Northern Arizona University
College of Engineering, Forestry, and Natural Sciences

CENE 486C Capstone Design Course Spring 2017
Final Report

Prepared for:

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05/09/2017

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FAMA Inc.

2112 S Huffer Ln, Flagstaff, AZ 86011

Alarick Reiboldt,

College of Engineering, Forestry, and Natural Sciences (CEFNS)

Dear Mr. Reiboldt,

FAMA Inc. has completed the research report of the Effects of Carbonated Cement Kiln Dust Substitution on the Strength and Durability of Concrete. The deliverable consists of the Project Description, Technical Sections, and a Summary of the Project Costs.

Thank you for giving our team the opportunity to be part of your research and we hope that we have satisfied the requirements for this report.

Sincerely,

FAMA Inc.

Ali Altameemi, Aide Robles, Felicia Curry, Mohamed Jatit

Table of Contents

Acknowledgements

We would like to express a deep gratitude to Alarick Reiboldt, our primary technical adviser and client, and the NAU CEFNS department for offering this research project and making the execution of this research possible. Mr. Reiboldt has provided the engineering team with guidance throughout all stages and has provided the team with all necessary materials for project completion. We would also like to thank Dr. Jun Ho and Dr. Robin Tuchscherer, our secondary technical advisers, for providing recommendations and clarification on concrete strength and durability testing procedures. Additionally, a special thanks to Gary Slim for providing all necessary testing equipment and lab access, as well as assisting in preparing the engineering team to use the CEFNS testing facilities.

List of Tables

List of Figures

1.0 Project Description

The cement industry is currently responsible for approximately 5% of all human carbon dioxide emissions in the atmosphere [1]. This is due to the fact that during the cement production process materials containing calcium and silicon are heated in rotary kilns; the heating process produces two bi-products in addition to cement clinker: cement kiln dust (CKD) containing calcium and silica oxides and carbon dioxide. The CKD is entrapped in filters and landfilled, and the carbon dioxide is emitted from the kilns into the atmosphere. The creation of carbonated cement kiln dust (CCKD) would involve sequestering the CO2 emitted in the cement production process, react it with the calcium and silica oxides to create calcium and silica carbonates. A diagram depicting the cement production process is found below in Figure 1. The utilization of this process could lead to a reduction in CO2 emissions. Figures 2 and 3 are images of CKD and CCKD, respectively.

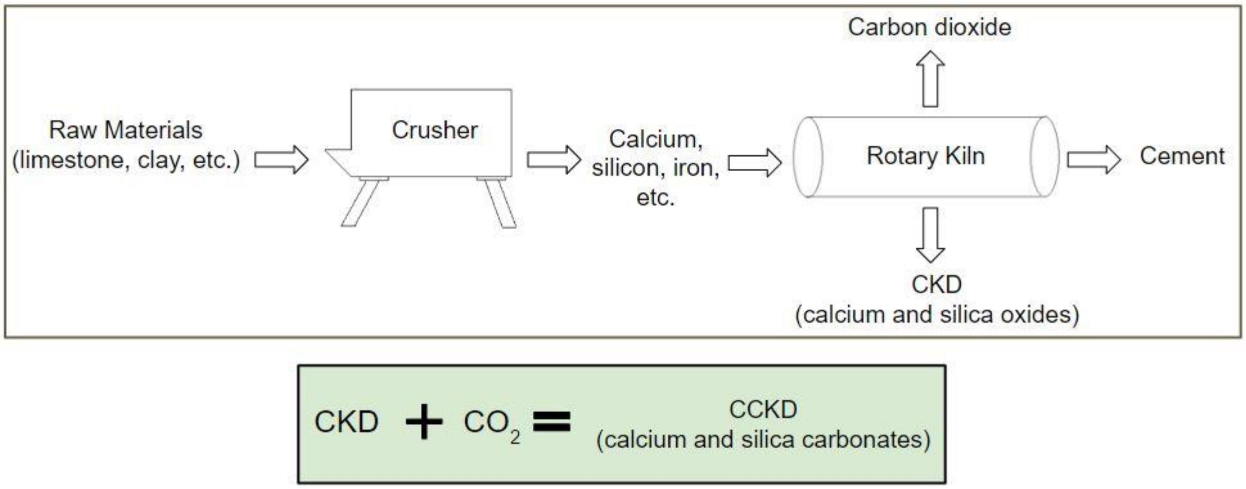


Figure 1: Cement Production Process

Mr. Alarick Reiboldt has developed the idea of carbonated cement kiln dust (CCKD) as a partial cement substitute. He requires the engineering team to investigate the plausibility of using CCKD as a partial cement substitute and its effect on the strength and durability of concrete, possibly leading to the publication of his work and lower carbon dioxide (CO2) emissions from the cement industry. The purpose of this project is to develop, execute and analyze an experiment to test the use of CCKD as a partial cement substitute on different concrete mixes.

Figure 2: Cement Kiln Dust [1]

Figure 3: Carbonated Cement Kiln Dust [1]

FAMA Inc. will be completing all project tasks at Northern Arizona University utilizing multiple labs in the College of Engineering, Forestry and Natural Sciences. Figure 4 below is an image of the soils lab utilized for the projects aggregate classification. Constraints and limitations the team considered before and during project execution included resources, scheduling, and safety. Due to limited funding, limited space and outdated equipment the team adjusted its testing standard and methods multiple times. The team had to follow a staggered testing schedule due to multiple tests requiring longer testing periods and tests calling for reading at specific times. The team also considered limitations on chemical and equipment use. The standards methods for testing required a thorough understanding of the procedures, equipment and chemical use to ensure safety of all team members.

The following tasks were completed: design of concrete mixes, testing, data analysis, and project management. Designing the concrete mix involved developing a cement to aggregate to water ratio for a dry slump with a compressive strength above 4000 psi.

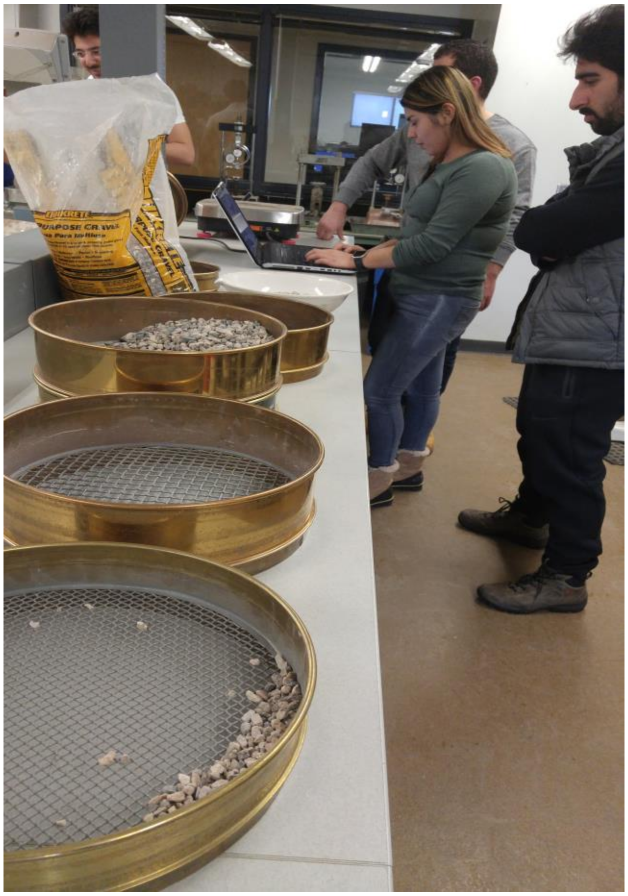


Figure 4: NAU Soils Lab used for sieve analysis

2.0 Experimental Design

The team designed an experimental method to test concrete strength and durability under a variety of conditions mimicking research published on CKD. The team's final experimental design can be seen in Table 1 on the next page.

