loaded to failure. Once failure occurs the maximum load or force (F) is recorded. The Tinius Olsen only shows the maximum force in pounds, to change the force from pounds (lbs) to pounds per square inch. (psi) Equation 1 is used.

$$compression\ strength = \frac{F}{A}$$

Equation 3.1 Compression Force

F: Recorded force from compression testing machine

A: Cross-sectional area of specimen

After all specimens are tested (before and after respectively, Fig 3.7 and Fig 3.8) the results are immediately documented.

Figure 3. 7. Concrete Sample

Figure 3. 8. Broken Concrete Sample

4.0 Results

4.1 Slump Test Results

A slump test is performed to show the immediate reaction of how the glass aggregates effect the concrete slurry. Table 4.1 originally generated by *Civil Engg. Dictionary* [8] defines what the degree of slump means, and how workable a concrete is due to the amount of slump.

Table 4. 1: Concrete degrees of workability

Degree of workability	Slump		Compacting Factor	Use of concrete considering slump
	mm	in		
Very low	0-25	0-1	0.78	Used in road making
Low	25-50	1-2	0.85	Used for foundations with light reinforcement
Medium	50-100	2-4	0.92	Manually compacted flat slabs using crushed aggregates. Normal reinforced concrete manually compacted and heavily reinforced sections.
High	100-175	4-7	0.95	For sections with congested reinforcement.

Immediately after mixing, a slump test was performed for each experiment, the results are documented in Table 2. The results show that the concrete is very high in workability, so high in fact that the slump test is not an accurate representation of the concretes cohesion. However, during experiments that consisted of recycled glass powder the slump test results in a true measureable slump.

Table 4. 2: Slump test results

Experiment	Slump (in)
Control	9
10% glass powder	7
20% glass powder	4.25
30% glass powder	2.5
10% glass coarse	9
20% glass coarse	9
30% glass coarse	9

As previously stated the results permit the control and coarse glass experiments to be in the extremely high degree of workability, but the slump of the glass powder experiments ranges in the high to medium degree of workability. The difference in slump between glass powder and coarse glass can only be the product of water absorption. Glass powder absorbs a considerable amount of water when compared that of regular cement and the coarse glass. This means the coarse glass does not actually absorb enough water to become stiff enough, this is why those experiment results in a "collapsed" state instead of a true slump.

It is important to consider how the admixtures effect the concrete's workability. Both the Delvo and P900 increase set time, and workability of concrete. It is critical to note that if these two admixtures were not involved the slump tests could yield very different results.

4.2 Compressive Strength Test Results

Concrete cylinders are tested on the 7th and 28th day of curing (3 specimens per test day, per experiment). Compressive strengths for all seven (7) experiments can be found in Table 4.1. Average 28 day psi values range anywhere from 6500 psi to 8500 psi. The highest strength coming from the control experiment, this was expected because glass doesn't adhere as well as sand and cement.

Table 4. 3: Compressive Strength Results

Experiment Number	Experiment Detail	7 Day Average (psi)	28 Day Average (psi)	Standard Deviation (28 Day)
1	Control (0% glass)	6608	8557	503
2	10% glass powder	5865	8090	530
3	20% glass powder	5759	7348	1115
4	30% glass powder	5786	7772	603
5	10% glass coarse	5621	7401	239
6	20% glass coarse	5361	7215	166
7	30% glass coarse	5037	6552	256

Results for the recycled glass experiments were surprising, not only did the concrete get weaker when more glass was added but, the larger the glass particle, the less compressive strength. This observation validates our theory that glass does not perform out-right as well as traditional mixing materials.

AASHTO Article 5.4.2.1 (AASHTO, 2012) [9] specifies a minimum design strength of 4000 psi at 28 days. All seven (7) experiments show compression strengths over 4000 psi, meaning if only compressive strength was considered these mix designs could be used in various applications.

