Recycled Glass Concrete

Final Proposal

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From: Molten Sand Research Center

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Table of Contents

1.0 Project Understanding

1.1 Purpose of Project

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 recycling glass helps to conserve natural resources.

1.2 Background Information

Previous research on the use of glass concrete was performed at Northern Arizona University (NAU) in 2015-2016 [1]. This research is to be continued in this project, which will be to improve the strength of recycled glass concrete and reduce cracking that may occur in the concrete [1]. In the previous project, recycled glass-powder and glass-sand were used to replace cement and sand components of concrete. Slump and compressive strength tests were performed. The previous research concluded that glass concrete can be an effective alternative for conventional concrete, but it is slightly more expensive than conventional concrete. The team could not fully complete the research due to lack of materials and time constraints, and did not perform the thermal impact analysis on the concrete.

Table 1.1 shows the mixtures that were used in the previous study; only mix designs 1-7 were completed. Glass powder was substituted for cement and glass coarse was substituted for sand in the experiments.

Table 1.1: Original Experimental Matrix [1]

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

Table 1.2 shows the compressive strength of the chosen mix designs from the Table 1.1. The mix designs were compared to the control sample. However, the results in Table 1.2 show that none of the mix designs from 2-7 exceeded the control mix design, either in 7 days or 28 days of curing. According to Table 1.2, the team concluded that the larger the particle of the glass replacement, the lower the compressive strength [1]. The recycled glass concrete design is mainly purposed for sidewalks and parking lots. According to the international codes for concrete properties code section 1904.2 Chapter 19 "concrete", the strength in concrete should be able to handle a minimum of 4000 pounds per square inches (psi) for the sidewalks and parking lots. Table 1.2 shows that all mix designs exceed the minimum specified compressive strength [2].

Table 1.2: Compressive Strength Results [1]

Mix Design	Experiment Detail	7Day Average (psi)	28 Days 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	7458	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

1.3 Stakeholders

The stakeholder of this project is the client and technical advisor, Dr. Jun Ho. Northern Arizona University, the engineering community and society, as well as the engineering students will benefit from this project. Since this project is focused on parking lots and sidewalks, people who will use the parking lots and sidewalks will also benefit from this project.

1.4 Technical Aspects of Project

The purpose of this project is to show that recycled glass can achieve a high or constant compressive strength in concrete. Therefore, the main technical aspect is finding an appropriate range of cement and recycled glass ratios that provide high strength concrete. Other technical aspects of project will also be involved: concrete mixing, curing, testing and obtaining statistically significant data. The general ratio of mixing concrete is 1:2.5:3.5 for cement, sand and aggregate [2]. Testing will include compressive strength, freeze-thaw cycle, slump, tensile splitting and electron microprobe lab.

1.5 Project Challenges

The most common challenges that could face the team are obtaining the required materials to have more mixtures, and the time for running tests. Companies that are willing to donate for research purposes will provide the materials needed, or the team will ask the client for research funds to obtain these materials. Both processes consume time, and need approval either from the client or from the companies willing to donate. Mixing and testing is a critical aspect of this research project. It needs to be carefully done to obtain correct results: accurately curing the samples, measuring for freeze-thaw cycles, slump, compressive and tensile strength, density, and thermal expansion. These tests take more than four months to perform, including mixing, provided there is no shortage of materials.

2.0 Scope of Services

In this section, the following tasks will be performed in order to complete the project. This project will consist of literature review, developing mix formulae, preparation, experimental procedures, testing, data analysis, and project management tasks as described below. Each task will include subtasks which provide more detail.

2.1 Task 1.0 Research

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

2.1.1 Task 1.1 Previous Projects

The team will study all aspects of the previous project from 2015-2016, to develop a mix that can withstand a larger load and resists thermal impacts when being installed.

2.1.2 Task 1.2 Alkali Silica Reaction (ASR)

The team will research the ASR in order to develop a mix that includes how concrete with recycled glass performs with this reaction.

2.1.3 Task 1.3 Glass Size Properties

The team will research how the particle size of the recycled glass affects the concrete strength and the ASR.

2.1.4 Task 1.4 Material Properties

The team will search for materials that will produce a design mix that improves the strength and thermal resistance, as well as reduces the ASR in the concrete.

2.2 Task 2.0 Developing Mix Formulae

The team will develop different mix formulae based on the results of the research in Task 1.0. An experimental matrix similar to that of Table 1.1 will be designed so that all variables can be studied.

2.3 Task 3.0 Experimental Preparation

The team will obtain the materials and equipment needed.