Table 1: Experimental Design to Test Effect of CKD, CCKD and Cement Reduction on Strength and Durability

	% of Cement Reduction	**Water to Cement Ratio**	**# of Samples**
Control **(4000 psi)**	None	0.44	3
CKD Substitution	5	0.46	3
	10	0.49	3
	15	0.52	3
CCKD Substitution	5	0.46	3
	10	0.49	3
	15	0.52	3
Cement reduction	5	0.46	3
	10	0.49	3
	15	0.52	3

The team is working with a concrete holding a strength of 4000 psi. As seen in Table 1, a control is used as a frame of reference. CKD and CCKD have been partially substituted for cement at amounts of 5, 10, and 15 percent. Substitution at these three percentages were chosen based on previous work completed on CKD. Previous work revealed that 10% is the optimum cement substitute. In order to model a trend the team chose to additionally test 5 and 10 percent.

The amount of cement was then reduced at the same percentages and tested to verify that any effects on strength and durability in the results are due to CKD and CCKD and not a reduced amount of cement in the concrete samples. A minimum of three samples were prepared and tested from each mix to yield statistically significant data, resulting in a total minimum of 30 samples per test method.

3.0 Concrete Mix design

After conducting research on concrete it was discovered that it is important to design a mix before it is made so that the experiment can be recreated and the results confirmed. The research experiment needs to control as many variables as possible. Additionally, it is equally important to characterize each ingredient in the mix so those conducting the research know as much about the materials being used as possible.

3.1 Materials Used

The material required for the concrete mix was provided by the client. The materials included Quikrete brand all-purpose sand, all-purpose gravel and Portland Cement type I/II, mortar and cement mortifier, CKD, and CCKD. The CKD and CCKD were donated from a local company called CEMEX, a leader in the cement industry. The sand, gravel, and cement were purchased from a local Home Depot. The super-plasticizing admixture was used in the concrete mixtures to increase plasticity and viscosity and make the concrete mixes easier to work with.

3.2 Sieve Analysis

The team decided to calculate the mix proportions for each batch based on weight. Therefore, a sieve analysis was conducted on both the fine and coarse aggregates in order to characterize the aggregates and determine the largest aggregate size. All of the aggregates used were from multiple ready mix bags of the same brand and characteristics requiring the sieve analysis to only be completed once. The results of the sieve analysis can be seen in Figures 5 and 6 on the next page..

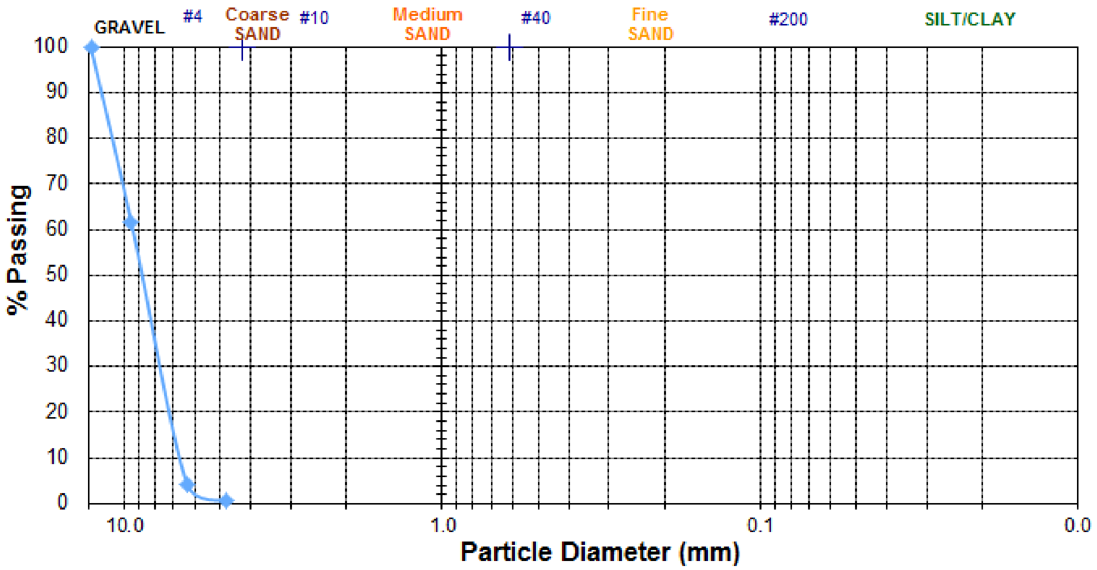


Figure 5: Sieve Analysis of Coarse Aggregate

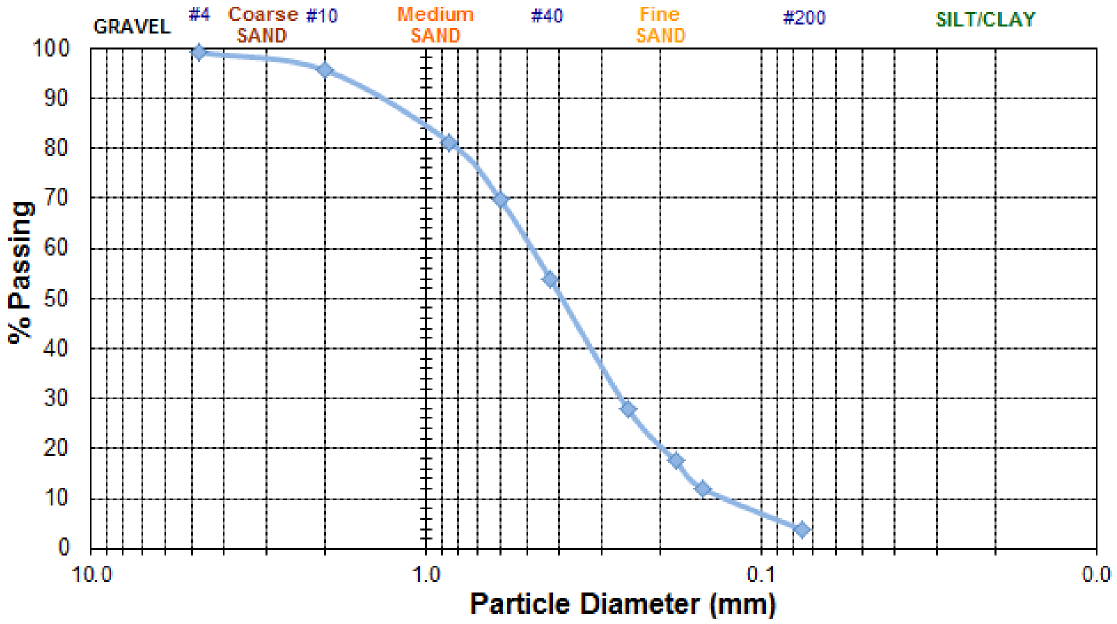
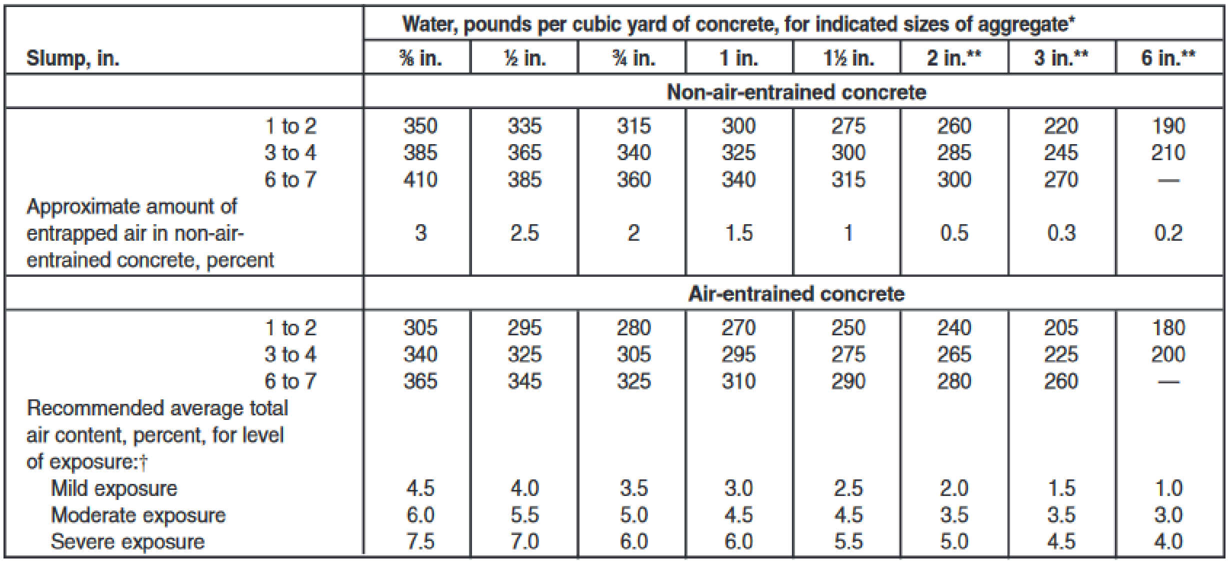


Figure 6: Sieve Analysis of Fine Aggregate

Based on the sieve analysis results, the team determined the largest aggregate size to be ½ inch in diameter. The team used this value with a desired slump of 0-1 and the information provided in Table 2 on the next page to determine the weight of water needed to produce a cubic yard of concrete. This number was then altered to determine the weight of water needed for a single concrete batch to produce three 4 inch by 8 inch cylinders and three 4 inch by 2 inch cylinders for strength and water absorption durability testing, respectively.

