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Pervious Concrete Research Design

Phase Two

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PERVIOUS CONCRETE RESEARCH TEAM

12/09/2014

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Dr. Chun-Hsing Jun Ho
Department of Civil Engineering,
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Environmental Engineering.

Dear Dr. Chun-Hsing Jun Ho,

The final report attached to this letter is in response to the request for final research report dated August 26th, 2014 regarding developing pervious concrete mix design formulas. In the report, you will find the final mix design formula decided upon several tests.

Thank you for letting us to be part of your research and we hope that we have satisfied your requirements from this report.

Sincerely,

Pervious Concrete Research Team

Fawaz Almutairi   Fahad Aloqaili

Fawaz Almutairi   *Fahad Aloqaili*

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1.0 INTRODUCTION

The purpose of this project is to conduct research for developing pervious concrete mix design formulas. A primary concern is that the pervious concrete mix design formula must withstand the cold climate conditions of Flagstaff, Arizona. During the second phase of this research project, the team continues working on the project using results and mix formulas created in Phase One. This project includes producing specimens, laboratory testing, creating the final data sheet and the final mix design formula. Also, the team will compare mix design formulas depending on which material they have: silica fume, and fiber.

2.0 BACKGROUND

2.1 Pervious Concrete

The US Environmental Protection Agency (EPA) recommends pervious concrete pavement systems to manage surface storm-water runoff and treat the storm-water. When looking at the mix materials and the mixing techniques, the conventional concrete mix is similar to pervious concrete mix. Pervious concrete has a higher void ratio, which reduces its strength when compared to the conventional concrete. Pervious concrete has been applied in pavements for more than 20 years around the United States. Unfortunately, 25% of the installations have failed.

2.2 The City of Flagstaff, Arizona

The City of Flagstaff is located in the northern part of the state of Arizona. Flagstaff has an elevation of 6,910 ft and an area of 63.9 square miles. The City of Flagstaff winter climate is often below freezing and experiences high frequency of freeze-thaw cycles which affects the performance of the mixes. The number of cycles is around 250 cycles. Northern Arizona University is located in the City of Flagstaff. A first attempt in using pervious concrete in the pavement was in 2007 when it was applied in the parking lot near the Applied Research and Development Building (ARD). NAU is the first institution in the State of Arizona to use pervious concrete in the parking lot pavement.

2.2 Phase One

The parking lot located near the Applied Research and Development building (ARD) of the campus was made with pervious concrete in 2009. This parking lot failed after three years from the application and completion. A team in charge of Phase One developed pervious concrete mix formulas. The team members included Junyi Shen and Darius Ikan-tubui Ishaku. Then, based on the formulas, the team produced specimens. While a few pervious concrete mixes appeared to be a promising product, there is still a need to improve its performance in durability, strength, and air void. The information gathered from Phase One is necessary for applying the mix design formula and monitoring it. Also, the information is important to know the mistakes made by the Phase One team as well as the different mixes created in Phase One. This will help in avoiding the same mistakes and having more ideas in creating more appropriate mix for the parking lots.

3.0 PROJECT DESCRIPTION

3.1 Project Understanding

Pervious concrete is a concrete mix that has a high void ratio to allow water to pass through the pavement to the ground in a short amount of time. This helps to manage storm water by reducing runoff and localized flooding. The purpose of Phase Two of the pervious concrete is to create a stronger mix of the pervious concrete by adding an admixture, silica fume, which increases the strength of concrete. The new mix includes fiber, aggregate, cement, water and silica fume. These mixes will be expected to increase the strength and void ratio of specimens, which will advance the performance of pervious concrete. Another purpose of this project is to compare the mixes in strength and void ratio with or without silica fume and fiber.

3.2 Current Conditions

3.2.1 Existing Parking Lot

The ARD parking lot failed after three years from completion. The failure was due to shear force from large trucks. The failure of the parking lot motivated the project. Since then, specimens have been created in order to find the best concrete mix design formula and apply it to the parking lot. The new specimens have to withstand the high shear force from large trucks.