For each experiment the strength reduces in an almost linear fashion (shown in Figure 4.1). Experiment number three (3) has a greatest standard deviation and a lower compressive strength than experiment four (4). The results for experiment three (3) should be considered suspect and the experiment should be reattempted. Based on the current data, experiment 3's strength should be in between that of experiments two (2) and four (4). However, based on a 95% confidence interval the compressive strength of experiment three (3) still exceeds that of 4000 psi.

Figure 4. 1: Compressive Strength Comparison

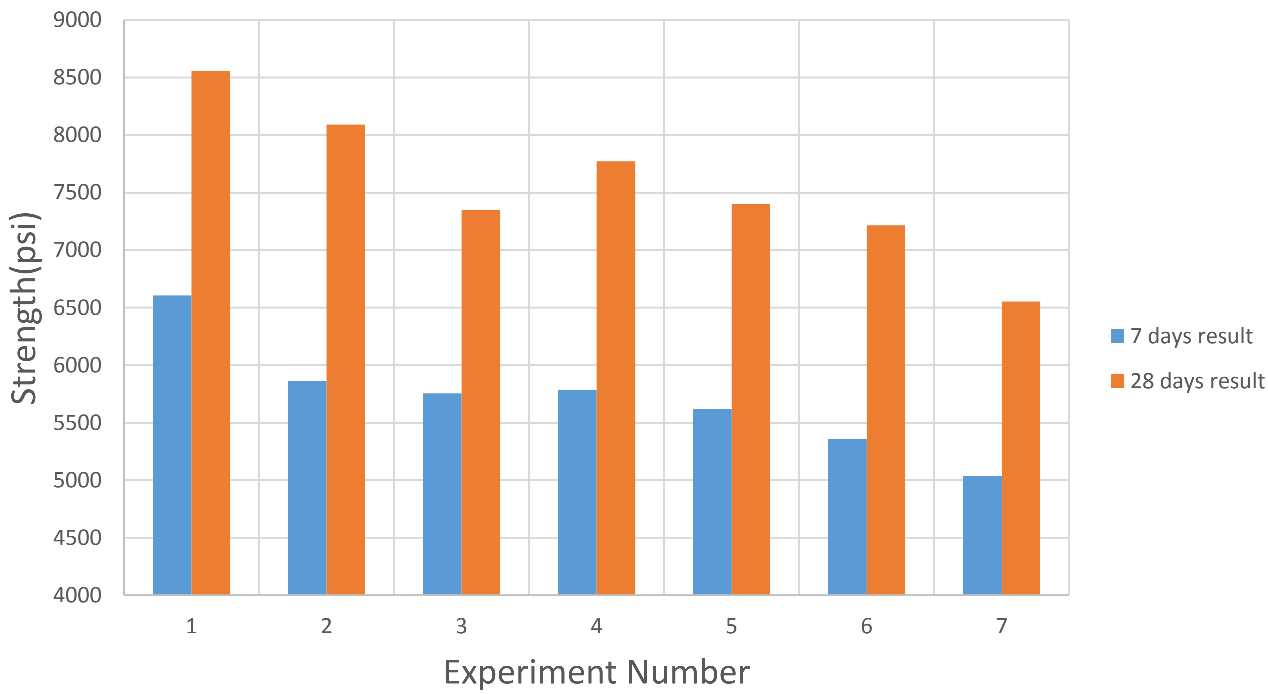

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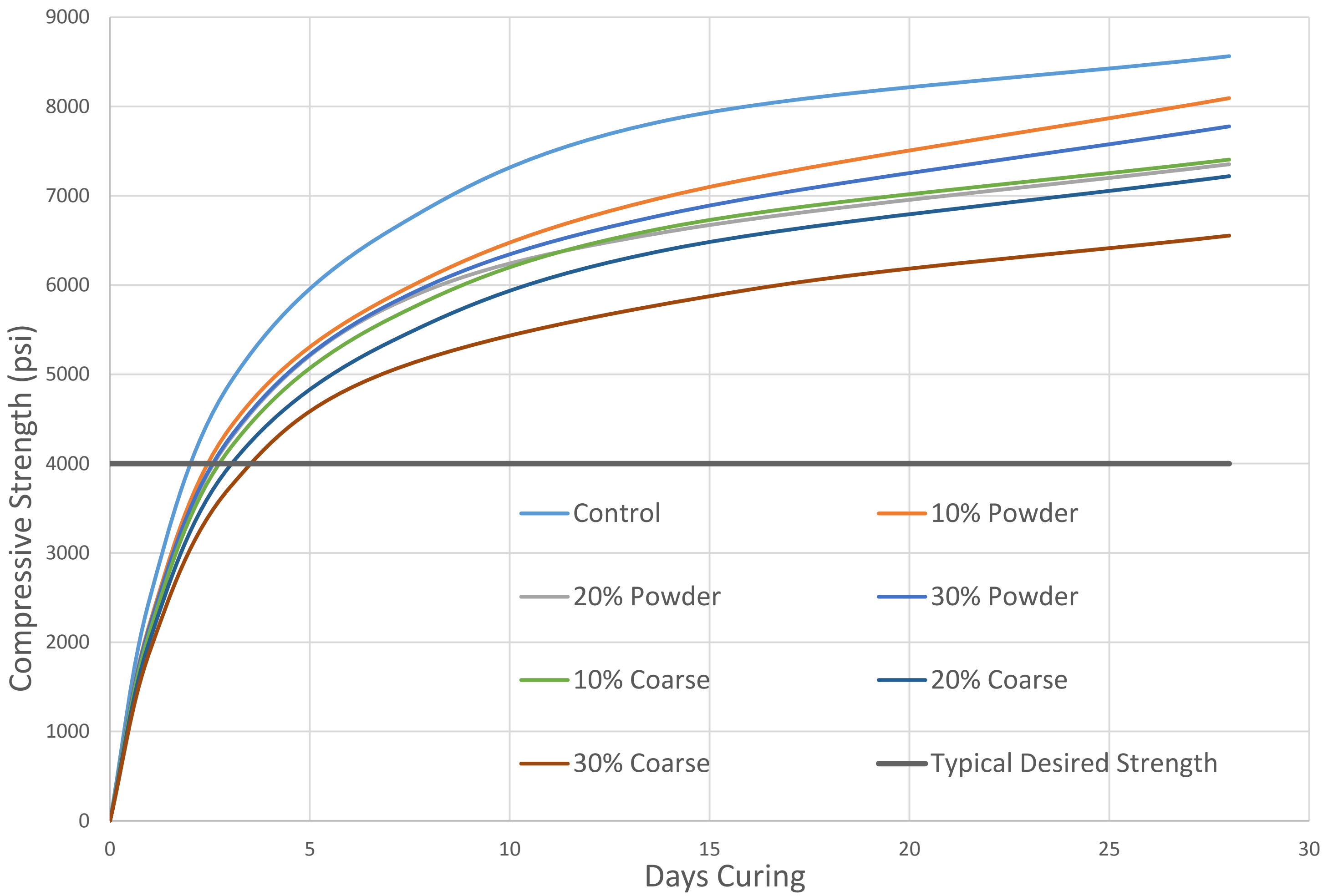
Figure 4. 2: Compressive Strength Tendency



Using data from the 7th and 28th day results, a strength per day curing curve was estimated for each experiment. Figure 4.2 was created to show how concrete strengthens quickly at first then reaches a peak and strength increase begins to drastically slow down. Concrete continues to harden throughout its life, although after a certain point, strength increase becomes so small its negligible.