Table 2: Approximate Mixing Water and Target Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregate [3]

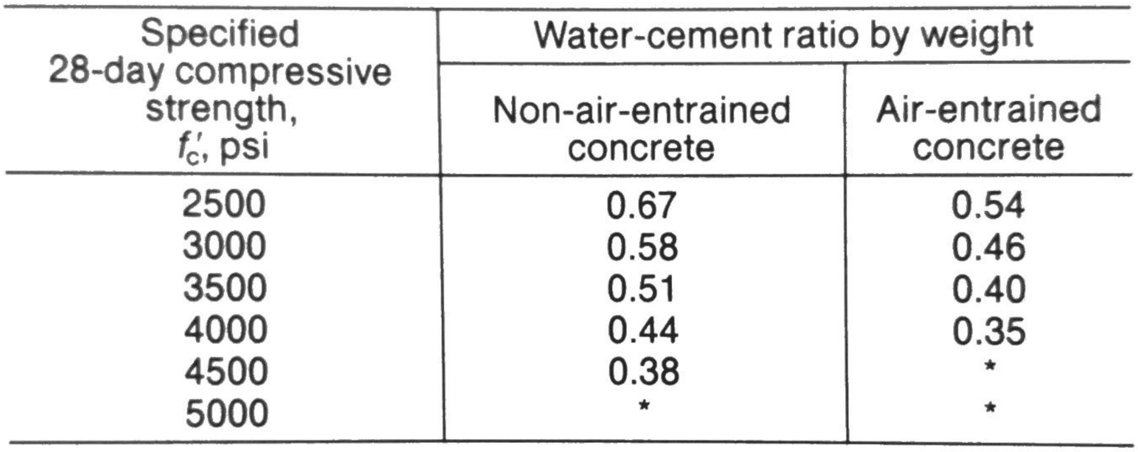


Slump, in.	Water, pounds per cubic yard of concrete, for indicated sizes of aggregate*							
	⅜ in.	½ in.	¾ in.	1 in.	1½ in.	2 in.**	3 in.**	6 in.**
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
Recommended average total air content, percent, for level of exposure:†								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate exposure	6.0	5.5	5.0	4.5	4.5	3.5	3.5	3.0
Severe exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

3.3 Water to Cement Ratio

The water to cement ratio is the amount of water to amount of cement used in a mix. This ratio can be determined by weight or by volume. As mentioned before, the team chose to determine the mix by weight in order to simplify calculations and proportioning. The selected water to cement ratio of 0.44 was determined using Table 3 below. The team chose this ratio based on the design compressive strength of 4000 psi at 28 days of curing and minimal air entrapment.

Table 3: Maximum Permissible Water-Cement Ratios for Concrete When Strength Data from Field Experience or Trial Mixtures Are Not Available.



Specified 28-day compressive strength, f'_c, psi	Water-cement ratio by weight	
	Non-air-entrained concrete	Air-entrained concrete
2500	0.67	0.54
3000	0.58	0.46
3500	0.51	0.40
4000	0.44	0.35
4500	0.38	*
5000	*	*

3.4 Mix Design Formula

Originally, the team decided not to develop the concrete recipe consisting of aggregates, admixture, cement and water as outlined in the project proposal. After consulting the client, the team decided to follow the ASTM method of a 1-2-3 ratio of cement to sand to gravel. The amount of water for each batch was calculated based on the weight required to make three strength samples and three durability samples. The amount of cement was then determined using the water to cement ratio. From there the 1-2-3 ratio was used to determine the amount of sand and gravel required for each batch. The amount of cement was reduced or substituted by weight with CKD and CCKD per batch requirements. A plasticizer at a 1-1 water replacement ratio was used to improve the workability of the mix. A table outlining all mix proportions can be found in Figure A1 in Appendix I.

4.0 Mixing and Sample Preparation

For mixing and preparing samples, the team followed standard methods and recommendations given by all technical advisers.

4.1 Mix Procedure

For everyday of mixing, the team prepared all proportions and molds the day prior. Once all of the batch proportions were calculated and measured accordingly, the team used a small concrete mixer of 1.5 cubic feet in volume to mix all batches. The mixer was buttered and then the sand and gravel were put in the mixer and allowed to fully combine. Next, the cement was added. Once the sand, gravel and cement were well mixed, the water/superplasticizer mixture was added in small increments. The batch was then allowed five to seven minutes to mix.

Once the concrete was completely mixed, a slump test was conducted. Based on the experimental design and following ASTM C39 and ASTM 1585, the team prepared three 4 inch by 8 inch cylindrical samples for strength testing for the trial batch testing day and three 4 inch by 8 inch cylindrical samples for strength testing and three 4 inch by 2 inch cylindrical samples for water absorption testing from each batch each subsequent mixing day following the slump test. In order to create the samples, concrete was compacted into molds in three layers. The samples were rodded 25 times after each layer to ensure an even compaction and to reduce air pockets per ASTM standards.

The initial batch was created as a trial run and did not follow ASTM standards. Its purpose was to familiarize the team with the mixing procedure. For this reason, the control samples and reduction samples were re-mixed and poured. The trial batch strength samples were tested but were not included in the results analyses. The concrete batch trail run and all other batch mixtures with their respective mixing dates can be seen below in Table 4 on the next page.

Table 4: Mixing and Testing Schedule

Mix	Mixed	Submerged	Finished Curing	Tested
Trial Control (Strength)	1/28/2017	1/29/2017	2/26/2017	2/26/17
Trial 5% Reduction (Strength)	1/28/2017	1/29/2017	2/26/2017	2/26/17
Trial 10% Reduction (Strength)	1/28/2017	1/29/2017	2/26/2017	2/26/17
Trial 15% Reduction (Strength)	1/28/2017	1/29/2017	2/26/2017	2/26/17
Control (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
Control (Durability) C1585	2/10/17	2/11/17	3/10/17	NA
5% Reduction (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
5% Reduction (Durability) C1585	2/10/17	2/11/17	3/10/17	NA
10% Reduction (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
10% Reduction (Durability) C1585	2/10/17	2/11/17	3/10/17	NA
15% Reduction (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
15% Reduction (Durability) C1585	2/10/17	2/11/17	3/10/17	NA
5% CKD (Strength)	2/24/17	2/25/17	3/24/17	3/24/17
5% CKD (Durability)	2/24/17	2/25/17	3/24/17	NA
10% CKD (Strength)	2/24/17	2/25/17	3/24/17	3/24/17
10% CKD (Durability)	2/24/17	2/25/17	3/24/17	NA
15% CKD (Strength)	2/24/17	2/25/17	3/24/17	3/24/17
15% CKD (Durability)	2/24/17	2/25/17	3/24/17	NA
5% CCKD (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
5% CCKD (Durability)	2/10/17	2/11/17	3/10/17	NA
10% CCKD (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
10% CCKD (Durability)	2/10/17	2/11/17	3/10/17	NA
15% CCKD (Strength)	2/10/17	2/11/17	3/10/17	3/10/17
15% CCKD (Durability)	2/10/17	2/11/17	3/10/17	NA

All durability samples listed in Table 4 above were mixed for use with the water absorption durability test. Additional 2x2x2 inch cubes were mixed by hand and molded on 3/31/17 for the alkali-silica reactivity test. Testing of these samples began the very next day.