2.3.1 Task 3.1 Material Acquisition

The team will contact companies that produce materials needed such as aggregates, admixtures, cement, fly ash, silica fume, and recycled glass. It is expected that most materials will be donated. Materials will be purchased as required.

2.3.1.1 Task 3.1.1 Aggregates

Aggregate will be obtained 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). Aggregates in most concrete are more or less chemically inert. However, some aggregates react with the alkali hydroxides in concrete, causing expansion and cracking over a period of time. This reaction causes ASR reaction and aggregates of this type are referred to as ASR aggregate.

2.3.1.2 Task 3.1.2 Admixtures

Admixtures are used to improve strength and to provide the design mix with the resistance against thermal and fatigue cracks. The admixtures are Mid-range Water Reducer (P900), Hydration Stabilizer (Delvo), Air Entrainment (Micro Air), and Viscosity Modifier (VMA). Companies will be contacted to provide these admixtures.

2.3.1.3 Task 3.1.3 Recycled Glass

2mm to 0.177mm sizes of recycled glass will be used as a replacement for 0.074mm Portland cement, sand from 0.0625mm to 2mm, and aggregate sizes that are mentioned in Task 3.1.1. The recycled glass will be provided from a company called "Vitro Minerals" which is located in Jackson, Tennessee.

2.3.1.4 Task 3.1.4 Silica

The team will use silica if no ASR aggregates are found, to create a design mix that produces ASR, to observe if recycled glass prevents ASR. Approximately 0.044mm silica powder sizes will be used to allow the whole sample to be experienced to the reaction.

2.3.2 Task 3.2 Testing Equipment

The team will contact the CECMEE Lab Manager in order to test in the CENE materials lab in the engineering building at NAU. The lab has the needed equipment for the compressive strength, freeze-thaw cycle, tensile strength and slump tests.

2.4 Task 4.0 Experimental Procedures

This section will include mixing, creating the cylindrical samples, curing and testing tasks.

2.4.1 Task 4.1 Mixing

Mixing will be performed in the CENE Soils and Material labs at NAU, using a mini electric cement mixer. The samples will be 4-inch diameter and 8-inch long (mold size). Each design mix formula will provide four samples, three samples that will be cured for 7, and 28 days prior to testing and the last one saved for experimental error and/or display.

2.4.2 Task 4.2 Curing

Cylindrical specimens will be placed into water buckets for 7, 14 and 28 days to cure in order to strengthen the concrete using hydration.

2.4.3 Task 4.3 Testing

Sample cylinders will be tested by performing the following tests.

2.4.3.1 Task 4.3.1 Compressive Strength Test

A Compressive Strength test will determine the strength of the concrete. The compressive strength-testing machine (Figure 2.1) is located in the CENE Mechanics of Materials Lab in EGR at NAU. ASTM C39-C39M standard method will be used to perform the compressive strength test method.

Figure 2.1: Compressive Strength Test Machine

2.4.3.2 Task 4.3.2 Freeze-Thaw Cycle Test

The team will perform a Freeze-Thaw Cycle test to test the resistance of the concrete to rapid freezing and thawing. A “Gilson HM-120 Automatic Freeze Thaw Apparatus” apparatus (Figure 2.2) will be used to complete the freeze thaw cycle test by following ASTM C666 standard method. The machine is located in the Construction Materials Lab in EGR at NAU.

Figure 2.2: Gilson HM-120 Automatic Freeze Thaw Apparatus [3]

2.4.3.3 Task 4.3.3 Slump Test

A Slump test will determine the consistency of the fresh concrete. Slump test will be performed immediately after mixing by following ASTM C143-C143M standard method. A metal slump cone, a scale for measurement, a temping steel rod and a big tray from Mechanics of Materials Lab at NAU will be used to complete the slump test. Figure 2.3 shows the materials set for Slump test.