3.2.2 Phase One Mix Design

The specimens have different ratios of cement, coarse aggregate, water and sand. Also, the specimens have chemical admixtures added to them like Hydration Stabilizer (DELVO), Mid-range Water Reducer (P900), Viscosity Modifier (VMA), Air Entrainment (Micro Air). These chemical admixtures were added to the specimens for both phases; however, for the second phase and after looking up for more admixtures, silica fume admixture was added to the mix formulas. These admixtures are used to increase the quality of performance of concrete. Two different molds were used to test the specimens created. The first mold is a cylindrical mold with a diameter of 4 inches and a height of 8 inches. This mold is used for the Compression Strength Test and the Void Ratio Test. The second mold is rectangular mold that has a length of 16 inches, width of 4 inches and a height of 4 inches. These molds are used for the freeze-thaw cycle tests.

3.3 Constraints and Limitations

There are several constraints and limitations for the concrete mix design formula. A water to cement ratio of 0.265-0.3 is required for the design. The resulted compression strength for the specimens must be no lower than 2500 psi. Moreover, the void ratio must exceed 17%. This is because having a lower percentage than 17 would decrease the chance of the seepage of water when applying pervious concrete on the pavement. The City of Flagstaff experiences around 250 freeze-thaw cycles in one year. The specimens must withstand the weather conditions and the high frequency of freeze-thaw cycles.

3.4 Task Lists

A set of tasks was developed in order to complete the second phase of this research project. The tasks include all aspects related to finishing the second phase. This include deliverables, meetings, preparation, designing and testing. The list of tasks for the second phase of pervious concrete mix design formula are:

Task 1- Team Management

Task 2- Project Development

Task 3- State of the Art Literature Review

Task 4- Material Preparation

Task 5- Mix Formula Development

Task 6- Specimen Production

Task 7- Lab Testing

Task 8- Data Analysis

Task 9- Final Deliverable

4.0 LITERATURE REVIEW

In the past eight years, many studies and projects have been carried out on pervious concrete. Also, some of the researches were done for the performance of pervious concrete at low temperatures and high frequency of freeze-thaw cycle. Roseen et al. studied the performance of pervious concrete pavement for storm water management [1]. Their research stated that pervious concrete had demonstrated its ability for drainage, but the pavement color and shading had been the major factors influencing the snow and ice accumulation in the studied parking lot. Wang et al. examined the freeze and thaw durability of low permeability concrete with and without air entrainment [2]. They found that the effectiveness of air entrainment for resisting freezing and thawing deterioration was dependent on air void system. The air void system did not depend on the type of cementations material. They recommended the amount of air voids needed to be 6% or greater.

Kevern et al. investigated the influence of freeze-thaw cycle on the strength of pervious concrete and monitored the performance with some laboratory testing [3]. They used many mix design formulas with and without fiber and the durability test was done under some number of freeze-thaw cycles. The results of the tests confirmed that the short fibers improved the strength of concrete, permeability, and freeze-thaw durability of the mixes that do not have additional sand.

The National Ready Mixed Concrete Association (NRMCA) stated that most of pervious concrete mixes had water-cement-ratio between 0.27-0.45 and containing no fine aggregate and made of single sided aggregate [4]. The aggregate influences the integrity of the pervious concrete structure. Particularly, the interlock effect of aggregate particles transfers loads between individual particles from the surface to the bottom of the pavements. It is still not clear as regard to how to maximize the strength and the freeze-thaw durability of pervious concrete. The strength and the freeze-thaw durability can be changed by adjusting the rate of aggregates, fibers, admixtures, and voids. The mix design presented in the paper considered all the factors by using locally available limestone and basalt, fibers, and admixtures (air entrainment, water reducer, viscosity modified, and hydration stabilizer). The mix design was made to produce a number of pervious concrete specimens and then characterize their porosity, compressive strength, and freeze-thaw resistance.