5.0 Testing and Results

As previously mentioned, slump tests were conducted on all concrete batches mixed. Strength samples were compressive strength tested following ASTM Standard Method C39. Water absorption and alkali-silica reactivity durability tests per ASTM 1885 and ASTM 1567 were both intended for completion.

5.1 Slump Test

A slump test was done to determine the workability of the concrete mixes, as well as to verify that the mix design yielded a 0-1 slump. The test was completed immediately after mixing the concrete following the ASTM Standard Method C-143. A metal slump cone, a calliper for measurement, a steel rod and a big steel tray were used to perform the test. Figure 7 shows the equipment needed for the slump test.

Figure 7: Slump Test Equipment

The slump test results can be one of four slump types. Type 1 is a true slump in which the concrete simply subsides, keeping more or less to shape. Type 2 is a zero slump which is the most preferred type for projects. Type 3 is a collapse slump in which the concrete collapses completely. Type 4 is a shear slump in which the top portion of the concrete shears off and slips sideways. The four types of slump are shown in figure 8 below.

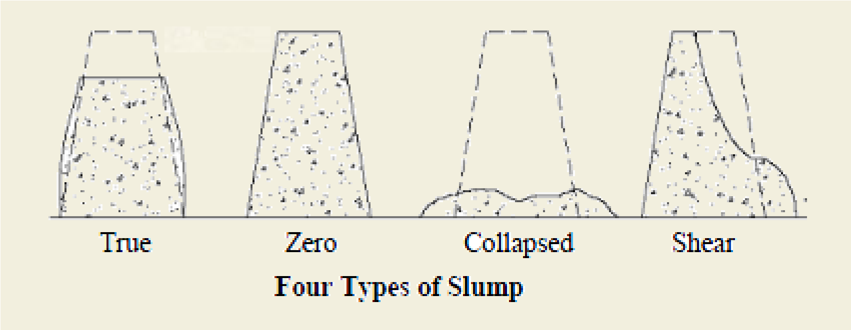


Figure 8: Types of Slump

For the Control batch, 5%, 10%, and 15% reduction batches, the slump test results were within the range of 0 - 1 inch meaning they all had a very low slump. The same results were obtained for CKD and CCKD 5%, 10%, and 15% batches which were in the range of 0 - 1 inch. Additionally, the slump for all mixes were observed as true slumps. In conclusion, the results confirmed that the design mix was a zero to one slump, indicating that it was a relatively dry mix, and the mix experienced a true slump.

5.2 Compressive Strength Test

A compressive strength test examines the behavior of the concrete under a certain applied load. The compressive strength machine utilized for testing compressive strength is shown in figure 8 below. The testing was completed on the trial batches following the ASTM Standard Method C39. All subsequent samples will follow this standard. This test was completed after the samples had cured for 28 days in buckets of tap water. A curing period of 28 days was chosen because it is the standard method for testing concrete in the industry. Testing must begin immediately after the sample has been removed from the moist condition. Each sample was towel dried, then the top and bottom diameters were measured along with the length and weight.

To avoid damaging the samples and creating stress concentrations, a pair of metal caps were placed around the top and bottom of the samples before vertically placing them on the testing machine platform. The machine used to perform this test can be seen in Figure 9 on the following page.

Figure 9: Compressive Strength Test Machine

Loading was applied at a rate in the range of 300-520 lb/sec until the samples failed and the max load reading was taken directly from the screen of the testing machine. Subsequently, the shape of the fracture was recorded and used to indicate the type of fracture that occurred to the sample following Figure 10.

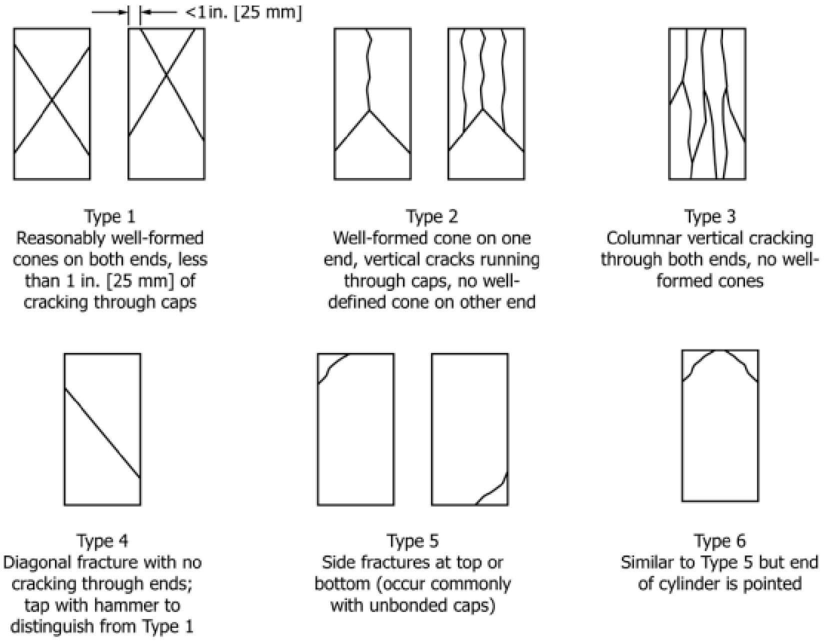


Figure 10: Schematic of Typical Fracture Patterns

5.2.1 Compressive Strength Test Results

All batches have been compressive strength tested and the results obtained such as max load and failure type are outlined based on the typical fracture patterns. Table 5 on the next page shows the strength value obtained for each of the three replicates in each mix.

Table 5: Strength Test Results

Mix	**Strength (psi)**		
Control	3905.70	4812.10	3649.40
5% Red.	4771.50	5170.20	4952.90
10% Red.	4618.70	3468.80	3534.00
15% Red.	3814.20	3554.70	4235.60
5% CCKD	4734.1	3390	3497.4
10% CCKD	2809.9	4418.9	4629.8
15% CCKD	2568	4992.7	3199.8
5% CKD	1373.5	1845.4	1506.4
10% CKD	401.0	62.1	63.7
15% CKD	0	0	0

5.3 Rate of Water Absorption Test

The purpose of this test is to determine the susceptibility of an unsaturated concrete to the penetration of water. Per ASTM 1585 the test required either an environmental chamber, which the team did not have access to, or an oven and a desiccator containing a potassium bromide solution to regulate humidity while the test is being conducted. The team prepared the samples and cured them approximately 28 days to reach their full strength and be ready for testing. After contacting the lab manager, it was discovered that there was insufficient oven space available at NAU to perform this test. Subsequently, the engineering decided to exclude the water absorption test and focus on the alkali silica reaction test to perform the durability testing of concrete for this experiment.

5.4 Alkali-Silica Reactivity Test

Alkali-silica reaction is the reaction that occurs between sodium and potassium, which are alkaline, contained in cement, silica contained in the aggregates and moisture which leads to the formation of alkali-silica gel. The gel absorbs water and swells leading to the expansion and eventual cracking of concrete over time. This results in major structural problems. Figure 11 shows a section of a concrete median wall displaying signs of cracking caused by an alkali-silica reaction.

Figure 11: Cracked concrete median wall

The Alkali-Silica Reaction test was performed following ASTM 1567-13 to detect the potential for deleterious alkali-silica reaction of combinations of cementitious materials and aggregates. All the required materials for the test were requested and the perspective ASTM Standard Method was reviewed for thorough understanding of the testing process. After mixing and molding all the samples, they were left to set up for 24 hours. The next day the samples were demolded and zero measurements of height, width, and length were taken.

The next step was to submerge the samples in the water for another 24 hours at a constant temperature of 80℃ and measurements were taken the following day. After taking specific safety precaution, a Sodium Hydroxide solution of 4% weight by volume was prepared, the samples were submerged in the solution and left in the oven at 80℃ for 24 hours. The following day, measurements of height, width, and length were taken. After that, subsequent measurements were taken for four days until the end of the 14 day test period.

5.4.1 Alkali-Silica Reactivity Test Results

A total of six measurements were taken for the height, width and length of each of the three replicates from each mix. These values were used to determine the volume of each sample. The results can be seen in section 6.0 Data Analysis.

6.0 Data Analysis

Once all of the data from the strength and durability tests was compiled, it was analyzed for each test.