5.0 Summary of Project Costs

The team calculated cost for each experiment based on the design formula and the cost of each material. The following graph (Figure 5.1) is the cost tendency for each research experiment. The units for the cost are in U.S. dollars. From Table 5.1, the cost of the recycled glass concrete is slightly higher than that of regular concrete. The cost for each pour includes the buying of all equipment, materials used, and renting the machines used during testing.

Figure 5. 1: Total Cost for Each Concrete Pour

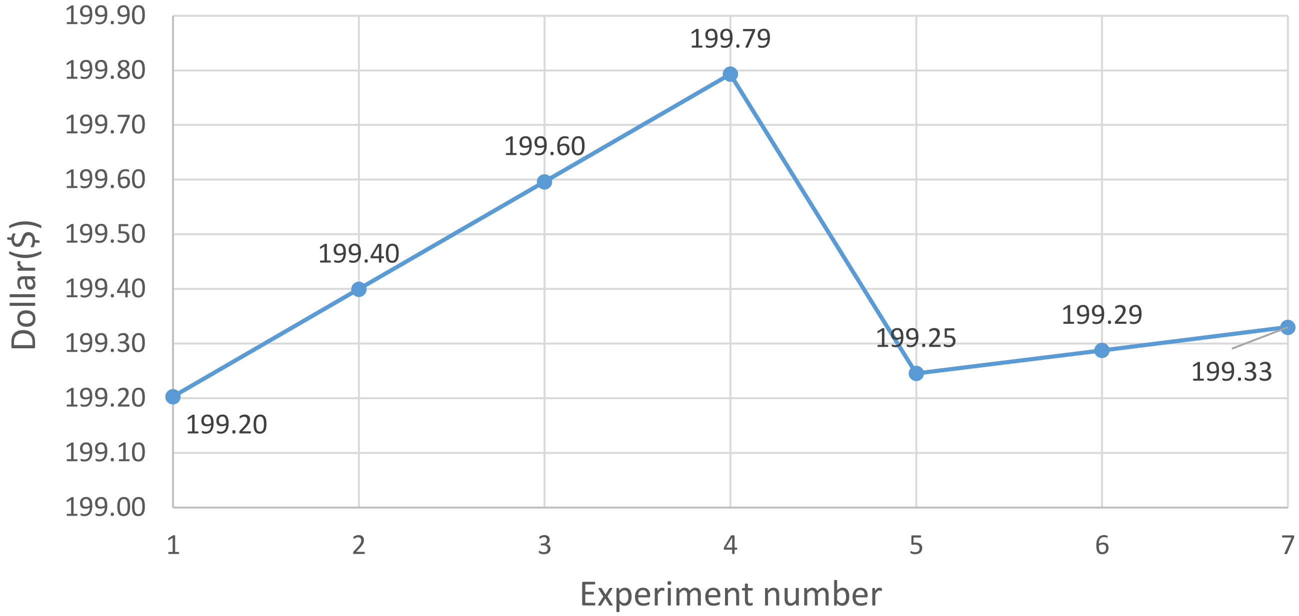


Table 5.1 shows the individual cost for equipment and the cost for all material bought by the pound. used and the materials bought for this project. Table 5.2 shows the total amount of time each employee spent working on the research project, and the total cost of labor for each individual employee.

Table 5. 1: Cost of Materials and Equipment

Total Cost of Materials		
Sieve Machine/ Sieves	Buy	700
Mixer	Buy	170
Compressive Strength Machine	60$ /hr.	480
Molds	2.25$ /each mold	94.5
Cement	0.096$ /lb.	12.21
Aggregate	0.058$ /lb.	11.43
Sand	0.10$ /lb.	3.56
Recycled Glass Powder	0.195$ /lb.	2.32
Grain Recycled Glass	0.176$ /lb.	0.59
Total		$1,474.61

Table 5. 2: Total Costs of Project

Type of Worker	SENG	ENG	LAB	INT	AA
Hours per position	51	67	92	62	63
Rate$/hour	148	75	57	27	50
Cost per position	7,548	5,025	5,244	1,674	3,150
Labor Cost	**$22,641**				
Equipment Cost	**$1,475**				
Project Total	**$24,116**				

Total project cost includes equipment cost, all time spent during: meeting hours, completing project tasks, and developing deliverables. The total materials cost is $1475 and total labor cost $22,641. The total cost of this project is roughly $24,000.