5.0 MATERIAL PREPARATION

Specimen materials should be prepared before mixing in order to produce pervious concrete. The pervious concrete specimens were produced using the following materials: Portland cement type II and V , water, coarse aggregate (#4, 3/8", 1/2", and 3/4"), fine aggregate (nature sand) up to 2% fine sands by weight, fiber (Fibermesh@150), Air Entrainment, Mid-range Water Reducer, Hydration Stabilizer, Viscosity Modifier, and silica fume. Admixtures were used in the mix design to improve the strength of pervious concrete mixes. Using some ready admixtures such as Micro Air, air-entraining admixture, is recommended because it provides more protection for the concrete by generating small, strong and closely spaced air bubbles. It also decreases the internal stresses caused by expansion and contraction of water in the concrete pores upon freezing and melting during a daily cycle. Viscosity-modifying (vma) admixture increases the viscidness of the concrete by enabling stability and flexibility in the concrete during the placement. Also, Stabilizer admixture (DELVO) delays the setting time of the concrete which controls the hydration of Portland cement. To improve the durability of the pervious concrete, P900 admixture is used as a high range water reducing admixture along with fiber. For this phase, silica fume is added to the mix formulas to improve the compressive strength.

6.0 SPECIMEN PRODUCTION

A series of pervious concrete mixes are created when specimen production was needed. The mixes include three different sizes of coarse aggregate (3/4", 1/2", 3/8" and No.4). The mixes have different ratios of each kind of aggregate and sometimes they were not included in the mix. The mixes also incorporated at a rate of 2% by weight. Water and cement are added into the mix with a water to cement ratio of 27%. Four different admixtures in liquid forms are added to the mix with each having their influence on the performance of the specimens. The admixtures are Hydration Stabilizer (DELVO), Mid-range Water Reducer (P900), Viscosity Modifier (VMA), Air Entrainment (Micro Air) with masses of 105 oz, 36 oz, 12 oz, and 20 oz, respectfully. Moreover, some of the mixes have fibermesh 150, which is a micro reinforcement system for concrete. For this phase, a new admixture is added to mix, which is silica fume. Silica fume is different from the other four admixtures in being in solid powder form. For each mix design formula, four specimens are made. For this project, the volume is considered for five specimens in case of any mistakes taken through the mixing procedure. Steps for producing specimens can be found in Appendix A.

7.0 TESTING/ANALYSIS

There are three tests that need to be conducted to determine the best mix design formula. They are: Compressive Strength, Void Ratio and Freeze-Thaw Cycle. Each test has its steps in order to find the results.

7.1 Compressive Strength Test

The Compressive Strength Test decides how much pressure a specimen can withstand. For this test, a cylindrical specimen is needed. The specimens created had a four inch diameter and the height of eight. The specimens were placed in the machine and the pressure is applied until the specimens failed and a screen shows the maximum applied pressure.

7.2 Void Ratio Test

The Void Ratio Test measures the void ratio of the specimen. After completing the Void Ratio Test Procedure (Appendix B), the porosity also known as void ratio can be calculated using the following equation:

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

P is the porosity or the void ratio of the specimen. (%)

W_1 is the weight under water of the specimen. (g)

W_2 is the dry weight of the specimen. (g)

ρ_w is the density of water. (1 g/cm^3)

Vol is the volume of the specimen. (cm^3)

7.3 Freeze-Thaw Cycle Test

The Freeze-Thaw Cycle Test measures how many cycles a specimen can withstand before cracking. The specimen is made into a rectangular shape. The length of the specimen is 16 inches while the base and height of the specimen are four by four. The machine (Figure 5) will run cycles on the specimens placed inside with a low temperature of -18°C and a high temperature of 4°C.

Flagstaff, Arizona usually experiences around 250 cycles per year. Therefore, the specimens are required to withstand at least 250 cycles and the testing will last till 300 cycles.