6.2 Compressive Strength Data Analysis

A Thomson Tau test was conducted on the strength results outlined in Table 5. This test indicated that the first sample in the 10% reduction mix and the first sample in the 5% CCKD were outliers. Table 6 below shows the average strength and standard deviation of each mix removing the two outliers.

Table 6: Average Strength Test Results Excluding Outliers

Mix	Average Strength (psi)	Standard Deviation
Control	4122.4	610.9
5% Red.	4964.9	199.6
10% Red.	3501.4	46.1
15% Red.	3868.2	343.6
5% CCKD	3443.7	75.9
10% CCKD	3952.9	995.4
15% CCKD	3586.8	1257.8

5% CKD	1575.1	243.3
10% CKD	175.6	195.2
15% CKD	0	0

From Table 6, and Table 5, it can be seen that the strength results of the CKD mix samples was far below the control mix design of 4000 psi. Figures 12 and 13 below show a visual comparison of a CKD strength and a control sample.

Figure 12: CKD Strength Sample Figure 13: Control Strength Sample

When the sample in Figure 12 was de-molded and prepared for curing it closely resembled the sample in Figure 13. When the sample was removed from its curing conditions, it had obvious degradation. Due to the fact that all of the samples from the three CKD mixes showed signs of degradation, the pH of the curing water was tested for all the mixes. Figure 14 below shows the results of the pH test.

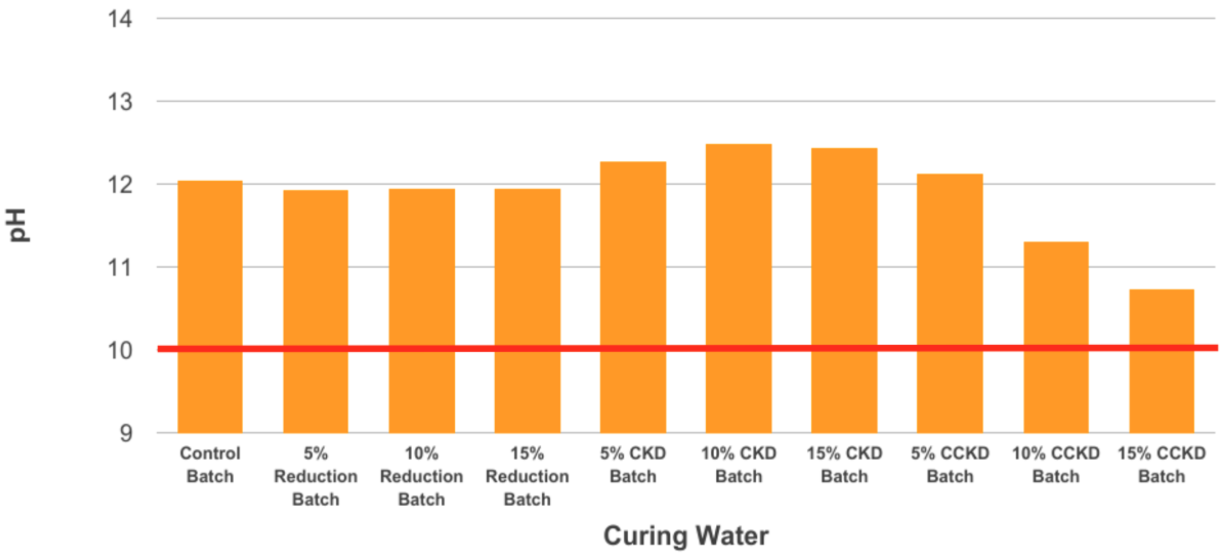


Figure 14: pH Of Curing Water for Different Mixes

Figure 14 shows a spike in pH for all three of the CKD mix's curing water, meaning that the CKD curing water was more alkaline than the curing water for the other mixes. This increase in alkalinity could be a cause of the low compressive strength results observed in the CKD mixes. The red line indicates the threshold for an increase in the potential for reinforcement corrosion. Due to the drastic difference between these strength values and the increase in the pH of the curing water, the CKD mixes were not used in any further analysis.

A comparison of the average strength values between the reduction and the CCKD batches with respect to the water to cement ratio can be seen in Figure 15 on the next page.

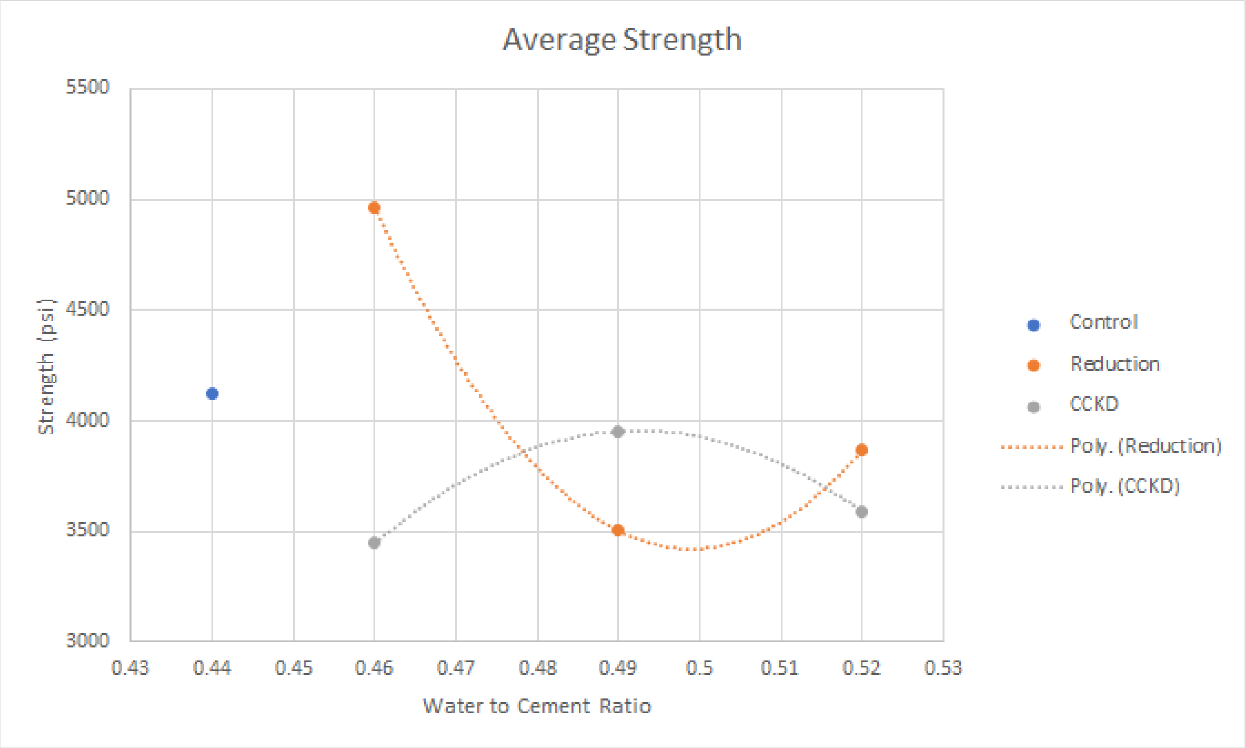


Figure 15: Average Strength Graph For Reduction and CCKD

The average strength for the control mix is lower than strength of the 5% reduction mix. In theory, this value should be lower than the control. The inconsistency in the data could be due to the variability in the loading rate applied to the sample. Another cause of the increase in strength for the 5% reduction could be due to the metal caps used on the samples. The rubber film between the concrete and the metal was worn down and could have created stress concentrations during testing. However, based on Figure 15, it can be concluded that the optimal CCKD substitution is around 10%. This correlates to previous studies conducted on CKD substitution.

6.2 Alkali-Silica Reactivity Data Analysis

The potential for deleterious alkali-silica reactions of cementitious materials and aggregate in the concrete samples is reported by using the change in volume of each sample for the entire testing period. The change in volume for each sample was determined by calculating the volume of each cube based on a height, width and length reading, then an average value for each batch was obtained. Once, all average values were determined for the entire testing period, normalized values were determined by making the first reading the zero reading. A positive percent difference indicates an increase in volume based on the zero reading, while a negative percent difference indicates a decrease in volume. Figure 16 below is a graph showing a normalized percent difference of volume from the zero measurement against time for the control samples and percent reduction samples.