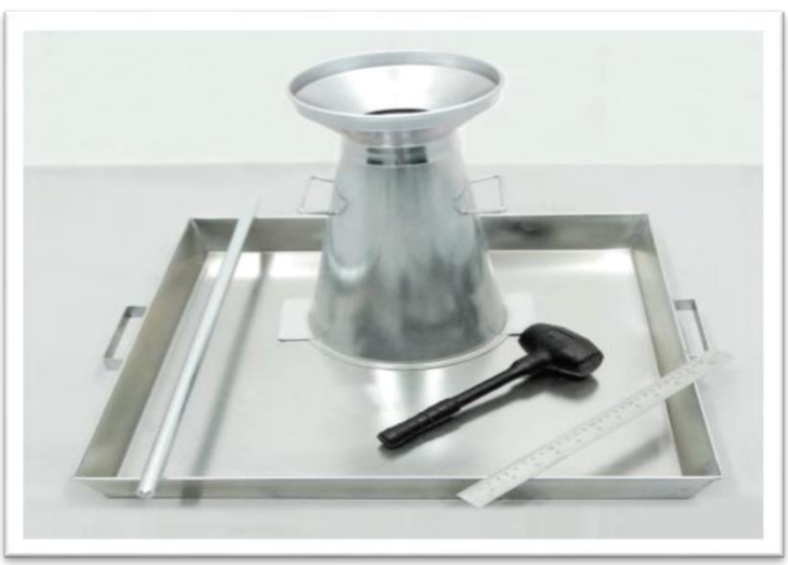

Figure2.3: Material Set for Slump Test [4]

2.4.3.4 Task 4.3.4 Tensile Splitting Test

The team will perform a Tensile Strength test to evaluate the behavior of the concrete under the applied loads. A tensile strength test machine (Figure 2.4), which is located at Mechanics of Materials Lab in EGR at NAU, will be used to determine the tensile strength test. ASTM C496 method will be used to accomplish the tensile strength test.

Figure 2.4: Tensile Strength Test Machine

2.4.3.5 Task 4.3.5 Electron Microprobe Lab Test

The test will determine ASRs of the materials in the concrete mix design. The NAU Electron Microprobe Lab (Figure 2.5) in Bilby Research Center at NAU will be used to perform the test.

Figure 2.5: Electron Microprobe Laboratory [5]

2.5 Task 5.0 Data Analysis

The team will present data and perform statistical analysis on results to assure accuracy and precision of results. Conclusions and recommendations for further work will be discussed.

2.5.1 Task 5.1 Analysis of Variance (ANNOVA)

ANNOVA will be performed using the Microsoft Office Excel software to analyze the variance between data sets of chosen samples. The test will be performed in a fixed effect factor, which will be either tensile splitting load or compressive load in psi.

2.5.2 Task 5.2 Statistical Significance (One Sample T-test)

The One Sample T-test helps to observe the significant difference of a mix design, depending on tensile and compressive strength for one design formula. The team will conduct this test for the chosen mix design formulae to prove that the obtained strengths are within an acceptable range without errors.

2.6 Task 6.0 Project Management

The project management section will include team management, client management and deliverables tasks.

2.6.1 Task 6.1 Team Management

The team will hold meetings weekly to discuss the project and information presented by the client for 60 - 90 minutes. Weekly team meetings will be documented and scheduled to discuss the deliverables. The team will prepare an agenda and compile minutes for each meeting.

2.6.2 Task 6.2 Client Management

The team will meet with Dr. Jun Ho, who is not only the client but also the technical advisor, every other week. During the duration of 45 - 60 minutes meetings, each team member will present the current work on the project and will discuss future work. The team will prepare an agenda and record the minutes during the meeting.

2.6.3 Task 6.3 Deliverables

The team will deliver a 50% design report, a final design report, a final presentation and a website.

- **50% Design Report**

  The team will deliver a 50% design report to Dr. Bero and Dr.Ho. The project will be completed to the professors and the report will be informed.

- **Final Design Report**
  Final design report will be provided in December to Dr. Bero and Dr Ho.to present the final results. It will include analysis results of testing and the developing formulae to improve the design.

- **Final Presentation**
  The team will perform an oral presentation describing the project in December, 2016.

- **Website**
  The team will share and upload a website to the public, which will include all the information that is related to project.

2.7 Task 7.0 Exclusions

As the team can only obtain recycled glass in available sizes, there will be some limitations on the sizes of recycled glass. Since the air void of the conventional concrete is almost zero, the team will not perform permeability. A permeability test is purposed to measure the water flow rate through the sample. The Air Void test will measure the air content in the concrete because entrained air plays an important role in protecting the concrete from freeze-thaw damage. Air void test will be followed ASTM D7063-D7063M standard method.

3.0 Schedule

The schedule includes all the six main tasks associated with the project. It shows the start and end dates for each task in the project. Gantt Chart was used to construct the project schedule. Figure 3.1 shows the schedule chart for the project. The tasks are listed in the left part of the figure and the time line is listed in the right side of the figure. The arrows represent that the tasks are connected, either it cannot be started unless another task is completed as represented in the Second task, where the arrows points down. When the arrow starts from the beginning of the task it means that the task can be done while another task is started. When the arrow coming from the end of the task and extend until the end of the other task it means that both tasks can be ran in the same time but it is needed to perform the first one to end the second one. The solid line within the task period represented the percent completion of the task. The diamond shaped points represents the milestones of the project, where the important deadlines are indicated.