8.0 MIX DESIGN FORMULAS

After understanding the current conditions, reading about recent research and Phase One results, the team started designing the pervious concrete formulas. The mix design formulas from Phase One are developed in Phase Two. The mix design formula has coarse aggregate (3/4”, 1/2", 3/8” and/or No.4), cement, water, sand, admixtures, and fiber. Each have their percentage in the mix formula. Most of these materials do not change from one formula to the other. The percentage change mostly with the coarse aggregate and whether or not a certain size is available in the formula. The water to cement ratio is kept between 26.5% and 30%. A new admixture is added to the mix design formula, silica fume. Silica fume is new to this research as it was not used in Phase One. This admixture replaces 5% of the cement added to the mix. Four other admixtures (vma, P900, Micro Air, DELVO) are in the mix design formula. Each admixture have their impact on the performance of the specimen. The impacts were mentioned in section 6, *Material Preparation.* The fiber used in the formulas is Fiber mesh @150. A small amount of sand is added to the mix formula. Sand is known to fill the voids between the aggregate. Therefore, a small amount is enough for pervious concrete. Pervious concrete is designed so that it allows water to pass through it without any obstacles. The following tables (1, 2) include the mix design formulas produced for testing. Table 1 is for developing the mix design formula and finding the best one that has the highest compressive strength and the highest void ratio. Table 2 is for the comparison of the effects of the admixture, silica fume, and fiber. A mix design formula from table 1 was chosen to compare the four mix formulas. The first formula has only fiber, the second does not have any of them, the third has both and the last one has only silica fume

Table 1: Concrete Mix Design Formulas

Mix ID#	Material Proportion (lb./yd^3)								Admixture(oz.)				Fiber (kg/m^3)
	Cement	Water	w/c ratio	Sand	Aggregate Gradation				Delvo	P900	Micro Air	vma	
					#4	3/8"	1/2"	3/4"					
#24 CV	616	197.4	0.320	200	-	650	1850	-	105	36	12	20	0.6
#25 CV	616	239.2	0.388	200	250	400	1850	-	105	36	12	20	0.6
#26 CV	616	169.4	0.275	200	500	500	1500	-	105	36	12	20	0.6
#27 CV	616	169.4	0.275	200	250	750	1500	-	105	36	12	20	0.6
#26 PR	616	169.4	0.275	200	500	500	1500	-	105	36	12	20	0.6
#27 PR	616	169.4	0.275	200	250	750	1500	-	105	36	12	20	0.6
#30 PR	616	169.4	0.275	200	500	500	1250	250	105	36	12	20	0.6
#31 PR	616	166.3	0.270	200	-	1000	1500	-	105	36	12	20	0.6
#32 PR	616	166.3	0.270	200	750	200	1550	-	105	36	12	20	0.6
#33 PR	616	169.7	0.275	200	750	350	1400	-	105	36	12	20	0.6
#16 PR	616	163.2	0.265	200	1000	1500	-	-	105	36	12	20	0.6
#34 PR	616	196.9	0.275	200	850	450	1200	-	105	36	12	20	0.6

Table 2: Comparison of Specimens with/without Silica Fume and Fiber

Mix ID#	Material Proportion (lb./yd^3)								Admixture(oz.)				Fiber (kg/m^3)	Silica Fume (g)
	Cement	Water	w/c ratio	Sand	Aggregate Gradation				Delvo	P900	Micro air	vma		
					#4	3/8"	1/2"	3/4"						
#31 no-Fiber/SF	616	166.3	0.270	200	1000	-	1500	-	105	36	12	20	-	-
#31 Fiber	616	166.3	0.270	200	1000	-	1500	-	105	36	12	20	0.6	-
#31 SF	585.2	166.3	0.270	200	1000	-	1500	-	105	36	12	20	-	30.8
#31 SF/Fiber	585.2	166.3	0.270	200	1000	-	1500	-	105	36	12	20	0.6	30.8

9.0 TESTING RESULTS

After producing the specimens using the ASTM C 192/C 192M-02 Specimen Preparation Procedure and testing the specimens using the three tests specified in the Testing/Analysis section, the team was able to create tables showing the results.