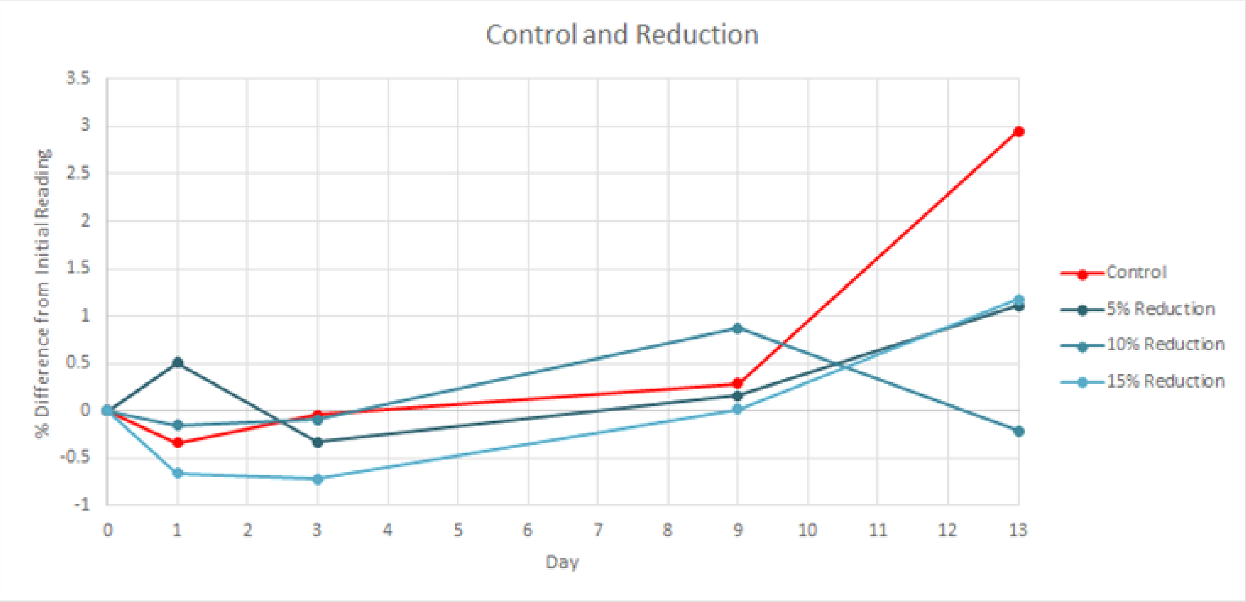


Figure 16: ASR results for Control and Reduction Samples

As seen in Figure 16, there is an increase in volume from the 9th day to the 13th day with all of the reduction samples having a smaller increase in volume compared to the control samples. All of the changes in volume are below 3 percent and are therefore insignificant changes in volume. These results correlate with the decrease in the amount of cementitious material available to react. The same graph was recreated for the CCKD samples. Figure 17 below is a graph showing a normalized percent difference in volume from the zero measurement against time for the control samples and CCKD samples.

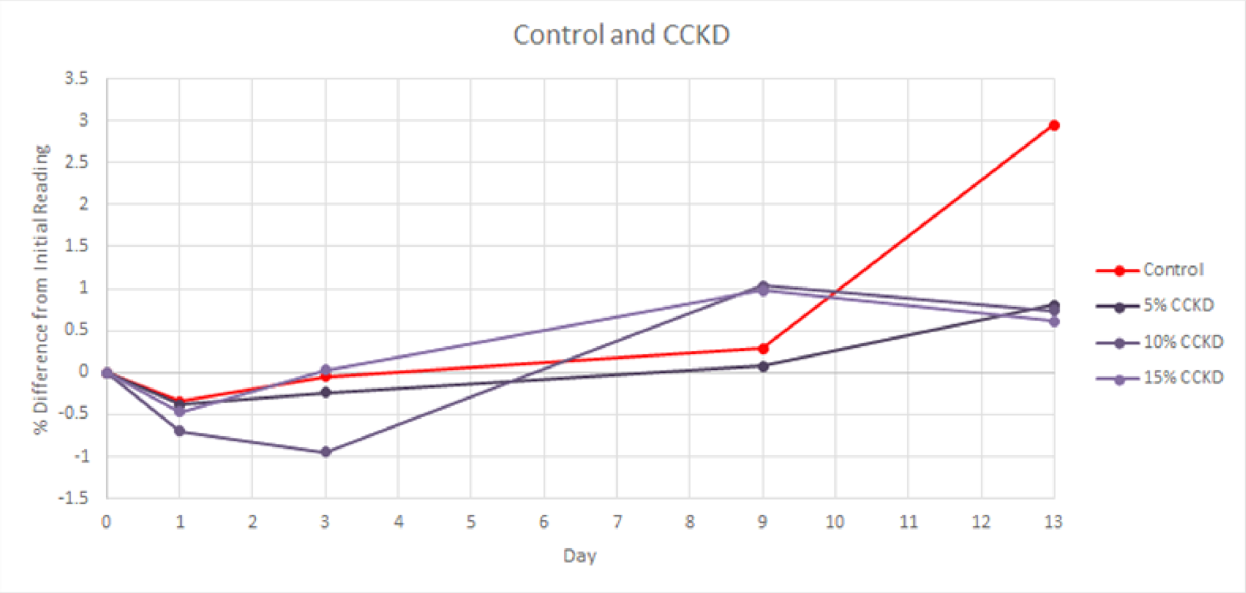


Figure 17: ASR results for Control and CCKD Samples

As seen in Figure 17, there is a consistent increase from the 3rd day to the 9th day and then a decrease from the 9th day until the end of the testing period for CCKD. Similar to the results obtained for the reduction samples, the changes are insignificant when looking at the percent difference. The results obtained for CCKD also correlate with a decrease in sodium and potassium material available to react. Figure 18 below is a graph comparing the percent difference of volume over time for all samples.

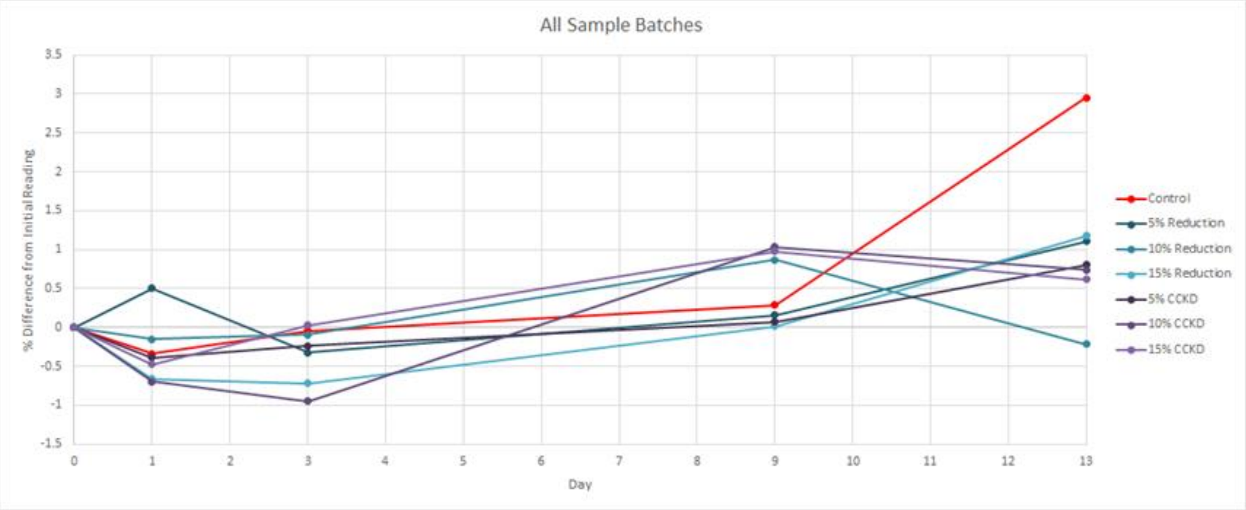


Figure 18: ASR results for all samples

All three figures show that there is not a decrease in durability with the substitution of CCKD, but an increase in the durability of concrete based on the engineering team's parameters.