6.0 Conclusion

After finishing the experiments and documenting the results, it has been found that recycled glass aggregate is a viable alternative to make concrete with. After completing the research pertaining to recycled glass concrete, the following are proposed recommendations that should be pursued in future capstones:

- Glass aggregate is an effective alternative to traditional mixing materials.
- The more recycled glass used, the weaker the concrete becomes.
- Create samples to be tested periodically through the 28 day curing process. For example, test specimens on curing day(s) 1, 3, 5, 7, 10 ,14, 20, 28. Testing the concrete more often will give the engineers more data to possible create an expression that determines the compressive strength based on how much recycled glass is used.
- Recycled glass concrete cost slightly higher than conventional concrete. The cost to use recycled glass powder instead of cement is about $0.10 more per pound; to use coarse recycled glass over sand it costs roughly $0.07 more per pound.
- Research needs to continue. The nine (9) experiments left should be done to see how the different types of glass work together.
- The cause and effect of the ASR needs to be further investigated and confronted. It is paramount that recycled glass concrete be used in structural applications in the future.

7.0 Project Comparison

A project comparison was requested to show how accurate students were at estimating a projects cost, tasks performed and total working hours. Unfortunately, a direct comparison is not possible for our group. Initially the team was tasked to develop and implement mix designs for pervious and traditional concrete while also including recycled glass. Later, the project was amended to the research project laid out in this report. Table 7.1 is a direct comparison between our initial proposal with the final research report.

Table 7. 1: Project Comparison

	Proposal	Final	Variance
Scope	Pervious and Traditional Concrete with Recycled Glass Additive	Crushed Glass as a Sustainable Alternative Aggregate for Concrete	Only traditional concrete
Number of Tasks	19	16	3
Man Hours	554	335	219
Total Cost	$46,160	$24,116.00	$22,044.25

The initial proposal consisted of a lot more work, and overall the project would have difficult to finish in 16 weeks. The project changed from doing both pervious and traditional concrete to solely traditional. The proposal was only speculation and may not have costed or required as many hours to complete as speculated but, since we are unable to confirm or deny this. We can only assume that the final project required over 200 less hours than the proposal, and costed only $24,000 instead of $46,000. Changing the size and scope of the initial project saved everyone time, resources and money. The total proposed hours and Gantt chart timelines can be found in Appendix C

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8.0 References

[1] Waste stuff. “German Waste Exports.” <http://www1.american.edu/TED/germwast.htm>

[2] Edson Jansen Pedrosa De Miranda Júnior. "Increasing the Compressive Strength of Portland Cement Concrete Using Flat Glass Powder.” Materials Research UFSCar - Dep. De Engenharia De Materiais Vol.17 May, 2014.

[3] F. Rajabipour, S. Shafaatian and J. Wright. “Utilizing Coal Fly Ash and Recycled Glass in Developing Green Concrete Materials.” June 2012.

[4] “Alkali-silica reaction in concrete.” < http://www.understanding-cement.com/alkali-silica.html>

[5] “Construction Materials Testing Equipment: Slump Test Sets for Concrete Testing” <http://www.humboldtmfg.com/test_sets.html>

[6] C Meyer et al., “Concrete with waste glass as aggregate”. The international symposium concrete technology unit of ASCE and university of Dundee. March 19-20, 2011

[7] Fawaz Almutairi, and Fahad Aloqaili. Pervious Concrete. Rep. Vol. Phase Two. Flagstaff: Northern Arizona University, 2014.