9.1 Compressive Strength Results

The compressive strength results varied due to different kinds of aggregate were used in the mix design formulas. First, the team brought aggregate for the city of Camp Verde, Arizona and the results were not consistent. This is because the coarse aggregate from Camp Verde is a combination of Basalt, Limestone, Quartzite, and Granite. Each kind of rock has different characteristics in terms of compression strength. Therefore, the team brought aggregate from the city of Prescott, Arizona. The results came out to be very consistent. This is because the coarse aggregate was mainly Basalt. The specimens created were tested on the 7^{th} and 28^{th} days of curing. Table 3 shows the results of compressive strength on the specimens created. Since Phase One team started with specimen production, the team from Phase Two continued with the numbering. The first mix starts with the number 25 as it is the 25^{th} mix formula from the start of the project. CV means that the aggregate is from the city of Camp Verde, AZ and PR means that the aggregate is from the city of Prescott, AZ. Table 3 shows the compressive strength results for the specimens with or without silica fume and fiber. The mix design formula #31 was chosen as it resulted in the highest compressive strength.

Table 3: Compressive Strength Results

Mix Number	Test Result			
	7-day Comp.(psi)		28-day Comp.(psi)	
#25 CV	1107	955	N/A	1115
#26 CV	1300	1354	1415	1354
#27 CV	1115	1258	1369	1831
#26 PR	2548	2189	2651	N/A
#27 PR	1871	N/A	2014	2309
#30 PR	1433	1690	1823	1779
#31 PR	2699	2879	2946	2923
#32 PR	2538	1982	2787	2548
#33 PR	2502	1911	2946	2962
#16 PR	2866	2906	3177	2986
#34 PR	1831	1672	2070	N/A

Table 4: Compressive Strength Results for Specimens with/without Silica Fume and Fiber

Mix Number	Test Result			
	7-day Comp.(psi)		28-day Comp.(psi)	
#31 No Fiber/SF	2150	2229	2389	2477
#31 Fiber	2492	2548	2673	2708
#31 SF	3362	3424	3495	3554
#31 Fiber/SF	3838	3933	4154	4033

9.2 Void Ratio Results

After completing the ASTM C127 procedure, the void ratio results were obtained for the specimens produced. Table 5 has the results for the specimens. The team's goal is to have a porosity ratio higher than 17%. Most of the specimens were tested on the 28th day of curing and that's why no results were found for the other two specimens on the formulas (25 CV- 33 PR). The last two formulas have the four specimens testing results (16 PR and 34 PR). Some of the specimens tested had a lower void ratio than 17%. This might be because the smaller size aggregate, either No. 4 or 3/8", had a high percentage in the formula and that caused the voids to close more than needed. Table 6 shows the porosity results for the specimen with or without silica fume and fiber.

Table 5: Porosity Test Results

Mix Number	Porosity (%)			
	Sample 1	Sample 2	Sample 3	Sample 4
#25 CV	24.5	26.7	N/A	N/A
#26 CV	23.6	22.6	N/A	N/A
#26 PR	18.7	23.8	N/A	N/A
#27 CV	22.2	20.4	N/A	N/A
#27 PR	19.2	16.5	N/A	N/A
#30 PR	20.1	20.5	N/A	N/A
#31 PR	17.5	17.1	N/A	N/A
#32 PR	20.6	18.8	N/A	N/A
#33 PR	17.2	16.9	N/A	N/A
#16 PR	21.2	23	18.2	19.2
#34 PR	17.3	17.2	17.8	17.1

Table 6: Porosity Test Results for Specimens with/without Silica Fume and Fiber

Mix Number	Porosity (%)			
	Sample 1	Sample 2	Sample 3	Sample 4
#31 No Fiber/SF	20.8	20.9	20.4	21.8
#31 Fiber	21.6	21	19.3	21.9
#31 SF	18	19.2	18.3	18.8
#31 Fiber/SF	20	19.1	19.4	18.8

9.3 Freeze-Thaw Cycle Test Results

The team placed the specimens inside the freeze-thaw cycle machine in November 2014. The test is currently running the 100th cycle and none of the specimens being tested had failed. The test finishes when the specimens either fail or last until the 300th cycle. The late testing was due to being late with producing the best mix design formula. When the best mix design formula was produced, the freeze-thaw cycle test started.