7.0 Summary of Project Costs

The original Gantt Chart created by the team can be seen in Figure A2 in Appendix I. A schedule showing the anticipated end date of each task compared to the actual completion date can be seen in Table 7 below.

Table 7: Schedule

1.0 Design of Concrete Mixes	**Scheduled End Date**	**Actual End Date**
1.1 Concrete Mixing	02/24/17	03/25/17
1.2 Sample Preparation	02/24/17	03/25/17
2.0 Testing		
2.1 Strength Testing	03/24/17	03/24/17
2.2 Durability Testing	03/24/17	04/14/17
3.0 Data Analysis	03/31/17	04/23/17
4.0 Project Management		
4.1 Communication	05/02/17	05/02/17
4.2 Deliverables	05/02/17	05/02/17
4.2.1 50% Design Report	03/02/17	03/02/17
4.2.2 Reflection Document	04/06/17	04/06/17
4.2.3 Final Report	05/02/17	05/02/17
4.2.4 Final Presentation	04/26/17	04/26/17
4.2.5 Website	05/02/17	05/02/17

As seen in Table 7, the engineering team had anticipated to be done with the design of concrete mixes, which included concrete mixing and sample preparation, by March 10th but had to remix the control and 5%, 10%, and 15% reduction batches because of inconsistent curing conditions. The samples were not demolded before being placed in the buckets of water to cure for 28 days. This pushed the completion for the design of concrete mixes back to March 24th.

Compressive Strength Testing was completed on March 24th as scheduled, but after excluding the Water Absorption test, deciding to focus on the Alkali Silica Reactivity test for durability testing, and reviewing ASTM 1567, it was discovered that the samples did not need to cure for 28 days. Additionally, it only takes 14 days to carry out the test, so it was decided to keep the test until a later date and finish it on April 4th. After finishing testing, the results from both tests were compiled for statistical analysis.

For project management, the team conducted bi weekly team meetings and meetings with the technical advisor. Furthermore, the team had submitted the required tasks during the semester which include the 50% design report, the Final Presentation, the Website and individually worked on the Reflection Document.

The cost of Engineering Services can in Table 8 below.

Table 8: Cost of Engineering Services

Classification	Rate, $/hr	Projected Hours	Projected Cost	Actual Hours	Actual Cost
SR ENG	$207.00	68	$14,076	65.5	$13,559
2 ENG	$120.00	402	$48,240	309.5	$37,140
LAB TE	$78.00	95	$7,410	60.5	$4,719
INT	$35.00	95	$3,325	80.5	$2,818
Total personnel		660	$73,051	**516**	$58,235
Laboratory	$100.00	61	$6,100	**97.5**	$9,750
TOTAL			$79,151		**$67,985**

Staffing is classified by Senior Engineer, Engineer, Lab Technician, and Intern. The team anticipated a total of 660 hours, but at the end of the project, a total of 516 hours were accumulated by the team.

A total of 61 lab hours was projected, but the engineering team ended up spending a total of 97.5 hours. The team had to spend additional hours in the lab due to having to re-mix batches. Also, when the team was compressive strength testing the samples using the Humboldt machine, the samples were being loaded at a rate that was lower than the loading rate mentioned in the ASTM Standard Method C39 which lead to the team spending extra hours in the lab as well. The total cost of the project was projected to be $79,151 but at the end, the actual cost of implementing the project came out to be $67,985.

8.0 Conclusion

Based on the results of the tests conducted for this project it can be concluded that the use of CCKD does not significantly decrease the strength or durability of concrete- it has the potential to increase the strength for a specific range of water to cement ratios which was 0.48 to 0.515 as shown in the results for the Compressive Strength Testing. Previous research conducted on CKD substitution indicated that the addition of CKD decreases the strength for specific percentages, but experiences an increase in strength at 10% substitution. This is consistent with the results obtained during this project. Additionally, CCKD has the potential to improve resistance against Alkali Silica Reaction since the results obtained show a significantly lower volume increase compared to the control.

9.0 Recommendation

At the conclusion of the team's research, the engineering team recommends future capstone projects to conduct the compressive strength testing with higher number of replicates. For instance, instead of using three samples per batch, using 9 samples in order to complete data analysis more accurately. With more replicates outliers are easily identified and more statistically significant data is obtained.

The team would also recommend performing the Alkali Silica Reactivity test for at least 60 days and not only 14 days in order to observe higher changes in the volume of each sample, as well as testing the samples using the Scanning Electron Microscope (SEM) to have a closer look at the samples and investigate the structure of the gel formation on each samples.

Lastly, the team would recommend conducting more research as to why the CKD samples experienced such a large strength decrease. The engineering team believes this might be due to the mix design formula used, the mixing procedure used or contaminate in the curing water.

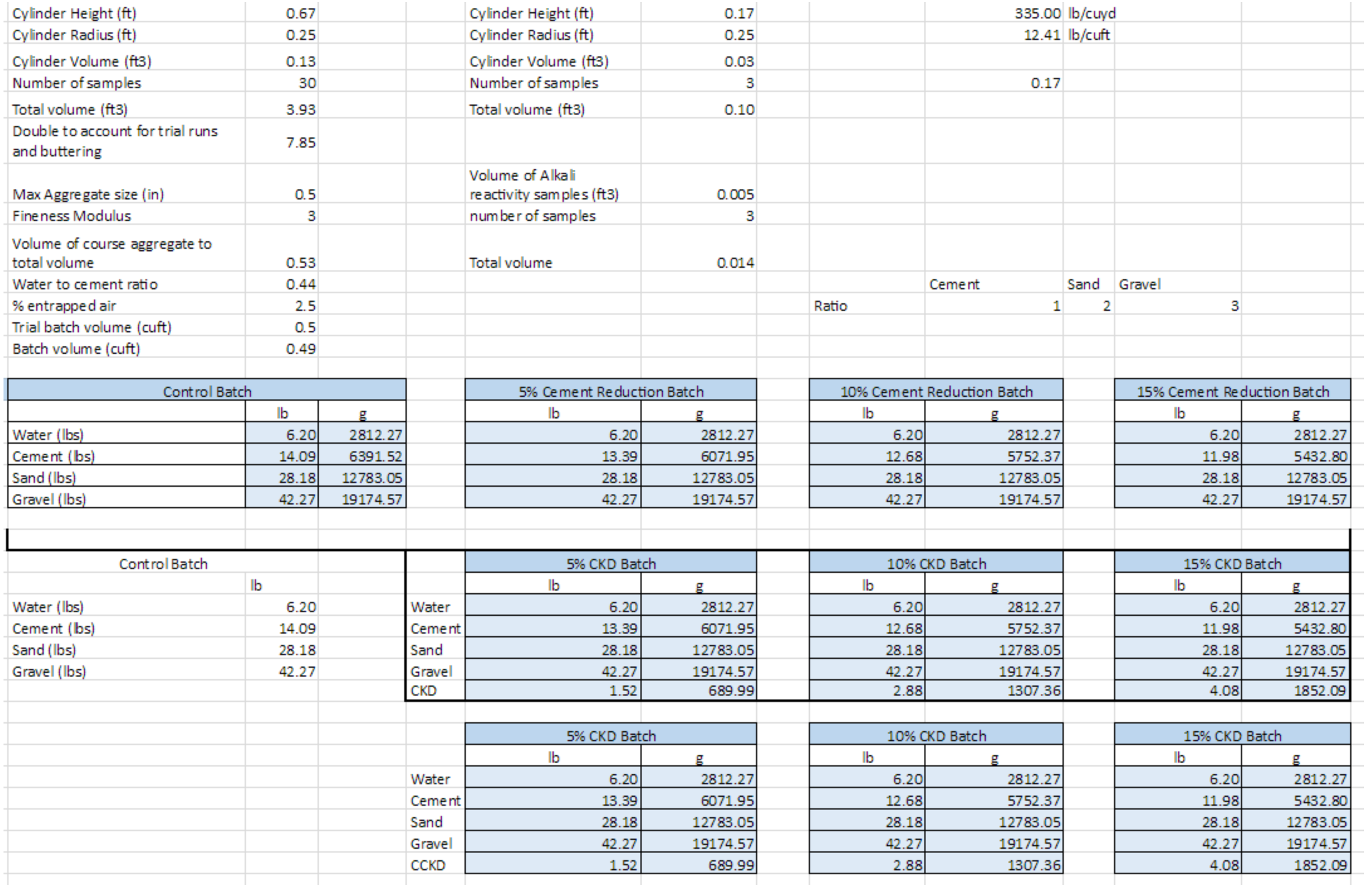
10.0 References

[1] “Carbon dioxide sequestration in cement kiln dust through miner carbonation.” Michigan Technological University. 13 Sep. 2016. Web. http://digitalcommons.mtu.edu/cgi/viewcontent.cgi?article=1324&context=etds