[8] “Concrete slump test.” <http://www.aboutcivil.org/concrete-slump-test.html>

[9] Basham, Kim. "Testing Fresh Concrete." The Aberdeen Group, 1993. Web. <http://www.concreteconstruction.net/Images/Testing%20Fresh%20Concrete%20in%20the%20Field_tcm45-342628.pdf>

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Appendix A: (Tables)

Table A1: ASTM Standards and Codes

ASTM STANDARDS	
C 31-00	Standard Practice for Making and Curing Concrete Test Specimens in the Field
C 33-01	Standard Specification for Concrete Aggregates
C 39-01	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
C 125-00	Standard Terminology Relating to Concrete and Concrete Aggregates
C 136-01	Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates
C 143-00	Standard Test Method for Slump of Hydraulic Cement Concrete
C 150-00	Standard Specification for Portland Cement
C 172-99	Standard Practice for Sampling Freshly Mixed Concrete
C 192-00	Standards for Mixing and Storing

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Appendix B: (Figures)

Fig B1: Specimen Storage before Demolding

Fig B2: Demolding and Sample Labeling

Appendix C: (Comparison Documents)

Fig C1: Hours Log (Final Report)

Total Time Spent Working						
Major Task	Task	Hours				
		SENG	ENG	LAB	INT	AA
1.0 Research	1.1 Pavement	3	3	3	3	3
	1.2 Concrete Design	3	6	6	3	3
	1.3 Recycle glass additive	3	3	6	3	3
	1.4 Standards and Codes	3	3	0	6	6
2.0 Acquire Materials	2.1 Typical Concrete Materials	3	0	0	6	0
	2.2 Recycled Glass Powder	0	0	0	0	0
	2.3 Concrete Support Materials	0	0	0	0	0
3.0 Design and Experimentation	3.1 Experimental Design	0	0	11	0	0
	3.2 Prepare for mixing	0	0	20	0	0
	3.3 Concrete sample pouring	0	0	21	0	0
	3.4 Testing and Analysis	0	0	12	11	0
4.0 Project Management	4.1 Project Schedule	3	8	0	0	0
	4.2 50% Design	8	10	3	3	9
	4.3 Final Design Report	15	20	5	15	20
	4.4 Final Presentation	6	6	5	6	5
	4.5 Website	4	8	0	6	14
	Hours per Worker	51	67	92	62	63
	Total Hours	335				

Fig C2: Hours Log & Cost (Proposal)

Task	Hours				
	SENG	ENG	LAB	INT	AA
1.1 Pervious Pavement Design	2	2	0	10	5
1.2 Concrete Design	2	2	0	10	5
1.3 Recycle glass additive	2	2	0	10	5
2.0 Review Documentation	5	5	0	5	5
3.1 Basic Materials	0	0	2	10	0
3.2 Recycled Glass Powder	0	0	2	10	0
3.3 Extra Additive	0	0	2	10	0
4.1 Perivous Pavement with Recycled Glass	10	15	0	0	0
4.2 Regular Concrete wth Recycled Glass	10	10	0	0	0
5.1 Mix Procedure	0	2	20	2	0
5.2 Test Phase 1	0	2	30	30	0
5.3 Test Failure 1	0	2	6	1	0
5.4 Test Phase 2	0	2	30	30	0
5.5 Test Failure 2	0	2	6	1	0
6.1 Project Schedule	15	10	0	0	0
6.2 50% Design Report	20	30	0	0	30
6.3 Final Design Report	20	30	0	0	30
6.4 Final Presentation	0	5	0	0	0
6.5 Website	0	0	0	20	20
Hours per Worker	86	121	98	149	100
Rate$/hour	148	75	57	27	50
Cost for each type of engineer	12728	9075	5586	4023	5000
Total Labor Cost	**$36,412**				
Total Equipment Cost	**$3,727.35**				
Project Contigency @ 15%	**$6,020.90**				
Total Project Price	**$46,160.25**				

Gantt charts follow prospectively:

Final

Proposal

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