9.4 Final Mix Design Formula

The final mix design formula is decided when it has the highest compressive strength results, the highest void ratio and can withstand the highest number of freeze-thaw cycles. After producing several mix design formulas and testing them, the team found that mix design number #31 gave the best results with regard to compressive strength and void ratio. Four #31 mix design formulas were then produced to be tested for freeze-thaw. The freeze-thaw cycle test is not finished and none of the specimens failed. Each of the four different specimens either have or not have fiber and silica fume. Two #31 mix design formulas gave the best compressive strength results and void ratio results; the #31 with silica fume only, and the #31 with both silica fume and fiber. Table 7 shows the mix design formula for both of these mixes. The following materials and their ratios are the same for both mix design formulas: water, cement, sand, and the admixtures.

Table 7: Final Mix Design Formulas

Mix ID#	Aggregate Gradation (lb./yd^3)				Fiber (kg/m^3)	Silica Fume (g)
	#4	3/8"	1/2"	3/4"		
#31 SF	1000	-	1500	-	-	30.8
#31 SF/Fiber	1000	-	1500	-	0.6	30.8

9.4.1 Final Mix Design Formula Results

The mix design formula #31 have the best results in compressive strength and porosity. Table 8 shows the compressive strength results and porosity results for both mix design formulas. Since the freeze-thaw cycle test is not finished, the final mix design formula is not decided. Once the freeze-thaw cycle ends, the final mix design formula will be chosen.

Table 8: Compressive Strength and Porosity Results for Final Mix Design Formulas

Mix Number	Compressive Strength				Porosity (%)			
	7-day Comp.(psi)		28-day Comp.(psi)		Sample 1	Sample 2	Sample 3	Sample 4
#31 SF	3362	3424	3495	3554	18	19.2	18.3	18.8
#31 Fiber/SF	3838	3933	4154	4033	20	19.1	19.4	18.8

10.0 SUMMARY OF PROJECT COSTS

The costs of this phase of this project includes buying the materials used in the mixes, renting the machines used for testing, meeting hours, and completing phase tasks and deliverables. Table 9 shows the equipment used and the materials bought for this phase. Table 10 shows the rates of the different workers who work on the different tasks. Table 11 shows the hours spent by each worker on tasks, their fees and the type of workers. It also shows the total costs for completing this phase.

Table 9: Costs of Materials and Equipment

Equipment/Material	Rate	Price
Sieve Machine/ Sieves	Buy	700.00
Mixer	Buy	170.00
Compressive Strength Machine	60$ /hr	480.00
Void Ratio Machine	20$ /hr	140.00
Freeze-Thaw Machine	100$ /day	2000.00
Molds	80.95$ /36 molds	161.90
Cement	9.45$ /bag	28.35
Aggregate	20$ /cubic yard	28.80
Sand	4.17$ /bag	8.34
Total		**$ 3,717.39**

Table 10: Rates of Workers

Type of Worker	Rate $/Hr
1. Senior Engineer	140
2. Project Engineer	110
3. Engineer in training	75
4. Intern/Technician	60