According to Figure 3.1, Research (Task 1.0) has been started on January 18, 2016 and will be ended on November 11, 2016. Developing mix formulae (Task 2.0) has been started on January 29, 2016 and will be finished on April 2, 2016. Experimental preparation (Task 3.0) has been started on February 1, 2016 and will be done on October 26, 2016. Experimental procedures (Task 4.0) has been started on April 2, 2016 and will be completed on November 26, 2016. Data analysis will be started on August 15, 2016 and will be done on December 15, 2016. Team management has been started on January 18, 2016 and will be ended on December 16, 2016.

The critical path for this project includes Task 2.0, Task 4.0, and Task 5.0. These three tasks are dependent on each other, where Task 4.0 can only be started when Task 2.0 is finished. Once Task 3.0 is done, Task 4.0 can be performed.

The project will be ongoing during the summer as represented in Figure 3.1, where the team will perform mixing, curing and testing. The team will also conduct research how to increase the strength of the concrete based on the test results from the mixed samples. Since the team will be working over the summer period, team management will be needed to either to confirm results with the client, or to discuss the results and upcoming tasks as a team.

Figure 3.1: Gantt Chart

4.0 Staffing and Cost of Engineering Services

This design project will need one senior engineer, one engineer, one lab technician, one intern and one administrative assistant. A senior engineer (SENG) will manage others and review work of others. An engineer (ENG) is responsible for leading the project by developing the formulae, supervising experimental procedures, and writing the report. The intern (INT) will assist engineers, and lab. A lab technician (LAB) is responsible for mixing and testing the recycled mix designs. An administrative assistant (AA) will help in various kinds of work to support the group to communicate with the clients and companies to obtain resources.

Table 4.1shows the major tasks, tasks, hours and codes for staff roles. The total hours for SENG, ENG, LAB, INT and AA are 51 hrs, 229 hrs, 120 hrs, 152 hrs and 46 hrs respectively. The total hours for all staff are 598 hrs. They are highlighted in yellow.

Table 4.1: Total Hours for Staffs

Staffing and Cost						
Major Task	**Task**	**Hours**				
		SENG	**ENG**	**LAB**	**INT**	**AA**
1.0 Literature Review	**1.1 Previous Projects**	4	10	0	12	0
	1.2 Alkali Silica Reaction (ASR)	4	20	0	8	0
	1.3 Glass Particle Size	3	15	0	6	0
	1.4 Material Properties	25	1	0	20	0
2.0 Developing Mix Formulae		3	40	0	22	0
3.0 Experimental Preparation	**3.1 Material Acquisition**	0	47	7	30	20
	3.2 Testing Equipment	0	3	15	0	0
4.0 Experimental Procedure & Data Analysis	**4.1 Mixing**	0	5	50	10	0
	4.2 Curing	0	0	1	0	0
	4.3 Testing	0	15	47	20	0
5.0 Project Management	**5.1 Team Management**	6	20	0	0	0
	5.2 Client Management	0	10	0	0	16
	5.3 50% Design Report	1	20	0	12	0
	5.4 Final Design Report	2	20	0	12	0
	5.5 Final Presentation	3	3	0	0	0
	5.6 Website	0	0	0	0	10
	Hours per worker	**51**	**229**	**120**	**152**	**46**
	Total Hours	**598**				

Table 4.2 shows the total project cost with the required staff, total hours, hourly rates and total estimated cost for this project. Overhead is included in the billable rates for staff. The personnel expenses will cover the SENG, ENG, LAB, INT, and AA costs. The hourly pay rates for the SENG, ENG, LAB, and AA are $ 195, $67, $48, $ 22 and $ 56. If the aggregates are needed, it will be obtained from CEMEX in Flagstaff, Arizona. Two round-trips are included, using NAU vehicles. To accomplish mixing, curing and testing, the lab rental fee is $30 per hour. The total project cost is $40,437, which is the combination of total labor cost, travel and lab rental cost.

Table 4.2: Total Cost Estimate

1.0 Personnel	Classification	Hours	Rate, $/hr	Cost
	SENG	**51**	**195**	**$9,945**
	ENG	**229**	**67**	**$15,350**
	LAB	**120**	**48**	**$5,760**
	INT	**152**	**22**	**$3,344**
	AA	**46**	**56**	**$2,576**
	Total personnel			**$36,975**
2.0 Travel	**2 trips× 7.4 miles/trip**	**$0.40/mi**		**$12**
3.0 Lab Rental		**120**	**30**	**$3,600**
4.0 TOTAL				**$40,437**

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