[2] Rubenstein, M. “Emissions from the Cement Industry.” Columbia University. 9 May 2016. Web. http://blogs.ei.columbia.edu/2012/05/09/emissions-from-the-cement-industry/

[3] “Designing and Proportioning Normal Concrete Mixtures” The Portland Cement Association Manual Web. http://www.ce.memphis.edu/1112/notes/project_2/PCA_manual/Chap09.pdf

11.0 Appendix I



Cylinder Height (ft)	0.67
Cylinder Radius (ft)	0.25
Cylinder Volume (ft3)	0.13
Number of samples	30
Total volume (ft3)	3.93
Double to account for trial runs and buttering	7.85
Max Aggregate size (in)	0.5
Fineness Modulus	3
Volume of course aggregate to total volume	0.53
Water to cement ratio	0.44
% entrapped air	2.5
Trial batch volume (cuft)	0.5
Batch volume (cuft)	0.49

Cylinder Height (ft)	0.17
Cylinder Radius (ft)	0.25
Cylinder Volume (ft3)	0.03
Number of samples	3
Total volume (ft3)	0.10
Volume of Alkali reactivity samples (ft3)	0.005
number of samples	3
Total volume	0.014

	335.00	lb/cuyd	
	12.41	lb/cuft	
	0.17		
	Cement	Sand	Gravel
Ratio	1	2	3

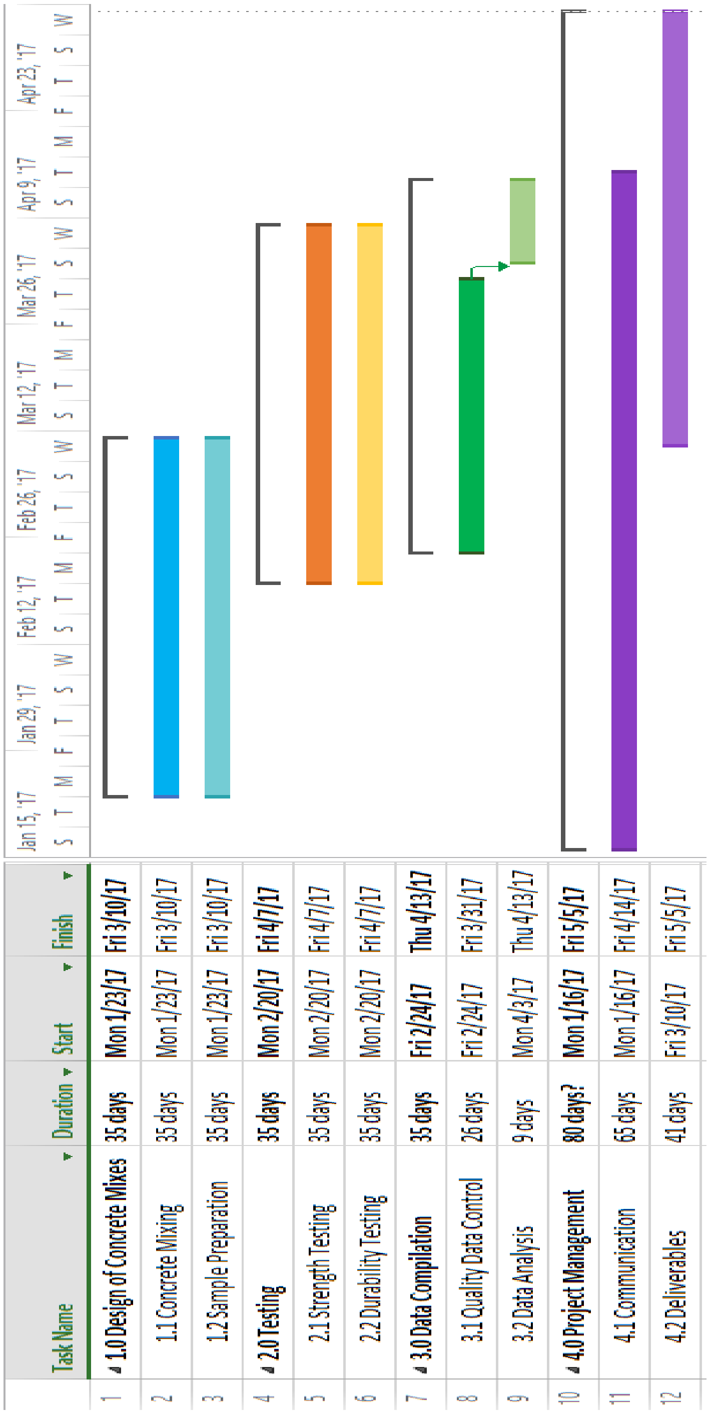
	Control Batch		5% Cement Reduction Batch		10% Cement Reduction Batch		15% Cement Reduction Batch	
	lb	g	lb	g	lb	g	lb	g
Water (lbs)	6.20	2812.27	6.20	2812.27	6.20	2812.27	6.20	2812.27
Cement (lbs)	14.09	6391.52	13.39	6071.95	12.68	5752.37	11.98	5432.80
Sand (lbs)	28.18	12783.05	28.18	12783.05	28.18	12783.05	28.18	12783.05
Gravel (lbs)	42.27	19174.57	42.27	19174.57	42.27	19174.57	42.27	19174.57

Control Batch	
	lb
Water (lbs)	6.20
Cement (lbs)	14.09
Sand (lbs)	28.18
Gravel (lbs)	42.27

	5% CKD Batch		10% CKD Batch		15% CKD Batch	
	lb	g	lb	g	lb	g
Water	6.20	2812.27	6.20	2812.27	6.20	2812.27
Cement	13.39	6071.95	12.68	5752.37	11.98	5432.80
Sand	28.18	12783.05	28.18	12783.05	28.18	12783.05
Gravel	42.27	19174.57	42.27	19174.57	42.27	19174.57
CKD	1.52	689.99	2.88	1307.36	4.08	1852.09

	5% CKD Batch		10% CKD Batch		15% CKD Batch	
	lb	g	lb	g	lb	g
Water	6.20	2812.27	6.20	2812.27	6.20	2812.27
Cement	13.39	6071.95	12.68	5752.37	11.98	5432.80
Sand	28.18	12783.05	28.18	12783.05	28.18	12783.05
Gravel	42.27	19174.57	42.27	19174.57	42.27	19174.57
CCKD	1.52	689.99	2.88	1307.36	4.08	1852.09

Figure A1: Concrete Mix Proportions



	Task Name	Duration	Start	Finish
1	**1.0 Design of Concrete Mixes**	**35 days**	**Mon 1/23/17**	**Fri 3/10/17**
2	1.1 Concrete Mixing	35 days	Mon 1/23/17	Fri 3/10/17
3	1.2 Sample Preparation	35 days	Mon 1/23/17	Fri 3/10/17
4	**2.0 Testing**	**35 days**	**Mon 2/20/17**	**Fri 4/7/17**
5	2.1 Strength Testing	35 days	Mon 2/20/17	Fri 4/7/17
6	2.2 Durability Testing	35 days	Mon 2/20/17	Fri 4/7/17
7	**3.0 Data Compilation**	**35 days**	**Fri 2/24/17**	**Thu 4/13/17**
8	3.1 Quality Data Control	26 days	Fri 2/24/17	Fri 3/31/17
9	3.2 Data Analysis	9 days	Mon 4/3/17	Thu 4/13/17
10	**4.0 Project Management**	**80 days?**	**Mon 1/16/17**	**Fri 5/5/17**
11	4.1 Communication	65 days	Mon 1/16/17	Fri 4/14/17
12	4.2 Deliverables	41 days	Fri 3/10/17	Fri 5/5/17

Figure A2: Gantt Chart