Table 11: Total Costs of Phase Two

Major Task	Subtask	Hours		Worker Fee		Type of Worker
		Fawaz	**Fahad**	**Fawaz**	**Fahad**	
Task 1	1.1 Meetings	20	20	2500.00	2500.00	1,2
Task 2	2.1 Project Description	4	4	370.00	370.00	2,3
	2.2 Task Breakdown	4	4	370.00	370.00	2,3
	2.3 Timeline, Staff Plan and Budget	4	4	370.00	370.00	2,3
	2.4 Final Project Proposal	7	7	647.50	647.50	2,3
Task 3	3.1 Previous Work	8	8	653.33	653.33	2,3,4
	3.2 Aggregate Gradation	8	8	653.33	653.33	2,3,4
	3.3 Mix Design	9	9	735.00	735.00	2,3,4
	3.4 Admixtures	6	6	490.00	490.00	2,3,4
Task 4	4.1 Material Preparation	8	8	480.00	480.00	4
	4.2 Testing Equipment Preparation	4	4	240.00	240.00	4
	4.3 Sieve Analysis	4	4	240.00	240.00	4
Task 5	5.1 Proportions Calculation	6	6	555.00	555.00	2,3
	5.2 Sieve Analysis	10	10	600.00	600.00	4
	5.3 Add new Admixture	6	6	490.00	490.00	2,3,4
Task 6	6.1 Specimen Production	11	11	1017.50	1017.50	3,4
Task 7	7.1 Void Ratio Test	7	7	647.50	647.50	3,4
	7.2 Compression Strength Test	8	8	740.00	740.00	3,4
	7.4 Freeze-thaw Cycle Test	8	8	740.00	740.00	3,4
Task 8	8.1 Final Data Sheet	5	5	541.67	541.67	1,2,3
	8.2 Final Mixture Formula	5	5	541.67	541.67	1,2,3
Task 9	9.1 Research Paper	20	20	2166.67	2166.67	1,2,3
	9.2 Presentation	8	8	866.67	866.67	1,2,3
	9.3 Website	10	10	925.00	925.00	2,3
	Hours per Worker	190	190	$ 17,580.83	$ 17,580.83	
	Total Hours	**380**		**$ 35,161.67**		
	Equipment Total			**$ 3,717.39**		
	Total Project Price			**$ 38,879.06**		

11.0 TIMELINE

The duration of this project lasted for one year starting from January 2014 till Decemeber 2014. Each task has its duration and some of the tasks are dependent on other tasks (e.g. Specimen Production and Lab Testing). Some of the tasks last for the full duration of the project (e.g. Team Management). The red diamond/milestone refers to deadlines. Most of the tasks were completed in the summer (June –August). The timeline can be found in Appendix E.

12.0 CONCLUSIONS

After producing specimens and developing the mix design formula from phase one, results were found regarding the compressive strength, the void ratio and the freeze-thaw cycles. After completing phase two from pervious concrete research, the following conclusions were drawn:

- Fiber has a great impact on the performance of pervious concrete. Fiber connects the components of the specimens together which makes the specimen stronger and can hold more under a lot of pressure. This leads to having a higher compressive strength for the specimen.
- Testing results show that the admixture, silica fume, had increased the compressive strength of the specimens. This helps the specimens in have to hold for a higher pressure if applied on the pavement.
- The void ratio is impacted by the components of the mix design formula; especially, the size of the aggregate used in the formula. As the size of the aggregate gets smaller, the void ratio of the specimen lowers and vice versa. Therefore, it is better to use a big size aggregate like 1/2" or 3/8" when designing the pervious concrete formula.
- Freeze thaw cycle test on the specimens is not finished as it is currently in the 100^{th} cycle. The test will finish when the specimens experience the 300^{th} cycle of fail before that cycle.
- When comparing four different mix design formulas, it turns out that the mix design formulas with silica fume and the mix design formula with fiber and silica fume had best results with regard to compressive strength and porosity.

- The best mix design formula was #31 as it resulted in the best compressive strength and porosity. The next step is to decide whether having both silica fume and fiber or just silica fume would be the best formula. Since the freeze thaw cycle test

13.0 ACKNOLEDGEMENTS

This project acknowledges the work done by Dr. Chun-Hsing Ho, Junyi Shen, Darius Ikan-Tubui Ishaku, Mengxi Du for Phase One of the same project, starting January 2013 and ending December 2013. This project also acknowledges Dr. Wilbert Odem, and Mr. Mark Lamer for helping the team construct professional proposal and report. Furthermore, the research team would like to thank Mr. Vere Harris from CEMEX Company for providing the team with coarse aggregate.

14.0 REFERENCES

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15.0 APPENDICES

15.1 Appendix A

ASTM C 192/C 192M-02 Specimen Preparation Procedure:

Figure 1: Mixer

- The aggregate is dried and mixed with 10% of the cement until coated.
- The mix is put inside the mixer (Figure 1).
- Admixtures are added to the water and then added to the mix with the rest of the cement.
- Some specimens have the admixture, silica fume, in the mix design formula. These specimens have 5% silica fume replaced with 5% of the cement used on the mix.
- The mixing lasts for three minutes. After, that three minutes for resting and another two minutes for mixing.
- The mix is then removed and placed inside cylindrical molds.
- When placing the mix inside the mold, the mix is compacted for 25 hits in two layers.
- The mold is pounded on the ground for ten times for each layer.
- The molds are then covered with lids for 24 hours. But since the city of Flagstaff is at a high elevation (7000 ft.) and the cold weather, the molds need more than 24 hours for covering (Figure 2). Therefore, the molds are covered for three day.
- After the three days, the specimens are de-molded (Figure 3) are placed in buckets of water for curing (Figure 4).

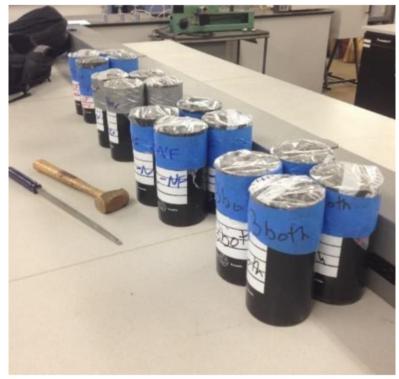

Figure 2: Covering Specimens

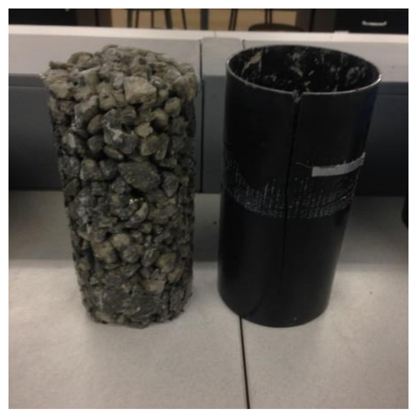

Figure 3: De-Molding

Figure 4: Curing Specimens

15.2 Appendix B

ASTM C39 Compressive Strength Test Procedure:

- The compressive strength test machine (Figure 5) in the Mechanic of Materials Lab in the Engineering building in Northern Arizona University was used for the test.
- A specimen is placed into the machine where the top layer lowers until it touches the specimen.
- The pressure is then increased manually with a small ratio.
- A screen next to the testing machine shows the amount of pressure applied on the specimen being tested.
- The pressure is increased until the specimen breaks.
- The screen does not show the maximum pressure applied to the specimen; therefore, the person looking at the screen must notice the number when the specimen breaks.

Figure 5: Compressive Strength Test Machine

15.3 Appendix C

ASTM C127 Void Ratio Test Procedure:

- The *Gilson Specific Gravity Bench* (Figure 6) was used for this test.
- The specimen tested is cylindrical and is placed on top of the scale and the dry weight of the specimen is measured.
- Then, the specimen is placed in the basket where it will lower into the bucket of water.
- After three minutes, the wet weight is measured.
- Porosity can be calculated using equation (1).

Figure 6: Gilson Specific Gravity Bench

15.4 Appendix D

- The specimens being tested are placed inside the *Gilson HM-120 Automatic Freeze-Thaw Apparatus.* (Figure 7)
- This machine is located inside the Mechanics of Materials Lab in the Engineering building at NAU.
- The machine will run cycles on the specimens placed inside on a low temperature of -18°C and a high temperature of 4°C.
- Every two days, 10 cycles end and the machine needs to be restarted.
- Every 20 cycles, the dimensions and the weights of the specimens are measured to know if the specimens' dimesions changed.
- The test continues until the specimens fail or pass the 300th cycle mark.

Figure 7: Gilson HM-120 Automatic Freeze-Thaw Apparatus

15.5 Appendix E: